Paleolimnological assessment of environmental changes occurring on Pim Island, Nunavut, High Arctic Canada

by

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ABSTRACT

Despite the documented sensitivity of polar environments, long-term monitoring data are especially sparse in these regions. Diatom-based paleolimnology has contributed significantly to understanding the response of Arctic lakes to climate change, but most studies have been conducted in regions with relatively high lakewater buffering capacity. As such, Pim Island (Nunavut, Canada) is a region of limnological interest because, due to the local geology, its surface waters are of relatively lower pH and previous research suggests that such softwater lakes may be especially responsive to climate fluctuations and therefore provide the best paleoclimate records. This thesis has two separate but related chapters, as well as an exploratory study included in appendix. First, a novel approach using visible-near-infrared spectroscopy (VNIRS) was used to infer lakewater dissolved organic carbon (DOC), from a 160-lake calibration set from the Canadian Arctic. Historically sound and similar trends were reconstructed when compared against a Canadian diatom-based DOC and Swedish VNIRS-based total organic carbon (TOC) model on Arctic Holocene sediment records. Second, a diatom and spectroscopically-based multi-proxy approach was utilized on Holocene sedimentary records from two lakes on Pim Island to assess long-term environmental change from this region. Benthic and epiphytic diatom taxa dominated the pre-19th century assemblages, although marked shifts in dominant species were recorded during the mid-Holocene. The mid-Holocene diatom assemblages underwent an abrupt ecological shift from alkaliphilous *Fragilaria sensu lato* to slightly acidophilous *Achnanthes* and *Navicula*. The post-19th century was characterized by an increase in the planktonic species (*Cyclotella radiosa*), indicating marked lakeice reductions. Third, the limnological properties and modern diatom assemblages of ponds and lakes surveyed from 1979 to 2009 on Pim Island were examined as part of an exploratory study. The ponds and lakes displayed typical characteristics observed in high Arctic lacustrine environments (i.e.

oligotrophic, very dilute) but with overall relatively low alkalinity. Poorly-buffered sites had diatom assemblages that were distinct from well-buffered lakes elsewhere in the High Arctic. Our findings contribute to an improved understanding of the interactions between local environments and limnological changes, and also provide insight on the biological responses of lakes to Holocene environmental change and allow us to compare responses to those in more alkaline sites.

CO-AUTHORSHIP

I was the lead author for the two publication-format chapters (Chapter 2 and Chapter 3) as well as the exploratory study presented in Appendix A. My M.Sc. supervisors, John P. Smol and Marianne S.V. Douglas, were co-authors on all the manuscripts. In Chapter 2, co-authors other than my M.Sc. supervisors included P. Rosén, who co-supervised me during a 3-months internship I completed at Umeå University, Sweden, where I completed the work on the VNIRS model development. P. Rosén also provided sediments from Seukokjaure for model testing. R. Pienitz provided surface sediment samples from Bylot Island, and reviewed the manuscript. Chapter 2 has been submitted to Journal of Paleolimnology. In Chapter 3, N. Michelutti was an additional co-author on the manuscript, and took part in the study design, interpretations and reviewing process.

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LIST OF ABBREVIATIONS

AMS	Accelerator Mass Spectrometry
CACS	Canadian Arctic Calibration Set
CCA	Canonical Correspondence Analysis
Chl *a*	Chlorophyll-*a*
DCA	Detrended Correspondence Analysis
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
Di-DIC	Diatom-inferred Dissolved Inorganic Carbon
Di-DOC	Diatom-inferred Dissolved Organic Carbon
Di-pH	Diatom-inferred pH
FTIRS	Fourier-transformed infrared spectroscopy
HTM	Holocene Thermal Maximum
PCA	Principal Component Analysis
PLS	Partial Least Squares Projections to Latent Structures
POC	Particulate Organic Carbon
R^2_{CV}	Coefficient of Determination obtained through Cross-Validation
$RMSEP_{CV}$	Root-Mean Squared Error of Prediction obtained through Cross-Validation
SedChl*a*	Sedimentary Chlorophyll-*a*
TOC	Total Organic Carbon
VNIRS	Visible-Near-Infrared Spectroscopy (400-2500 nm)
NIRS	Near-Infrared Spectroscopy (800-2500 nm)
VRS	Visible-Reflectance Spectroscopy for SedChl*a* (650-700 nm)
WA_{boot}	Weighted-Averaging with Boothstrapping

CHAPTER 1

General Introduction and Literature Review

Introduction

The fact that changes in the global climate have been occurring at an accelerated rate over the last two centuries has reached consensus amongst the broad international scientific community (IPCC 2007). The combination of increased greenhouse gas emissions, natural climatic variability and positive feedback mechanisms has already resulted in marked environmental changes at the global scale, such as a 40% loss of seaice extent from the 1980s to 2007 in the Arctic (Walter et al. 2006; Overland 2009). The warmer temperatures and changes in precipitation patterns observed across the globe since the mid-19th century (~1840 AD) marked the beginning of the "Anthropocene" (Crutzen 2006), and climate is predicted to continue changing (ACIA 2005) with major repercussions for our societies. The Earth's climate is changing, but the monitoring data provided by our instrumental records is too short to put the observed changes into a broader context and understand the processes involved (Smol 2008). Therefore, alternate methods are needed to assess this problem and obtain longer-term climatic and ecological information.

Studying extreme ecosystems is an important research initiative because of the simplified species-habitat relationships and the fact that polar regions are especially sensitive to the effects of climatic and other environmental changes. The harsh components in these ecosystems hinder the survival and reproduction of most organisms. High Arctic environments are characterized by low primary biological production in both terrestrial and freshwater ecosystems (Vincent and Laybourn-Parry 2008). The high Arctic provides scientists with valuable study systems because of their simplified ecological interactions, coupled with a high sensitivity to climate-induced environmental changes (Overpeck et al.

1997; ACIA 2005). Despite the important increase in data availability brought by, amongst others, the International Polar Year (IPY) research programs, environmental data on long-term limnological change at high latitudes is still lacking compared to temperate lakes (Wolfe and Smith 2004).

Polar aquatic ecosystems are particularly vulnerable to climatic changes (Rouse et al. 1997). The ice-covered Arctic freshwater systems have been closely linked to climatic changes over the Holocene owing to the marked relationship of climate with snow and ice cover (Michelutti et al. 2007). Many high Arctic aquatic primary producers are adapted to take advantage of the ice-free littoral zones that, in the summer, surround the extended ice cover. It is in these moats that most of the lakes' production occurs (Schindler and Smol 2006). Any modification on the availability of these habitats will lead to changes in lake properties and cause community shifts among biological assemblages (Livingstone et al. 1999; Schindler and Smol 2006). The Anthropocene's warmer climatic conditions have already shortened the duration and extent of ice cover (Smol et al. 2005). The resulting increase in the profundal habitat availability is mainly characterized by changes in nutrients and light regimes, longer growing season, and increased abundances of aquatic mosses, which may become a new available substrate for periphytic growth (Smol et al. 2005; Schindler and Smol 2006). Increases in lake primary production are already being documented in the Canadian high Arctic (Joynt and Wolfe 2001; Axford et al. 2009a) and in some instances have resulted in increased organic matter (OM) content (Antoniades et al. 2007).

The cold and dry conditions of high Arctic environments restrict terrestrial primary production in lakes' catchments. This low allochthonous input is thought to limit the influence of catchment processes on lake biological and chemical development (Pienitz et al. 2004; Michelutti et al. 2007). Effects of a changing climate (particularly the predicted increased temperatures and precipitation) on lake catchment properties may include changes in rock and soil weathering as well as in inputs of nutrients, major ions, and dissolved organic carbon (DOC) to the lake (Pienitz and Vincent 2000; Vincent 2009). For example, changing precipitation patterns, mire expansion, hydrology and vegetation composition are factors that alter DOC exports to lakes at high latitudes (Pienitz and Smol 1993) and these are expected to change with the global climate. Variations in DOC, and particularly the coloured fraction of the DOC (cDOM) that originates largely from terrestrial environments (e.g. humic substances), have a major influence on the optical environment for aquatic organisms (Vincent et al. 1998; Molot et al 2004; Rosén et al. 2009) through UV light attenuation effects (Laurion et al. 1997; Rautio and Korhola 2002). Finally, recent increases in ultraviolet (UV) penetration during the spring (associated with the detrimental effect of chlorofluorocarbons (CFCs) on the stratospheric ozone) could further amplify the consequences of climate warming on polar limnetic systems (Pienitz and Vincent 2000).

Paleolimnology in the high Arctic

Despite the documented sensitivity of polar environments (ACIA 2005), long-term monitoring data are especially sparse in these regions. To date, insufficient data have been collected at high latitudes to determine accurately the regional and local climatic fluctuations of the Holocene. It also remains to be established how sensitive these ecosystems are to changes in climate across the Arctic, and the main drivers of this regional variability are not fully understood (Pienitz et al. 2004). Hence, there is a need for more proxy-based studies.

Paleoecologists have developed a variety of approaches to compensate for the lack of long-term monitoring data, each with limitations and advantages. These include natural archives such as marine sediment cores, peat cores, ice cores, coral or dendrochronological records. A major approach to reconstruct past environmental changes is paleolimnology.

Paleolimnologists focus on interpreting proxy data archived in the sediments of lakes and rivers (Smol 2008). Sediments and the limnetic biota as well as the geochemical signatures they preserve are particularly good archives of environmental change (Smol and Douglas 2007a). Lake paleo-records can place current environmental changes in the context of the Holocene time-scale, and even beyond (Cremer and Wagner 2003; Axford et al. 2009b; Haberzettl et al. 2009).

Biological indicators that are well preserved in sediments, such as siliceous microfossils (diatoms, chrysophytes), invertebrates (chironomids, cladocerans), bacteria, pollen, macrofossils or charcoal, can be used as proxy data (Smol 1988; Smol 2008). Other types of biogeochemical (pigments) and geochemical signatures (e.g. percent loss-on-ignition (%LOI), C/N ratio, VRS, VNIRS, FTIRS), as well as different isotopic ratios ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) are also preserved in sediment cores and allow for retrospective analysis (Smol 2008). Multi-proxy studies also allow for a better understanding of the ecological processes behind climate signals and link the different variables that come into play. The interpretation of paleolimnological proxies is tightly linked to the quality of the lake sediment record (both physical and chemical properties).

In the extreme environments at high latitudes, reconstructions based on palynology and dendrochronology are often not possible or limited, given the paucity of vegetation. The paleolimnological approach is now an established, powerful method in the high Arctic (Smol and Douglas 2007a). In contrast to lakes in more populated temperate areas, remote Arctic lake basins are rarely affected by local anthropogenic-related disturbances (e.g. catchment disturbances, point source emissions). As a result, paleolimnological records are of major importance in the current knowledge about the most recent climate-related changes in the Arctic, the Holocene and beyond (Axford et al. 2009a). This has been highlighted by chapters in Pienitz and co-workers (2004), and summarized in Smol and Douglas (2007a).

Assigning a reliable chronology to a sediment stratigraphy is an important and challenging step in paleolimnological investigations (Telford et al. 2004; Birks and Birks 2006), and can present a major challenge to Arctic paleolimnology (Wolfe et al. 2004). Fly-ash particle counts and radioisotopic dating (e.g. ^{14}C, ^{210}Pb, ^{137}Cs) have been widely used in paleolimnological studies for providing geochronological control, spanning time from present to ~40,000 BP. Investigations on older paleorecords have to rely on tephrostratigraphical and optically stimulated luminescence techniques for their dating (e.g. Axford et al. 2009a). This crucial step, necessary to relate changes occurring between and within samples, sites, and paleolimnological proxy records together, can be particularly problematic in the high Arctic where the concentrations of ^{210}Pb and ^{137}Cs are low; the sedimentation rate is low; and terrestrial organic remains (plant macrofossils) are rare. Nevertheless, dating can be successfully applied in most cases, at least in an approximate way (Wolfe et al. 2004). Paleolimnological techniques have been applied around the world and, over the past 15 years, have been used increasingly in polar regions, which will be the focus of this thesis.

Indicators

Diatom-based lake sediment records from the high Arctic have provided some of the most reliable climate reconstructions for the Holocene period (Pienitz et al. 2004). Diatoms are unicellular algae of the class Bacillariophyceae (Smol and Stoermer 2010). The characteristics of diatoms (e.g. short life cycles, rapid immigration rates, ubiquity in lacustrine ecosystems, and species with well-defined limnological optima and tolerances) make them very sensitive to environmental changes (Smol and Stoermer 2010). This sensitivity allows paleolimnologists to use diatom records to reliably track changes in aquatic systems (Smol 2008). In high Arctic lakes and ponds, diatoms also account for a large portion of the autochthonous primary production (Douglas and Smol 2010). Finally, diatoms leave remains that preserve well in the sediments due to their siliceous cell walls; their distinct morphological structures allow for their identification to the species level (Smol and Stoermer 2010). These unicellular organisms are a particularly reliable proxy for climate changes in the high Arctic because the composition of their species assemblages are largely influenced by lake ice cover, which in turn is ultimately governed by climate (Smol et al. 2005). Lake water pH, which is tightly linked to the climate through the interaction of primary productivity and dissolved inorganic carbon (DIC), can thus also exert a strong influence on the algal community composition (Smol 1983; Wolfe 2002; Michelutti et al. 2006).

The autoecological literature for diatom distributions from the Arctic has increased immensely over the past ~20 years (Michelutti et al. 2007). By relating modern limnological variables (such as pH) to the lakes diatom species assemblages using multivariate numerical analysis, paleolimnologists have been able to infer past environmental variables from the developed transfer functions. Diatom-based models have also been used in several previous studies to infer quantitative measures of DOC (Kingston et al. 1990; Dixit et al. 1993; Pienitz and Smol 1993; Fallu and Pienitz 1999), and TOC (Rosén et al. 2000a) has been reconstructed from northern region calibration sets. But such reconstructions may not be robust for all lacustrine ecosystems because of the strong influence of lake pH on the siliceous algae assemblages (Smol and Stoermer 2010) - lake water DOC and TOC might be confounded with lake pH, resulting in ambiguous reconstructions and in limited applicability of the models. This may particularly be of concern at high latitudes where pH was shown to be the main driver of diatom communities. New methodologies, as described below, may become useful tools for such reconstructions.

Visible-near-infrared spectroscopy (VNIRS) is a rapid, inexpensive and non-destructive approach that can be used to infer limnological variables, although its applications are still in their infancy. Widely used in industry, the measurement of the absorbance on the visible and near-infrared wavelengths (400-2500 nm) provides information on the attributes of the chemical composition of organic materials in sediments. This technique has been used in paleolimnological studies to infer various limnological variables such as total phosphorus (TP), pH and elemental C, N, P using transfer functions (Korsman et al. 1992; Rosén et al. 2000b; 2001; Rosén 2005). Using models based on a northern Swedish lake training set, VNIRS signal from subarctic lake sediment have been linked to recent and past climate changes through their influences on watershed processes, especially on vegetation composition (Rosén et al. 2000b; 2001; Rosén and Hammarlund 2007), and used to infer TOC content in the water column (Cunningham et al. 2010; Kokfelt et al. 2009; Reuss et al. 2010; Rosén et al. 2000b; Rosén 2005). Visible-reflectance spectroscopy is another geochemical proxy developed in the last decade that has been used to infer sedimentary Chl *a* (650-700 nm) as a proxy for paleoproduction (Michelutti et al. 2005, 2007; 2009; 2010; Wolfe et al. 2006; Antoniades et al. 2007; Axford et al. 2009a). The use of multiple independent proxies helps strengthen trends observed in a stratigraphy and has become common in paleolimnological investigations (Rosén et al 2003; Birks and Birks 2006).

One of the most intensively studied regions for paleolimnological research in the Arctic is the Cape Herschel region of Ellesmere Island. Studies of a series of ponds have shown that the contemporary rise in temperature has led to higher evaporation rates, resulting in increased concentration of solutes and lower water levels in shallow ponds and, in the most extreme cases, to the loss of previously permanent waterbodies (Smol and Douglas 2007b). Monitoring at Cape Herschel since the early 1980's has been the most extensive at this latitude (78 °N), coupled with detailed paleolimnological investigation (Smol and Douglas 2007a). The Cape Herschel investigations provided strong evidence for recent climate warming at high latitudes (Smol and Douglas 2007b). At Cape Herschel, as in almost all other high and mid Arctic sites, sediment core analyses revealed more diverse diatom assemblages in recent sediments following long periods of relative biological stasis. Also, species that had previously only been reported in trace numbers in some of these aquatic systems were now abundant in the most recent sediments (~150 years to present) (e.g. Douglas et al. 1994; Michelutti et al. 2005; Antoniades et al. 2007). Together, these findings suggest that we are observing a “no-analogue” biosphere (Pienitz et al 2004).

Although the nature and magnitude of diatom changes occurring in alkaline, relatively high pH waters such as those at Cape Herschel are generally well understood (Douglas and Smol 1994), relatively little is known about the types of ecological responses that might be recorded in lakes of lower pH and alkalinity. Under a warmer climate, the reduction in ice cover results in higher pH through enhanced losses of CO_2 to the atmosphere and greater utilization of CO_2 by algal photosynthesis: the DIC pool is no longer dominated by CO_2 and undergoes a shift towards HCO^{3-} ions. In lakes with calcareous bedrock, the leaching of the carbonates would normally buffer the lake to such changes in the DIC speciation dynamics.

Diatom communities in Holocene sediment records from well-buffered sites such as Proteus Lake on Pim Island (Howard 1983), but also such as other Arctic sites like Kap Inglefield Sø, north-western Greenland (Blake et al. 1992), Lake PW02 on Russell Island, part of the Prince of Wales group (Finkelstein and Gajewski 2008), Sawtooth Lake (Perren et al. 2003) and Solstice Lake (Wolfe 2000) on the Forsheim Peninsula, Central Ellesmere Island, Lake KR02 on Victoria Island (Podritske and Gajewski 2007), Appleby and Brainard lakes in the Lake Hazen region, north-eastern Ellesmere Island (Smith 2002), are typically dominated by small benthic fragilarioids up until the late twentieth century when human-induced warming results in more diverse assemblages (Smol et al. 2005). However, more variable and diverse diatom assemblages have been observed in poorly buffered sites attributed to their heightened sensitivity to climate-driven pH dynamics from Holocene records of Baffin Island such as at Lake CF8 (Axford et al. 2009a, b), Kekerturnak Lake and Fog Lake (Wolfe 2002), Lake CF3 (Michelutti et al. 2007), and on central-eastern Ellesmere Island (Michelutti et al. 2006).

Several records from poorly buffered Arctic sites that included only partial records of the late-Holocene also show a more diverse diatom assemblage pre-dating the most recent anthropogenic-related climatic forcing, like ponds I-F and I-O at Isachsen, Ellef Ringnes Island (Antoniades et al. 2003), Sanagak Lake in the low Arctic (Stewart et al. 2008), and lake BC01 on Melville Island (Peros et al. 2010)). On the contrary, the well-buffered Self Pond near Alert (Antoniades et al. 2003), Elison Lake, Camp Pond and Col Pond at Cape Herschel (Douglas et al. 1994), Skeleton Lake, EP2 and EP3 in the Lake Hazen region (Keatley et al. 2008), BK3, BK5 and BKAH on Banks Island (Lim et al. 2008)) show a pre-1850 *Fragilaria*-dominated assemblage. This trend appears independent of whether sites are ponds (<2 m depth) or lakes (>2 m depth). A number of well-buffered sites, though, such as MV-AT on Melville Island (Keatley et al. 2006) and lakes Whisler and Hart in the Lake Hazen region (Smith 2002), do not illustrate this trend, i.e. the early assemblages were already more diverse. Nevertheless, much remains to be described on the influence of local edaphic factors, lake physical properties and the ongoing modifications of catchment processes on high Arctic freshwater systems.

Thesis Format

This thesis is divided into 4 chapters. Following this Introduction (Chapter 1), the VNIRS-based technique is used to develop an inference model for lake water DOC from a Canadian Arctic calibration set of surface samples (Chapter 2). In Chapter 3, the VNIRS DOC inference model developed in Chapter 2 and primarily diatom-based paleolimnological techniques are used to track Holocene postglacial environmental changes in two high Arctic lakes. As noted above, only few full Holocene diatom records from poorly-buffered sites are available from the literature. The changes in the proxy data are compared to the relatively well-studied (and near-by) alkaline sites from Cape Herschel and placed in a regional perspective. I will therefore be able to compare at a local and regional scale the climate signals observed in the sediment profiles and to understand better the modulating influence of geology and other environmental variables on high Arctic lakes' processes and sensitivity. In addition, an exploratory characterization of the limnological characteristics and diatom communities of five ponds and three lakes on Pim Island, is provided to support our long-term inferences in Appendix A.

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CHAPTER 2

Development and application of a model for inferring lake water dissolved organic carbon (DOC) from visible-near-infrared spectroscopy (VNIRS) measures in lake sediment

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Abstract

We develop an inference model to reconstruct lake water dissolved organic carbon (DOC) concentrations from lake sediments using visible-near-infrared spectroscopy (VNIRS). The inference model is based on 160 surface sediment samples collected from Arctic Canada covering broad latitudinal (60-83°N), longitudinal (71-138°W) and environmental gradients, with a DOC range of 0.6-39.6 mg·L^{-1}. The model is applied to Holocene lake sediment cores from Sweden and Canada and our inferences are compared to previous paleolimnological multiproxy investigations from these two sites. The inferred Swedish and Canadian DOC profiles are compared, respectively, to inferences from a Swedish-based VNIRS-total organic carbon (TOC) and a Canadian-based diatom-inferred (Di-DOC) models from the same sediment records. The 5-components Partial Least Squares (PLS) model yields a cross-validated (CV) R^2_{CV} = 0.62 and a cross-validated root mean squared error of prediction ($RMSEP_{CV}$) = 4.4 mg·L^{-1} (11 % of DOC gradient). The trends inferred for the two lakes were remarkably similar to the VNIRS-TOC and the Di-DOC inferred profiles and consistent with the other paleolimnological proxies, although absolute values differed. The differences in the calibration set gradients and lack of analogous VNIRS signatures in the modern datasets may explain this discrepancy. Our results corroborate previous geographically independent studies on the potential of using VNIRS to rapidly reconstruct trends in past lake water DOC concentrations.

Key words: Visible-near-infrared spectroscopy (VNIRS), Dissolved organic carbon (DOC), Arctic, Paleolimnology, Paleo-optics, Carbon cycling

Introduction

Changes in global climate are expected to alter dissolved organic carbon (DOC) export to freshwater systems at high latitudes. Some of the combined effects of modifications in growing season length, frequency of extreme climatic events and precipitation patterns on hydrology, permafrost thawing, mire dynamics as well as vegetation composition are already being observed (ACIA 2005; Bokhorst et al. 2009; Frey and McClelland 2009). Increasing trends in DOC levels are being recorded in some regions in North America and northern Europe and have been associated with climate warming, but may also be linked to chemical recovery from acid depositions and catchment changes (Schindler et al. 1996; Monteith et al. 2007). DOC levels in high latitude freshwaters have a predominant impact on both microbial (Jansson et al. 2008) and global (Cole et al. 2007) carbon dynamics. Variations in DOC, used as an estimate for chromophoric dissolved organic matter (CDOM) that originates largely from terrestrial environments (e.g. humic substances), have a major influence on the optical environment, structure and functioning for aquatic organisms (ACIA 2005; Karlsson et al. 2009). Ultraviolet (UV) light and photosynthetically available radiation (PAR) attenuation effects (Leavitt et al. 2003) together with the recent increases in UV penetration during the spring (associated with the detrimental effect of chlorofluorocarbons (CFCs) on the stratospheric ozone) could further amplify the consequences of climate warming on polar limnetic systems (Schindler et al. 1996; ACIA 2005).

Historical reconstructions are needed to provide a context to adequately address the impacts of the ongoing changes in watershed processes affecting freshwater DOC levels in relationship with the carbon cycle and paleo-optical variables. Multi-proxy studies, now recognized as an essential approach in paleolimnological investigations (Birks and Birks 2006), are very challenging because of the limited sediment availability as well as the costly and time-intensive analyses they require. Diatom-based models have already been used to infer quantitative measures of lake water DOC (Kingston et al. 1990; Fallu and Pienitz 1999; Curtis et al. 2009) and TOC (Rosén et al. 2000) from lake sediment in northern regions of North America and Europe. Such reconstructions may not be robust for all lake ecosystems because of the confounding effect of other water chemistry variables such as lake pH or nitrate on the siliceous algae assemblages (Curtis et al. 2009). In the last two decades, reflectance spectroscopy has become an important paleolimnological tool because it is a rapid, inexpensive and non-destructive method to recover information on the composition of sediment organic materials (Korsman et al. 2001) - such as Chl *a* (Wolfe et al. 2006; Michelutti et al. 2010) - and biogeochemical properties of sediment (Rosén et al. 2010).

Widely used in industry, the measurement of the absorbance on the visible-near-infrared wavelengths (400-2500 nm) provides information on the attributes of the chemical composition of organic materials. Visible-near-infrared spectroscopy (VNIRS) has been used in paleolimnological studies to infer various limnological variables such as total phosphorus (TP), pH and elemental C, N, P using inference models (Korsman et al., 1992). VNIRS signal from subarctic lake sediment has also been linked to recent and long-term climatic changes through their influences on watershed processes (Rosén et al. 2000; 2001). VNIRS-based models recently developed from a northern Swedish surface sediment training set, which was later extended to more southern latitudes (Cunningham et al. 2010), for the inference of past lake water total organic carbon (TOC) (Rosén 2005) allowed to further explore past environmental effects on aquatic systems. Changes in mire dynamics, tree-line location, vegetation composition, fire regimes and precipitation patterns were shown to be tracked by the VNIRS-TOC reconstructions (Rosén 2005; Rosén and Hammarlund 2007; Kokfelt et al. 2009; Cunningham et al. 2010). The potentials of the VNIRS technique for the inference of lakewater organic carbon contents have not been applied yet in North America, and very little is known on the geographical limitations of its inference models.

The goals of this paper were to determine: 1) if predictive inference models can be established between sediment VNIRS spectral signatures and lakewater DOC from northern boreal to Arctic Canadian lakes; and 2) if lake water DOC can be reconstructed from paleorecords at the Holocene scale using the model developed. In this study, a modern Canadian Arctic Calibration Set (CACS) of lake surface sediment ranging from the boreal forest to the high Arctic polar desert sites has been used to develop a model relating the VNIRS signal from lake surface sediments to lake water DOC concentrations following methods described by Rosén (2005). The Canadian model was then applied to two well studied Holocene lake sediment profiles from a Canadian and a Swedish lake at the tree line. The VNIRS-based technique could extend the applicability of a time- and cost-effective geochemical proxy for the integrated study of the C cycle between terrestrial and aquatic environments and for the understanding of the variability of underwater light regimes, amongst others.

Materials and methods

Study area

The 160 lakes included in the calibration set encompass a broad latitudinal (60 - 83° N) and longitudinal (65 - 138° W) gradient in northern Canada (Fig. 2.1). Most of the sites were part of previous paleolimnological published surveys (diatom calibrations sets), and the different regions are described elsewhere in greater details (see Table 2.1 for related published work). This geographically large study area spans large environmental gradients typical for the different regions covered, including bedrock geology, permafrost, soil development, vegetation, climate and limnological variables. The major part of the area covered by the CACS is located within the Arctic Archipelago and is underlain by sedimentary rocks of Phanerozoic age, with some Precambrian igneous intrusions, and the most southern parts are underlain by the granite and gneisse of the Canadian Precambrian

Shield (Thorsteinsson and Tozer 1970). The landscape features (permafrost and vegetation) were obtained using Arc-GIS Desktop ver. 9.2. The hydrological features displayed on the CACS map (Fig. 2.1) were obtained from the National Hydro Network (NHN) (GeoBase 2007) available at *Geobase* (www.geobase.ca). The vast majority (79 %) of the sites are located in continuous permafrost, and only 10 % and 2.5 % are on discontinuous and sporadic permafrost in more southerly locations, respectively (GSC 2002). Surface materials in the CACS lakes catchments are mostly unconsolidated materials (such as glacial deposits, sands, soils and organic terrains), but also bedrock and bedrock outcrops (GSC 1973). The various types of cryosolic, brunisolic (south of tree line only) and rock-dominated soils covering the catchments of the CACS sites (Soil Landscapes of Canada Working Group 2006) have substrate chemistry ranging from acidic (pH <5.5) to mineral-rich circumneutral (pH 5.5-7.2) and carbonate-rich (pH >7.2) (CAVM 2003).

The surface sediment dataset has an altitudinal gradient from sea-level to 1387 m a.s.l. and extends from subarctic boreal forest in the south to polar desert on the most northerly main Canadian island (Ellesmere Island). The bioclimatic zones (Fig. 2.1) are based on the Circumpolar Arctic Vegetation Map Team (CAVM 2003) classification north of the tree line as well as on the Ecological Working Group classification in EcoZones (2002) south of the tree line. 74 % of the CACS lakes are located above the tree line (CAVM 2003). The cover of vascular plants in the polar desert (Zone 1), i.e. cushion forbs in favourable microsites, is less than 5 %, and mosses and lichens can cover up to 40 % of lake catchments, forming an open and patchy vegetation. As one proceeds further south, the temperature and the growing season lengthen, allowing the moss and herbaceous layers to thicken and become taller, and woody prostrate dwarf shrubs (Zone 2) are progressively increasing in stature to become hemiprostrate (Zone 3) and are eventually being replaced by krummholz tree forms (Zone 4), reaching up to 2 m above ground at tree line (Zone 5).

The number of species and the overall cover of vascular plants increases from North to South to occupy 80-100 % of lake catchment areas at tree line (CAVM 2003). South of the tree line, the taiga ecosystem (Zone 6) was originally classified in 3 EcoZones from West to East, namely the Taïga Cordillera, Plains and Shield (Ecological Working Group 2002), grouped here into a subarctic transition zone characterized by a forest-tundra vegetation. The southernmost sites in the Yukon are located in the conifer-dominated Boreal Forest (Zone 7), and 6 of these sites are located in alpine settings (Pienitz et al. 1997). At these high latitudes, peatland is present in patches throughout the landscape, but they occupy a larger proportion of the catchment at the southernmost sites (GSC 2002a).

The annual precipitation and snowfall rates, as well as mean July and January air temperatures for the different zones are averages of the available data from the closest possible meteorological stations from the study sites and cover the CACS collection period (1990-2009; listed in Table 2.1) (Environment Canada 2010). Generally colder seasons, drier conditions and higher proportion of snowfall are observed towards higher latitudes. The study sites are located in remote areas and are therefore not affected by direct anthropogenic disturbances, with the exception of seven Inuvik sites that have small sumps for drilling mud and waste (mostly KCl) disposal in their catchment (Jenkins et al. 2008) that should not affect the VNIRS signal in the lake sediment.

The subset of the CACS water chemistry and other important limnological variables provided in Table 2.2 encompasses the typical environmental gradients observed in the Canadian Arctic (Vincent and Laybourn-Parry 2008). Most of the lakes forming the CACS are relatively shallow (mean = 7.6 m), with a summer water temperature that increases from north (mean = 5.6 ˚C in Zone 1) to south (mean = 7.7 ˚C in Zone 7) and a pH range between 3.5-8.8, the most acidic sites being found in Zone 1 and 3. The sites are generally oligotrophic (mean TPU = 8.6 $\mu g \cdot L^{-1}$, Chl*a*U = 1.1 $\mu g \cdot L^{-1}$, TN = 0.3 $mg \cdot L^{-1}$), but mesotrophic and even slightly eutrophic sites are also present across the set. While the TN levels seem to increase between the different bioclimatic zones from north to south, TP and Chl*a* do not seem to follow an equally clear trend. The systems are dilute on average (specific conductivity = 126 $\mu S \cdot cm^{-1}$, DIC = 12.8 $mg \cdot L^{-1}$, major ions < 21 $mg \cdot L^{-1}$), but the individual levels vary to cover wide ranges. As reported elsewhere (Pienitz and Smol 1993), a large gradient (0.6-39.6 $mg \cdot L^{-1}$) of generally decreasing DOC was recorded from southern Yukon to northern Ellesmere Island (about 10 fold difference between the means) following changes in bioclimatic and permafrost zones. The POC accounts for up to 38 % of the TOC with no clear trend between the zones.

Sample collection

The water and the surface sediment for this calibration were collected during previous paleolimnological investigations between 1990 and 2009 in the summer months (July and August). The sampling was conducted following the standard methods used in our other Arctic studies (Douglas and Smol 1994). At subarctic latitudes and when possible further north, the sediment was collected from the deepest part of the lake using a gravity corer. In high Arctic locations, the top cm of sediment was collected as far away from the shore as possible, i.e. typically at about 1 m depth. Most sediment samples were stored in the dark at 4 ˚C, except from the Bylot Island samples that were kept freeze-dried. The water collection and chemistry analyses were performed according to standard protocols described in the publications related to each region sampled (Table 2.1). The vast majority of the samples were sent to the National Laboratory for Environmental Testing (NLET) at the National Water Research Institute in Burlington Ontario for major and minor ions, phosphorus, nitrogen, carbon, and chlorophyll-a. Protocols for bottling and filtering, and methods for chemical analyses can be found at Environment Canada for all sites sampled

(Environment Canada 1979; 1994a; 1994b). The trace metals for the Inuvik samples were analysed at the Taïga Laboratory (Yellowknife, NWT). Given the logistical constraints of Arctic research, only a single DOC surface water measurement was performed for each site. Water temperature, pH and specific conductivity measurements were taken on location. The suite of limnological variables available for each site is provided in Appendix B.

Spectral analysis and model development

About 0.5 mL of freeze-dried sediment for each sample was sieved through a mesh size of 710 µm, hand-ground in a mortar and run for spectral analyses using a NIRSystems 6500 instrument (FOSS NIRSystems Inc., Silver Spring, MD, USA). A few (n= 22) samples with high sand content were ground using a planetary mill for 30 sec. The interactions between the light in the VNIR region and the sediment sample organic components are reported by the instrument as apparent absorbance wavelength and intensity values (A), according to $A = log(1/R)$, in which R is the measured diffuse reflectance. The sediment apparent absorbance spectra (VNIRS "signature") for each sample is formed by 1050 data points collected between 2500 and 400 nm at 2-nm intervals, thus capturing the spectral sensitivity to chlorophyll *a* and its derivatives in the visible light (400-700 nm) (Michelutti et al. 2005). All the samples utilized in the present study were run in a two weeks time frame to prevent potential instrument drifts, and standard samples were included at the start and end of each session to observe the potential drift.

The development of the calibration model followed the typical procedures of diffuse reflectance spectral calibration using multivariate statistics (Antti 1999) and is largely based on Rosén (2005). Ponds, those waterbodies that freeze to the bottom during the winter (typically <2 m depth), were removed for the numerical analyses from an initial set of 427 sites (Appendix C), resulting in a calibration set of 161 lakes. Outliers were detected using a principal components analysis (PCA) of the VNIRS spectra. Only one lake that was outside the 95 % root mean square error of the PCA was removed from the analysis prior to modelling. This lake was artificially dammed and heavily influenced the model fit. The transfer function was developed with a partial least squares regression (PLS) of the centred VNIRS spectra with standardized and square-root transformed lakewater DOC. Lakewater DOC was square-rooted to attain a normal distribution because the CACS contained a higher number of sampled lakes with DOC values less than 10 mg·L^{-1}. A multiplicative scatter correction (MSC), a linear transformation for which the mean VNIRS signature of the calibration set is subtracted from the spectral signature of every site, was also applied to the spectral data prior to perform multivariate analyses in order to remove noise effects caused by particle size, as well as varying effective path length and measurement conditions (Geladi et al. 1985). All multivariate statistics were performed using SIMCA-P+ (Umetrics AB, SE-907 91 Umeå, Sweden). The model chosen had the highest coefficient of determination (R^2_{CV}) between the observed and the predicted values and the lowest root mean squared error of prediction ($RMSEP_{CV}$) assessed by internal 10-fold cross-validation, in which one of 10 randomly split subsamples is used for validation (i.e. how accuratley the model predicts the variable) of the training set formed by the remaining nine groups, then repeated 10 times. The $RMSEP_{CV}$ was calculated from the measured and back-transformed predicted DOC values.

Downcore application

Slipper Lake, Canada

The CACS VNIRS-DOC model was applied to a Holocene sediment core from Slipper Lake (64° 35.65' N, 110° 50.07' W; 460 m a.s.l.), an oligotrophic tundra lake located approximately 50 km north of tree line in the Northwest Territories (NWT), Canada. Slipper Lake is a moderately deep lake (maximum depth 17 m) located in a remote area within the CACS geographical coverage (Fig. 2.1). Previous studies from this lake included the application of diatom-based models for DOC (Di-DOC), dissolved inorganic carbon (Di-DIC) and total nitrogen (Di-TN) (Rühland 2001; Rühland and Smol 2002) to two dated sediment cores, a main core (45.5 cm), and a replicate core (17.5 cm) collected through ice in March, 1997 (Rühland and Smol 2005). In addition, cladoceran assemblage changes were examined from the shorter core (Sweetman et al. 2008). As there was insufficient sediment available from the top to the 23.5 cm interval of the main Slipper Lake core, the shorter core had to be used to represent the most recent history of this lake. Thus, 25 samples from the shorter core represent the top section (0-17.0 cm) and 10 samples from the main core represent the bottom section analysed in this study (23.5-42.5 cm). Bulk sediment from the deepest part of the main core (43.5-44.5 cm) was dated with accelerator mass spectrometry (AMS) at 4760 ± 70 radiocarbon years before present (^{14}C yr BP), thus the period covered by the records does not encompass the entire Holocene history of Slipper Lake (since deglaciation). The site description details as well as sampling and dating techniques can be found in Rühland and Smol (2005).

The weighted-averaging (WA) diatom-based DOC inference model (Di-DOC) used for Slipper Lake was developed from a 67-lake training set (TS) in the central Canadian arctic tree line region (Rühland and Smol 2002) and applied to the sediment cores (Rühland and Smol 2005). The Di-DOC model had a bootstrapped coefficient of determination (r^2_{boot}) of 0.49 and a root mean squared errors of prediction ($RMSEP_{boot}$) of 0.28 Log(DOC+1.45) mg·L^{-1}. Diatom assemblages in Slipper Lake were relatively stable for the first five millennia with the largest change occurring in the last ca. 150 years (~ 5.0 cm). Rühland and Smol (2005) concluded that the substantial taxonomic shifts in the diatom flora to a more planktonic assemblage were largely due to 19th century warming (longer ice-free period) and associated changes to water column properties (e.g., prolonged thermal stratification). The pronounced taxonomic shifts in diatoms were not matched in the diatom-inferred model reconstructions for DOC, DIC or TN, suggesting that changes other than these reconstructed variables were the main drivers of the diatom changes (e.g. aquatic habitat). LOI measurements were stable in the record until they experienced a slight decrease from 25 to 15 cm, after which they increased until recent times (Rühland and Smol 2005). No substantial changes were observed in cladoceran assemblages throughout the shorter sediment core (Sweetman et al. 2008).

Seukokjaure, Sweden

The CACS DOC-VNIRS model was further applied to a well studied Swedish lake sediment core to assess how well the Holocene reconstruction based on the Canadian model matches an independent reconstruction based on the VNIRS-TOC model developed by Rosén (2005). A sediment profile from Seukokjaure (67° 46'N, 17° 31'E; 670 m a.s.l.), a small (max depth 6.1 m) oligotrophic tree line lake located in northern Sweden in an area with low human impact. The AMS radiocarbon dating on bulk sediment established the oldest date for this record at 9070±75 ^{14}C yrs BP (132 cm). This lake has been investigated for long-term environmental changes using multiple proxies, and detailed site information as well as sampling and dating descriptions are available elsewhere (Rosén et al. 2003; 2010; Rosén and Persson 2006; Reuss et al. 2010). Transfer functions were developed for pollen, diatom and chironomid assemblages to infer July air temperature over the Holocene (Rosén et al. 2003). Loss-on-ignition (Rosén et al. 2003) and Fourier transform infrared spectroscopy (FTIRS) (Rosén and Persson 2006) were also performed and used to reconstruct the treeline history of the lake catchment and to infer lake water TOC. In addition, conventionally-measured and FTIRS-inferred LOI, biogenic silica, pigments, δ^{13}C and δ^{15}N profiles were shown to support the interpretations of tree line changes from previous papers (Reuss et al. 2010; Rosén et al. 2010).

Based on a 99-lake set from northern Sweden, the Swedish four-component PLS model used has a R^2_{CV} of 0.63 and a root mean squared error of prediction by cross-validation ($RMSEP_{CV}$) of 1.7 mg·L^{-1} that represents 11 % of the TOC gradient. The details of the sample preparation and model development based originally on a 100 lake calibration set are described in Rosén (2005). According to the comparative analysis of the proxies for Seukokjaure, the lake's catchment started to become forested about 600 years after deglaciation (about 9500 calibrated years BP or ~130 cm sediment depth), to then become alpine again from 850 cal. yrs BP (~15 cm) until the present-day (Reuss et al. 2010). A similar pattern of change was observed in Di-inferred DOC reconstructed for Queen's Lake (NWT, Canada), currently located at northern tree line, over the Holocene (Pienitz et al. 1999).

Canadian and Swedish datasets signatures versus VNIRS profiles

PCA was used to explore changes in the VNIRS spectra through time. Sample scores from both reconstruction lakes were compared with sample scores from the Canadian and the Swedish calibration set to assess how downcore VNIRS spectra in Slipper Lake and Seukokjaure compare to the surface sediment spectra from lakes with different catchment vegetation. Slipper Lake and Seukokjaure are particularly well suited for this evaluation because they both have a detailed environmental history using multi-proxy paleolimnological studies. Further, the two sites are both located within the geographical boundaries and environmental gradients encompassed by the Canadian and Swedish training sets, allowing for meaningful comparison. This test also shows whether downcore samples have analogues in the calibration set (Rosén and Persson 2006).

Results and Discussion

Model performance

The model fit and predictive abilities of our VNIRS-DOC model were similar to those obtained for previous VNIRS-based models for TOC inference developed in Sweden (Fig. 2.2). A 4.4 mg·L^{-1} $RMSEP_{CV}$ of calibration (11 % of the calibration gradient) with a R^2_{CV} of 0.62 was obtained for a 5-components PLS model ($RMSEP_{CV}$ and R^2_{CV} for first four components: 4.8, 4.9, 4.8, 4.5 mg·L^{-1} and 0.52, 0.53, 0.55, 0.60, respectively). Considering the influence of the larger gradient covered by the CACS (0.6-39.6 mg·L^{-1}) on the $RMSEP_{CV}$, the model performance is comparable to the ones obtained for the Swedish 99 and 100-lake TS (present study; Rosén 2005) and the extended set (Cunningham et al. 2010) with, respectively, a R^2_{CV} of 0.61 and 0.72 and a $RMSEP_{CV}$ of 1.6 and 2.6 mg·L^{-1} representing 10.8 and 11.2 % of the gradient. The CACS-based inference model did not predict values as high as the ones observed in the lake dataset (maximum predicted DOC = 26 mg·L^{-1}) (Fig. 2.2), which highlights the model limitations in inferring quantitative estimates towards high values. Since most (76 %) of the sites have a DOC level below 10 mg·L^{-1}, higher levels of reconstructed DOC should be interpreted with caution as reported elsewhere (Cunningham et al. 2010). Integrating more lakes with higher DOC values would allow to account for a greater diversity of organic compounds in the model and probably improve predictive ability in the higher range of DOC. A further investigation of how the different regions of the VNIRS spectra weigh on the PLS analysis to infer lake water DOC could improve the model's performance, as well as reduce its complexity.

Slipper Lake

Similar reconstructions in lakewater DOC values were inferred for the Slipper Lake paleorecord by the VNIRS and diatom-based DOC models, although absolute values differed slightly (Fig. 2.3). The Di-DOC model recent estimate (5.0 mg·L^{-1}) is more similar to the present-day DOC reported in Rühland and Smol (2005), i.e. 5.0 mg·L^{-1} in 1996 and 4.5 mg·L^{-1} in 1997 (measured from water sampled in the winter through the ice), than the VNIRS-DOC estimate (2.9 mg·L^{-1}). However, the VNIRS-DOC reconstruction appears less noisy with more stable inferences between the intervals than the Di-DOC profile. Considering the models' prediction errors, no major fluctuations in lake water DOC were observed in both inferred profiles at the Holocene scale. Rather, reconstructed DOC from 5.5 cm to the top of the core followed a subtle decreasing trend, which would be in agreement with the effects of climatic warming as suggested by the other paleo-proxies analysed (Rühland and Smol 2005; Sweetman et al. 2008).

Apart from a similar recent slight decline, the paleolimnological records of a nearby lake (Toronto Lake; 63°43'N, 109°21'W) as well did not reveal major changes in diatom-inferred DOC levels over the Holocene despite larger variations in LOI (Pienitz et al. 1999). Even though the lake is located at the tree line and pronounced changes in diatom-inferred DOC over the Holocene were observed at another nearby site (Queen's Lake; 64°07'N, 110°34'W) (Pienitz et al. 1999), it is possible that Slipper Lake and its catchment have not undergone major changes affecting lake water DOC levels over the last few millennia. In fact, present-day measurements still reported only low DOC levels. Additionally, if tree line migrated northward onto the site during the Holocene Thermal Maximum (approximately 5000 yrs BP), it may not have been captured in this lake record since the full Holocene history of the lake was not covered in the 45.5 cm core.

Degradation processes could have caused the most recent slight decline in the VNIRS-DOC profile. However, previous studies indicate that sediment degradation probably only has a minor effect on the VNIRS signal compared to the effect from environment (Rosén et al. 2000; Rosén, 2005). Although we cannot assess if and to what extent degradation could have influenced the VNIRS-measured products, neither in the calibration set nor in the

Holocene sediment records, the good match with biological proxies supports our conclusions.

Seukokjaure

The Canadian and Swedish VNIRS-based models produced similar trends in inferred lake water DOC and TOC for Seukokjaure over the Holocene but, similar to the Canadian example, the absolute values differed (Fig. 2.4). Both the VNIRS-inferred DOC and TOC profiles show an initial increase towards a plateau that lasts until ~15 cm (850 cal. yrs BP), after which the levels decrease again to attain almost the same as the initial values. The reconstructed levels varied beyond the model predictive range of the DOC and the TOC model, ranging respectively from 1.9 to 20.6 $mg \cdot L^{-1}$ and from 0.15 to 6.9 $mg \cdot L^{-1}$. The early establishment of soil after deglaciation (increase in VNIRS-DOC) and the relatively recent switch from a lake in a forested zone to an alpine lake (decrease in VNIRS-DOC) tracked by other proxies (Rosén et al. 2003; Rosén and Persson 2006; Reuss et al. 2010) are similarly tracked by both models, i.e. the timing is the same, but the magnitude/amplitude is much wider in the Canadian model. Because the TOC from the Swedish 99-lake training set is almost entirely made of DOC (Rosén 2005), the models should be comparable. A preliminary CACS VNIRS-TOC model yielded only poor performance, probably due to the more variable particulate organic carbon (POC) fraction of these sites (up to 38 %).

Catchment influence on the VNIRS signatures

The principal components analyses of the VNIRS measurements of the Canadian and the Swedish sediment sets allow an interpretation of the relationship between the sets and the downcore applications independently from the associated DOC levels and from a catchment point of view (Fig. 2.5). The variation accounted for by the first two components is 56 and 31 %, respectively. The VNIRS signatures of surface lake sediment from the Swedish and the Canadian sets juxtapose along axis 1, with some overlap. The resemblance between the VNIRS signatures of the two sediment sets can be attributed to the overall similar characteristics of Arctic environments and may partly explain the surprisingly high agreement between the DOC and TOC trends inferred from the Seukokjaure record. Indeed, several differences in the sampling and handling techniques as well as in the dataset characteristics between the two sets could have created more disagreement in the outputs (Cunningham et al. 2010).

However, there are also variations in the permafrost extent and bedrock geology as well as soil and vegetation composition that could explain the observed distribution of sites along axis 1. While more than 75 % of the Canadian sites are located on permafrost (GSC 2002b), almost none from the Swedish set were located on frozen ground (Rosén 2005). The influence of permafrost on DOC export to aquatic systems is well documented (Frey and McClelland 2009). The soil types and bedrock geology are also much more diverse along the major geographical transect covered by the CACS than within the smaller area covered by the Swedish set (CAVM 2003; Rosén 2005). Additionally, the high latitude forested catchments of the Swedish sites are dominated by deciduous birch trees (Rosén 2005), while no such vegetation type can be found in the Canadian coniferous-dominated boreal forest (Ecological Working Group 2002). Different quality and quantity of allochthonous organic carbon input can be expected from a deciduous versus conifer forest (Rinnan et al. 2008). Finally, polar desert sites found in the high latitudes of the Canadian Arctic Archipelago are not represented in the Swedish dataset.

The VNIRS signatures from the two datasets are also distributed along a forested to non-forested gradient on axis 2. For the Swedish and the Canadian sets, respectively, 46 and 74 % sites were in non-forested catchments, while 54 and 26 % were located in forested catchments (above and below tree line). This distribution pattern suggests that the VNIRS signature reflects both quantitative and qualitative properties of organic material transported into the aquatic system which is then preserved in the sediment. This correlation between the VNIRS signature and catchment vegetation was shown before in the Swedish subarctic region (Rosén et al. 2000; 2001). This correlation could also at least partly be related to increasing ecosystem primary production with decreasing latitude: in fact, the sedimentary Chl*a* signal, shown to track primary paleoproduction (Michelutti et al. 2010), was inferred from visible reflectance spectra between 650-700 nm, a zone that is included in the signatures plotted here.

It is clear that the VNIRS signature is complex, and the nature of and the factors influencing the suite of organic compounds present in the DOC are far from being well understood. In the present study, no statistically significant relationship could be established between the VNIRS signatures and DOC when the ponds (<2 m deep) of the original calibration set were included in the preliminary analyses. The light- and oxygen-enhanced presence of epipelic living material at the sediment/water interface of ponds with a different VNIRS signal is likely contributing to explain the absence of correlation (den Heyer and Kalff 1998). Also, larger and deeper water mass may alter depository-diagenetic processes of organic matter compared to that of smaller waterbodies. A better understanding of the biogeochemical processes affecting lake water DOC through time during deposition in the water column, at the sediment/water interface and when stored deeper down in the paleo-record, may provide some answers on the mechanisms relating DOC to VNIRS signatures.

The patterns of the downcore VNIRS signal are consistent with the modelled DOC trends for both Slipper Lake and Seukokjaure. The Slipper Lake VNIRS profile varies slightly along axis 2 and groups with non-forested Swedish (alpine lakes) and Canadian (alpine and Arctic tundra lakes) sites, consistent with a DOC profile experiencing only minor variations (Fig. 2.3). On the opposite, Seukokjaure's profile displays a much wider variation along axis

1, in agreement with the reconstructed DOC and lake history (Fig. 2.4). The early Holocene intervals (>9500 cal. yrs BP) cluster outside the range of the Canadian set towards polar desert sites, and the profile then shifts rapidly towards forested Swedish sites for most of the period investigated. Finally, the most recent intervals (>200 cal. years BP) cluster towards the Canadian Arctic tundra and forest-tundra lakes after another rapid transition. Our results correspond well with that the lake is situated at the present tree line with only few scattered trees in the catchment. The position of the Seukokjaure VNIRS profile at the overlap between the Swedish and the Canadian datasets on the PCA biplot may help explain the similar trends inferred by the two geographically independent models.

Absolute values and model performance enhancement

Because most of the Slipper Lake and the Seukokjaure VNIRS profiles fall within the boundaries of the Canadian set distribution on the PCA, we are confident that analogous VNIRS signatures were included in the model to reconstruct past lake water DOC levels, supporting the trends from our DOC reconstructions. However, the Seukokjaure profile from the PCA (Fig. 2.5) shows on one hand that the organic compounds of the early Holocene sediment intervals (>9500 cal. years BP) recorded within the VNIRS signal seem to share more similarities with the ones characterizing modern high Arctic Canadian lakes. The closest sites are indeed Canadian polar desert lakes from Northern Ellesmere Island (EPF and Nan Lake) and Axel Heiberg Island (Buchanan and Colour lakes, Colour Lake being the most similar). These four lakes are dilute ultra-oligotrophic lakes of various sizes (7-1800 ha) and pH (3.6-8.8) with low DOC (1-5 $mg \cdot L^{-1}$), and they may represent the types of conditions that were driving the Seukokjaure catchment in the early Holocene. Although within the error bars of both models and thus to be interpreted with caution, the difference between the reconstructed Swedish and Canadian values is greater for that period (73-93%) compared to an average of 65% difference during the forested period (9500-850 cal. years

BP). Because the best analogues can be found among high Arctic lakes in Canada, the VNIRS-inferred DOC values for Seukokjaure are probably more reliably reconstructed by the Canadian model for that early period. Similarly, the most recent intervals (last ~200 cal. yrs BP) of the alpine lake record have better analogue sites within the Canadian set (Arctic-tundra lakes) as shown by the PCA clustering, and the difference in absolutes values inferred by the 2 models is also high (up to 80-87%). On the other hand, the PCA shows that the Swedish model probably reconstructs the most reliable values in the forested period of Seukokjaure, since only a few VNIRS signatures from Canadian lakes are "surrounding" the 9500 to 200 cal. years BP intervals, compared to a majority of forested Swedish lakes that display very similar VNIRS signals. Birch-dominated subarctic Swedish catchments are in fact not represented in the Canadian set, and this difference could be driving the spectral composition.

As mentioned before, absolute inference values have been an issue in the applications of the VNIRS-based models. Here, the large difference between the absolute values and amplitudes of trends of the Canadian and the Swedish reconstructions of Seukokjaure is likely due to differences in environmental gradients of the datasets and lack of modern analogues in the calibration sets. The remarkably similar trends observed between the Seukokjaure inferences of this study and the comparative outcomes obtained through models developed from geographically independent lake sets suggest that the application of VNIRS to lake sediments to qualitatively infer past DOC levels is robust and potentially without major geographical restriction at high latitudes. Additionally, our data suggest that larger calibration sets could be preferable for DOC-reconstructions to provide analogous VNIRS signatures in areas that are expected to have undergone large environmental fluctuations over the studied time, such as high latitude lakes over the Holocene. The combination of the Swedish and the Canadian datasets and further additions of southern

Canadian lakes to the model could benefit the model's performance and reliability by including a wider variety of signals (Cunningham et al. 2010). Further, extending the calibration to more southern latitudes in Canada and applying the model to sediment cores from the temperate region could facilitate answering important questions in the debate regarding the timing and causes of the DOC increasing trends observed in recent years (Schindler et al. 1996; Monteith et al. 2007).

Conclusions

We developed a lake water DOC-inference model based on VNIRS from a Canadian Arctic lake surface sediment calibration set. The Canadian model yielded similar performance to the Swedish VNIRS-TOC inference models, and allowed us to reconstruct Holocene lake water DOC levels from paleolimnological records of two northern tree line lakes. Our results suggest that the history of lake catchment changes is partly preserved in sediment cores (reflected in sediment profiles) in the form of a geochemical “fingerprint” that can be recorded using VNIRS and modelling approaches. Our analyses also suggest that VNIRS-based models to infer trends in past lake water DOC have potentially no major geographic limitation at high latitudes, and thus offer a wide scale of applicability. Uncertainties remain regarding absolute values reconstructed using the Canadian set, but improvement of the calibration set by providing additional analogues, further understanding of the mechanisms linking lake water DOC and the VNIRS and implementation of the technique for wavelength weight on multivariate analyses should provide insights on the potential causes and improve the overall reliability of VNIRS-based models. Most importantly, the indirect model developed here allows the reconstruction of overall trends in lake water DOC from lake paleorecords, highlighting the usefulness of VNIRS as a time- and cost-effective tool for the investigation of long-term changes in the optical environment and C cycle of freshwater ecosystems.

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Table 2.1. Canadian Arctic lakes calibration set (CACS) regions, with the names and number of sites (n), sampling years and reference for full water chemistry and/or lakes description

Region	Collection year (s)	n	Sites #ref	Publication
Northern Ellesmere Island and Oasis (**EP**)	2003	18	Appleby, D, F, G, "Lake A", "Lake C2", P, R, S, Nan, W, X, Skeleton, AB, AC, 10, Hazen, 24	Keatley et al. (2007a)
Axel Heiberg Island (**AX**)	1998	7	Q, Y, Z, AI, AJ, Buchanan, Colour	Michelutti et al. (2002a)
Cape Herschel (**CH**) and Pim Island (**P**)	2007	3	Elison Lake, Proteus, "Greely"	Douglas et al. (1994); Unpub.
Central Ellesmere Island (**E**)	2004	1	Rock Basin Lake	Michelutti et al. (2006)
Lougheed Island (**LO**)	2005	1	A	Unpub.
Bathurst Island (**B**)	1994, 2005	9	C, G, H, M, N, Y, AE, AJ, AT	Lim et al. (2001); Unpub.
Devon Island (**DV**)	2001	4	E, F, H, I	Lim et al. (2003)
Melville Island (**MV**)	2002	1	AE	Keatley et al. (2007b)
Cornwallis Island	1993	2	12 Mile, Trafalgar	Michelutti et al. (2007)
Banks Island (**BK**)	2000	9	A, Shoran, R, T, U, Y, Swan, AH, AI	Lim et al. (2005)
Somerset Island (**S**)	1994, 1996	3	AP, AQ, AS	Unpub.
Prince of Wales (**W**)	1995	9	E, G, L, N, Q, W, Fisher, AG, AK	Unpub.
Bylot Island (**BI**)	2005, 2006	16	1, 2, 4, 5, 7-11, 17, 20-22, 25, 26, 28	Côté et al. (2010)
Wynniatt Bay (Victoria Island) (**V**)	1997	1	G	Michelutti et al. (2002b)
Southern Baffin Island	2008	1	JUET-2	Unpub.
Yukon (**U**)	1990	44	2, 5-12, 18-23, 25-29, 31, 32, 34, 36-46, 49-50, 52, 54-56, 58, 59	Pienitz et al. (1997b)
Mackenzie Delta (Inuvik, NTW) (**IK**)	2009	17	C8, C23, DEM2, DEM4-5, I3, I8, I11, I17, I20, I23A, I25B, 5B, 7B	Kokelj et al. (2005); Unpub.
Yellowknife (Central NWT) (**Y**)	1991	19	1, 3-14, 16-20, 21, 23	Pienitz et al. (1997a)

Table 2.2. Averaged meteorological data (1990-2009) (mean July and January temperature, mean annual precipitations and snowfall portion of the mean total precipitations) available for the seven bioclimatic zones covering the CACS, with the number of sites (n)

Bioclimatic zone	n	Meteorological stations	Mean July temp (˚C)	Mean Jan temp (˚C)	Mean annual snow (% tot prec)	Mean annual prec (mm)
1	2	Alert	3.5	-32.3	85	148
2	32	Resolute Bay	4.2	-32.2	62	169
3	50	Eureka, Nanisivik, Sachs Harbour, Tuloyoak	6.5	-32.1	62	175
4	1	Kimmirut, Pangnirtung	8.8	-23.8	62	377
5	33	Kugluktuk, Rankin Inlet, Tuktoyaktuk	11.0	-28.2	41	245
6	33	Inuvik, Yellowknife	17.0	-25.8	39	283
7	9	Mayo, Whitehorse	15.4	-20.2	37	295

Table 2.3. Select water chemistry variables (i.e., chlorophyll a unfiltered (Chl*a*U), total phosphorus unfiltered (TPU), dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), particulate organic carbon (POC), particulate organic nitrogen (PON), total nitrogen (TN), silica (SiO_2), ions of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chlorine (Cl^-) and sulfate (SO_4^{2-}), as well as nitrogen pentoxida (NO_2NO_3), nitrites (NO^{2+}), and ammonium (NH_3^+)) and other important limnological variables (elevation (Elev), lake depth, water temperature (Temp), pH, specific conductivity (Cond)) for the 160 CACS lakes summarized by bioclimatic zonations (Zone). The mean values are presented with the zone range in parentheses.

Zone	Unit	1	2	3	4	5	6	7	Tot
Depth	m	-	3.6(2-6.9)	10.2(2.1-80)	8.5	6.1(2-20)	5.9(2-18.5)	14.4(3-49)	**7.6**(2-80)
Temp	˚C	6.0(4.5-7.5)	6.3(1.5-12.0)	8.3(1.5-15.4)	21.0	12.9(7.5-18.0)	16.2(11.5-20.3)	20.8(17.0-23.0)	**11.2**(1.5-23.0)
pH		5.6(3.5-7.7)	8.1(6.8-8.7)	7.4(3.6-8.8)	7.0	7.8(6.2-8.6)	7.6(5.9-8.8)	8.5(7.8-8.8)	**7.7**(3.5-8.8)
Cond	$\mu S\cdot cm^{-1}$	170(30-309)	147(10-780)	124(4-500)	48	97(8-343)	68(0-153)	331(49-1500)	**126**(0-1500)
Chl*a*U	$\mu g\cdot L^{-1}$	0.6(0.6-0.6)	0.7(0.05-2.7)	0.9(<0.1-3.2)	2.9	1.1(<0.1-2.6)	1.7(0.4-10.5)	1.2(0.05-2.8)	**1.1**(<0.1-10.5)
TPU	$\mu g\cdot L^{-1}$	15.3(7.4-23.2)	6.2(1.1-21.8)	9.6(0.1-34.3)	8.1	6.9(0.006-20.8)	10.1(0.01-43.9)	10.8(4.9-15.8)	**8.6**(0.006-43.9)
DIC	$mg\cdot L^{-1}$	1.7(0.6-2.8)	14.5(1.1-26.6)	12.7(0.3-59.5)	2.2	11.5(0.1-35.2)	6.1(0.3-20.5)	40.7(3.8-134)	**12.8**(0.1-134)
DOC	$\mathbf{mg\cdot L^{-1}}$	**1.7(0.9-2.4)**	**2.0(0.8-6.9)**	**3.5(0.6-18.5)**	**2.9**	**7.9(1.6-26.7)**	**12.3(3.1-39.6)**	**16.7(8.4-35.1)**	**6.6(0.6-39.6)**
POC	$mg\cdot L^{-1}$	0.3(0.1-0.4)	0.3(0.09-0.7)	0.4(0.2-1.0)	0.3	0.5(0.2-1.0)	0.6(0.2-1.5)	0.8(0.3-3.3)	**0.5**(0.1-3.3)
PON	$mg\cdot L^{-1}$	0.02(0.02-0.02)	0.02(0.001-0.05)	0.04(0.01-0.09)	0.03	0.07(0.02-0.1)	0.08(0.03-0.20)	0.11(0.04-0.4)	**0.1**(0.001-0.4)
TN	$mg\cdot L^{-1}$	0.05(0.03-0.07)	0.2(0.05-0.9)	0.3(0.03-1.2)	0.2	0.4(0.1-0.9)	0.5(0.1-0.9)	0.7(0.3-1.6)	**0.3**(0.03-1.6)
SiO_2	$mg\cdot L^{-1}$	3.9(0.2-7.7)	0.4(0.05-1.3)	1.1(0.06-4.6)	0.5	0.4(0.08-1.5)	1.1(0.1-3.3)	5.5(0.2-9.3)	**1.1**(0.05-9.3)
Ca^{2+}	$mg\cdot L^{-1}$	8.6(3.2-13.9)	20.5(0.4-43.7)	16.7(0.1-71.8)	2.1	16.6(0.5-59.6)	12.3(1.1-39.2)	30.1(7.8-50.3)	**17.1**(0.1-71.8)
Mg^{2+}	$mg\cdot L^{-1}$	3.7(0.7-6.6)	5.0(0.4-20.3)	6.9(0.1-57.3)	1.4	8.6(2.2-16.7)	4.7(2.2-10.9)	-	**6.1**(0.1-57.3)
Na^+	$mg\cdot L^{-1}$	13.5(0.7-26.3)	8.7(0.2-153)	4.1(0.1-42.8)	7.1	5.3(0.4-33.4)	2.7(0.2-13)	25.8(0.7-187)	**6.3**(0.1-187)
K^+	$mg\cdot L^{-1}$	1.3(0.07-2.5)	0.6(0.1-5.7)	1.2(0.1-8.5)	0.5	1.2(0.3-6.7)	0.9(0.1-2.1)	4.9(0.6-29.9)	**1.2**(0.07-29.9)
Cl^-	$mg\cdot L^{-1}$	16.7(1.2-32.1)	16.1(0.2-278)	6.2(0.2-63.5)	9.8	10.1(0.5-75.2)	2.1(0.0-6.1)	4.0(0.6-24.5)	**8.2**(0.04-278)
SO_4^{2-}	$mg\cdot L^{-1}$	60.8(1.5-120)	6.9(0.2-39.7)	18.9(0.3-182)	3.1	5.6(0.3-51.0)	12.4(0.3-72.0)	161(0.5-1242)	**20.8**(0.2-1242)
NO_2NO_3	$mg\cdot L^{-1}$	0.006 (<0.005-0.009)	0.02 (<0.005-0.1)	0.009 (<0.005-0.079)	<0.005	0.006 (<0.005-0.02)	0.01 (<0.005-0.04)	0.006 (<0.001-0.02)	**0.01** (<0.005-0.1)
NO_2^+	$mg\cdot L^{-1}$	<0.002	0.002 (0.0005-0.007)	0.002 (<0.002-0.006)	<0.002	0.001 (<0.0002-0.007)	0.003 (<0.0002-0.03)	0.0005 (<0.0002-0.001)	**0.002** (<0.0002-0.03)
NH_3^+	$mg\cdot L^{-1}$	0.009 (0.008-0.01)	0.008 (<0.005-0.04)	0.01 (0.002-0.04)	0.02	0.01 (<0.005-0.056)	0.01 (<0.005-0.1)	0.009 (<0.005-0.031)	**0.01** (0.002-0.1)

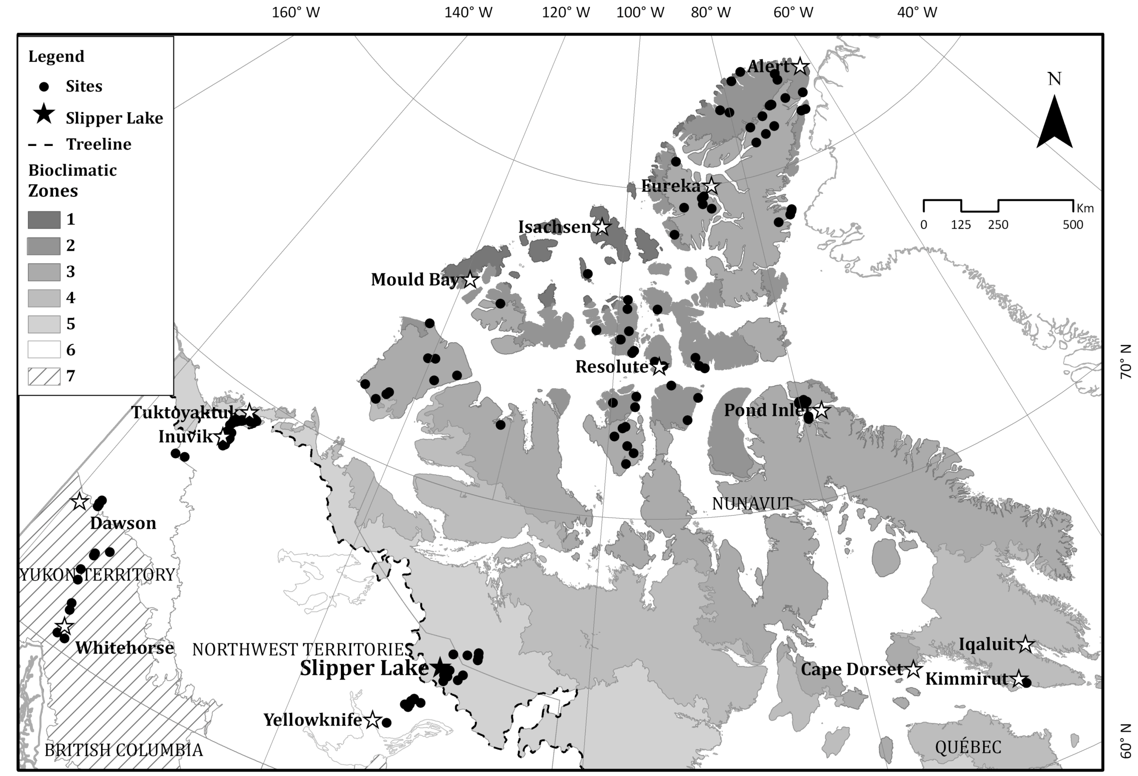

Fig. 2.1: Map of the Canadian Arctic Calibration Lakes Set (CACS) (filled circle) distributed along 7 bioclimatic zones as defined by the CAVM (2003) and the Ecological Working group (2002) ranging from boreal forest to high Arctic polar desert (60-83°N and 64-138°W) (see legend), including the major towns (empty stars), tree line (dashed line) and Slipper Lake (NWT) (filled star). Generated with Arc-GIS Desktop ver. 9.2.

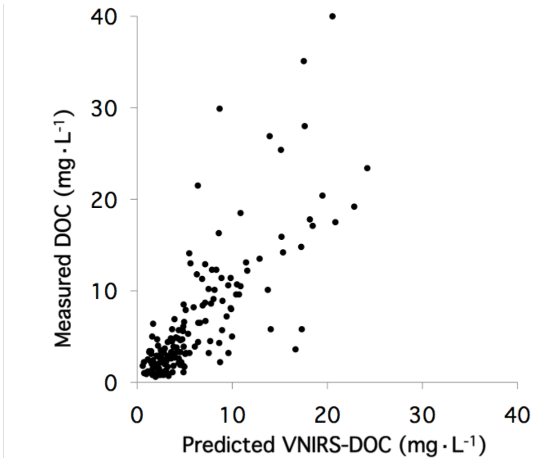

Fig. 2.2: Observed lake water dissolved organic carbon (DOC) versus near-infrared spectroscopy (VNIRS)-predicted lake water DOC (mg·L^{-1}) from the CACS with the model's fit (R^2_{CV}) and the root mean squared error of prediction as assessed by cross-validation ($RMSEP_{CV}$).

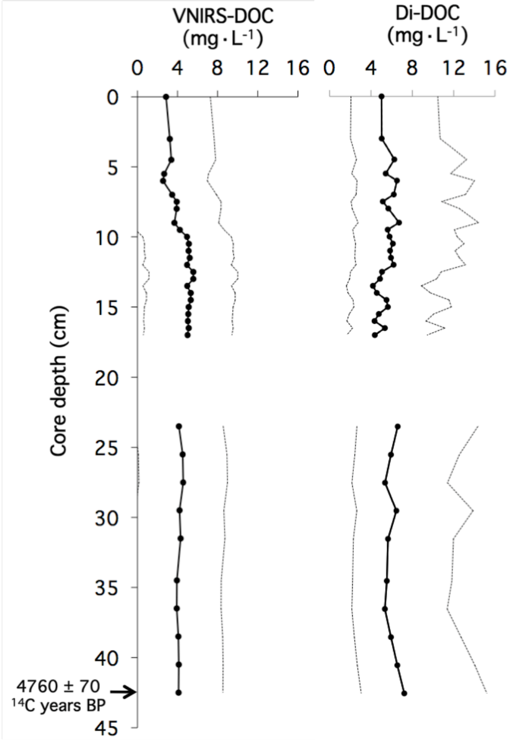

Fig. 2.3: Reconstructions of past lake water DOC from Slipper Lake (NWT, Canada), inferred using a partial least squares analysis (PLS) VNIRS-based (VNIRS-DOC) and a weighted-averaging (WA) diatom-based (Di-DOC; Rühland 2001: Fig. 6, Appendix 5.5) model applied to a Holocene sediment profile with bottom (23.5-42.5 cm) and top (0-17.5 cm) segments. $RMSEP_{CV}$ and back-transformed sample-specific bootstrapped errors ($RMSEP_{boot}$) are included to the VNIRS-DOC and Di-DOC reconstructions, respectively.

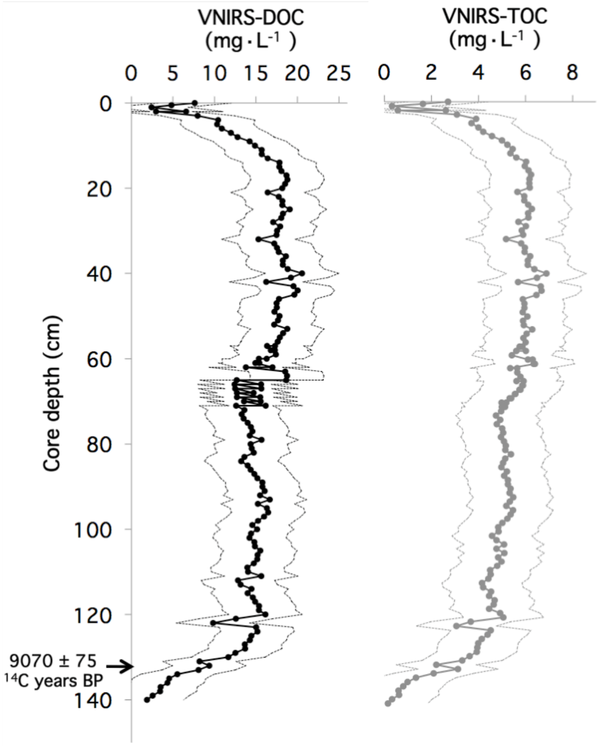

Fig. 2.4: Reconstruction of past lake water DOC and TOC (mg·L^{-1}) from Seukokjaure (Sweden) Holocene sediment core, inferred using a VNIRS-based model developed from the CACS (black) and the Swedish 99-lakes (grey), respectively.

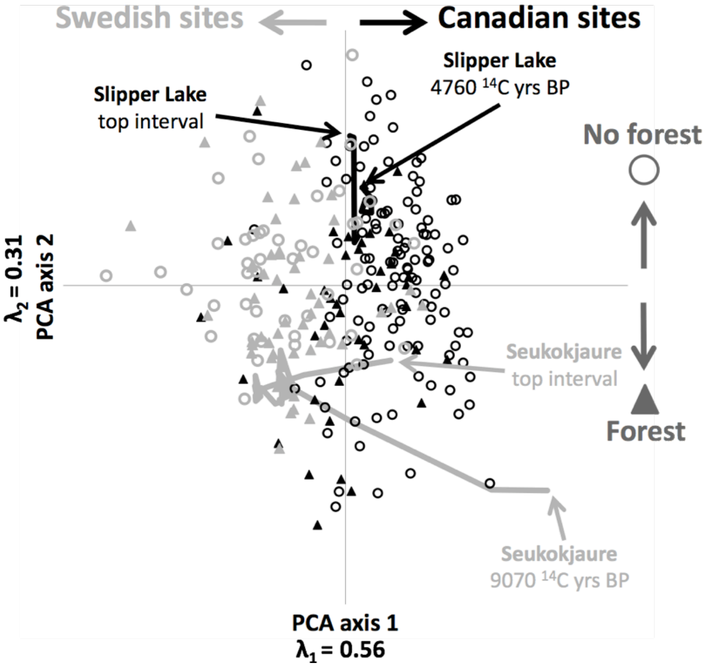

Fig. 2.5: Principal component analysis (PCA) of the VNIRS signatures from the Canadian 160 lakes (black) and the Swedish 99 lakes (grey) surface sediment training sets. Sites located in forested catchments are displayed as filled triangles, and in non-forested catchments as empty circles. 5-pts running means of the VNIRS spectra from downcore Slipper Lake (black line) and Seukokjaure (grey line) were plotted passively to the PCA. The weight on axis 1 and 2 are 0.56 and 0.31, respectively. All spectra have been centred and MSC-filtered prior to analysis.

CHAPTER 3

The response of poorly-buffered High Arctic lakes to climatic fluctuations over the Holocene

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Abstract

Despite the documented sensitivity of polar environments to climate changes, long-term monitoring data are especially sparse in these regions. Diatom-based paleolimnology has contributed significantly to our understanding of how Arctic lakes and ponds respond to environmental change. However, most of these studies have been conducted on lakes with relatively high buffering capacities, and recent research suggests that diatoms in well-buffered lakes may not respond as sensitively to climatic fluctuations as do poorly-buffered lakes. In this study, a multi-proxy approach including diatoms, spectroscopically-inferred DOC and sedimentary Chl*a* was utilized on Holocene sedimentary records from two poorly-buffered lakes on Pim Island (High Arctic Canada) to assess their responses to known climatic fluctuations over the Holocene. Both study lakes showed similar trends in their respective proxies over time, but were notably different from those recorded in nearby well-buffered regions. Following deglaciation, diatom assemblages were dominated by small benthic *Fragilaria sensu lato* taxa, but during the mid-Holocene there was an abrupt shift to more circumneutral and slightly acidophilous taxa dominated by *Achnanthes* and *Navicula* spp*.* The spectroscopically-inferred proxies track some of the main Holocene climatic trends documented in the region, such as the more favourable conditions of the Holocene Thermal Maximum and the Neoglacial cooling trends, but reconstructed variations in the lakes optical environments most likely did not affect the algal community. An ecologically striking changes occurred in the more recent sediments, with an increase in the planktonic species *Cyclotella radiosa*, indicative of a longer ice-free summer periods induced by a warming climate. Compared to nearby well-buffered sites, our softwater lakes showed a more variable and dynamic diatom response to Holocene climatic fluctuations. We suggest that, following an initial period of strong edaphic control, namely the release of alkalinizing base cations from easily weathered glacial deposits, the acid-base equilibria of our site became more strongly controlled by climate-driven pH dynamics, through controls on within-lake DIC dynamics. Our findings lead to an improved understanding of the competing influences of catchment processes versus climate fluctuations in driving lake trajectories. These data will ultimately guide future paleolimnological research in the selection of study sites that respond most sensitively to climatic and other environmental change.

Key words: Diatoms, High Arctic, Multi-proxy, Paleolimnology, Holocene, VNIRS, Sedimentary Chl*a*

Introduction

Since the mid 19th century, anthropogenic effects on radiative forcing and the resultant positive feedback mechanisms have had tremendous repercussions on the global climate. This is particularly true in polar regions, where numerous climate-related changes have already been observed in the physical and biological environment (ACIA 2005). Lakes and ponds constitute central elements of Arctic landscapes that support a large part of the cold-adapted fauna and flora and overall biological productivity. The recent temperature increases over the past ~150 years have given rise to drastic change in the structure of aquatic biological communities (Rühland et al. 2008; Smol et al. 2005).

There remains a great need for understanding and providing an appropriate context to the recent climatic trends and potential impacts on Arctic ecosystems. However, long-term monitoring data are scant and of short duration. This has led to a rise in paleolimnological investigations at high latitudes, with a particular focus on the last few centuries (Overpeck et al. 1997). Holocene-scale studies of climate change are few, despite well documented fluctuations in climate over this period (Axford et al. 2009a; Wanner et al. 2008), including warmer-than-present conditions during the Holocene thermal maximum (Kaufman et al. 2004) and cold reversals during the early Holocene (Axford et al. 2009a).

The regional variation in Holocene diatom (and other proxy) records from northeastern Greenland, amongst others, illustrates the importance of local influences on the limnological characteristics of lakes (Cremer et al. 2001; Wanner et al. 2008). The marked changes observed in response to the recent warming also raise questions on the mechanisms driving the shifts in aquatic biological communities (Schindler and Smol 2006). There are many factors that can influence diatom assemblages in Arctic freshwaters, including conductivity, nutrients, DOC, water temperature and habitat specificity, many of which are ultimately linked to climate (Rühland et al. 2008; Saulnier-Talbot et al. 2003; Smol et al. 2005). However, lake water pH is commonly identified as a main driver of Arctic diatom assemblages, and pH in poorly-buffered lakes is partly controlled by climatic-driven ice-cover dynamics (Michelutti et al. 2007; Wolfe 2002). For example, in warm periods there is a reduction in ice cover which results in higher pH, via enhanced losses of CO_2 to the atmosphere and greater utilization of limnetic CO_2 by algal communities. In lakes with calcareous bedrock, the leaching of the carbonates would normally buffer the lake to such changes in the DIC speciation dynamics.

Although the nature and magnitude of diatom changes occurring in well-buffered, relatively high pH waters, such as those at Cape Herschel, central-eastern Ellesmere Island (Douglas et al. 1994; 2000), are generally well understood (Douglas and Smol 1994), relatively little is known about the types of ecological responses that might be recorded in lakes of lower pH and alkalinity. Michelutti et al. (2006) highlighted the sensitivity of a poorly-buffered lake on Ellesmere Island in tracking climatic changes by recording more diverse and dynamic diatom shifts compared to nearby well-buffered sites. Wolfe (2002) suggested that this sensitivity is related to a first-order control of climate on lakewater pH, which does not exist in well-buffered sites. Softwater lakes of the high Arctic may therefore be especially sensitive recorders of climate change, yet the influence of bedrock geology has largely been unexplored to date.

Interpreting sedimentary records from high Arctic lakes remains a challenge (Wagner et al. 2008), and the importance of multi-proxy and multi-site studies for reconstructing/understanding past climate changes cannot be overemphasized (Birks and Birks 2006; Rosén et al. 2001; Wagner et al. 2008). Here, we present a detailed diatom analysis of Holocene environmental changes in two relatively small, poorly-buffered lakes from Pim Island, eastern-central Ellesmere Island (Fig. 3.1). We also use novel techniques in spectral reflectance, as described in Chapter 2, to infer sedimentary Chl *a* and lakewater DOC concentrations. The nature and magnitude of the changes recorded in these poorly-buffered lakes prior- and post-1850 will be compared to nearby well buffered sites and be placed in regional, local and postglacial contexts. The ultimate goal is to decipher the main factors influencing the modulation of changes in the limnological and biological responses over time.

Sites Description

Our study sites, unofficially named "West Lake" (78°44.283'N; 74°37.983'W) and "260 m Lake" (78°41.825'N; 74°22.557'W), are located above Holocene marine limit within ~4 km of each other on Pim Island (78°41'N; 74°25'W) (Fig. 3.1), a small island (~86 km^2) that lies at the junction of Kane Basin and Smith Sound on the east-central coast of Ellesmere Island, Nunavut. Pim Island is separated from Cape Herschel, Ellesmere Island, by Rosse Bay (~10 km wide). Pim Island’s maximum elevation is 550 m a.s.l. with a large gentle slope seaward on the northern side and steeper slopes on the southern side. Our observation data from the catchment basins of West and 260 m lakes show less than 5% vegetation cover, consisting mainly of cushion forbs. The freshwater lakes and ponds from this region typically have an ice-free season of ~3 months, however our ground observations suggest that some of the larger lakes can maintain persistent ice cover even through the summer months.

Uplift and erosion processes in the central Ellesmere Island region have created an amalgam of bedrock types (Christie 1962; Frisch 1983). The Pim Island bedrock geology is composed of Precambrian granites, migmatites, and associated rocks of the Canadian Shield. Calcareous till was, however, very reduced in the drainage areas of the two topographically closed basins, resulting in poorly-buffered lakes. This is in marked contrast to the nearby Cape Herschel, whose surface waters are predominantly influenced by calcareous tills. The paleolimnological records on Pim Island are constrained by the Wisconsinian glacial history ending with the retreat of the Innuitian Ice Sheet (Blake 1992). Pim Island is estimated to have been free of glacial ice since 10,400 ± 1,500 calendar years ago from cosmogenic ^{36}Cl dating of bedrock and erratics (Zreda et al. 1999). Also, the accelerator mass spectroscopy (AMS) ^{14}C dating of Proteus lake (Fig. 3.1) sediments recorded some of the oldest lake sediments along east-central Ellesmere Island (Blake 1977, 1981, 1987). Radiocarbon (^{14}C) sediment chronologies were established by the Geological Survey of Canada (GSC) for Proteus Lake and from our study core from West Lake: aquatic moss from basal organic lake sediment was dated at 9370 ± 110 radiocarbon years (TO-111) in Proteus Lake (52.5-53 cm depth) and at 8630 ± 180 radiocarbon years (TO-308) in West Lake (104.5-105.0 cm) (Blake 1985, 1992). The longest sedimentation record from Pim Island was retrieved from 260 m Lake, where 179 cm of organic sediments were measured above the inorganic material (gray sand and silt) from an early 1980s core from GSC (Blake 1981). However, a small carapace ice cap remains near the centre of the Island (Fig. 3.1).

Cape Herschel and Pim Island are influenced by the same sub-regional climatic system (Fig. 3.1) (Maxwell 1981), although the higher elevation of Pim Island makes its local climate somewhat colder. Pim Island is in the transition zone between the Eastern

(Northern Baffin Bay - Lancaster Sound sub-region) and the Northern (Nares Strait sub-region) climatic regions of the Canadian Arctic Islands as described by Maxwell (1981) (Fig. 3.1). Largely influenced by sea ice extent in Smith Sound and the remaining cyclonic activities coming from Davis Strait in the south (originating from the warm West Greenland Current), this coastal area is characterized by a mean annual precipitation of around 200 mm and a mean July temperature of ~3°C (Maxwell 1981). Pim Island is in an area where polar desert dominates the landscape, characterized by the quasi-absence of soil horizon development, absence of organic matter, with minimal but persistent vascular plant cover (< 5%) and a low standing crop (mostly herbaceous and non-vascular) (Lévesque 1997).

Several shallow yet relatively large lakes and ponds are situated on this island at different elevations, and 12 of these have been sampled on a semi-regular basis since the early 1980's as part of the "Cape Herschel Project" (Smol and Douglas 2007). Our study lakes are both located in rather sheltered depressions, although West Lake is somewhat more exposed to strong winds from its higher location on a large plateau (Fig. 3.1), and evidence of former higher water levels could also be observed on rocks. Although both lakes are relatively small and shallow (Table 3.1), West Lake is a slightly larger and deeper waterbody. West Lake is located at 315 m a.s.l. on the Pim Island western plateau but is surrounded by higher hills. The lake has an approximate surface area (SA) of 110,000 m^2 and a maximum depth of 12.1 m. The lake bottom is rock covered, and some organic material as well as sparse aquatic and semi-aquatic vegetation (grasses and mosses) grow in the littoral zone.

260 m Lake is formed by two basins divided by a sandy isthmus, and the main basin has a surface area of ~43,600 m^2. It is located at 260 m a.s.l., also in a rather sheltered depression closed in by cliffs or steep slopes on all sides. The lake appears to deepen rapidly, and the maximum water depth found in the main basin is 9.8 m. As observed from

the shore, virtually no aquatic macrophytes could be seen on the sandy bottom, which contained only a few rocks. Black water marks on boulders and cliffs surrounding the lake indicate past higher water levels.

Apart from temporary streams formed by ice and snow melt, no inflow or outflows were observed around either lake. In the summer (June-August) surveys of the years 1983, 1987, 2001, 2004 and 2009, the lakes were either partially or completely ice-covered, with slightly acidic to circumneutral pH values. As part of the limnological monitoring program of the "Cape Herschel Project", Pim Island lakes were also surveyed at multiple occasions since 1980. Water chemistry and other important limnological properties collected from West and 260 m lakes are summarized in Table 3.2. Characterisation of the catchment and water temperature, pH and specific conductivity measurements were made on site. The water samples were analysed at the National Laboratory for Environmental Testing (NLET) at the National Water Research Institute (Burlington, ON, Canada) following Environment Canada standard protocols for major and minor ions, trace metals, phosphorus, nitrogen, carbon, and chlorophyll-a can be found at (Environment Canada 1979, 1994a, b). Available geographical, physical and averages of a selection of chemical characteristics of West and 260 m lakes from previous field seasons are summarized in Table 3.1. Refer to Appendix D for full water chemistry.

Methods

Coring

The West Lake and 260 m Lake piston sediment cores were retrieved as part of a GSC field season during the first week of June 1981 using methods described by Blake (1981). The West Lake core used in this study (BS-81-39-Core 1) was collected on June 7, 1981. It was originally 109 cm long, and was collected in 9.7 m of water below 2.4 m of ice (total depth = 12.1 m) and 10-15 cm of corn snow. The surface sediment was noted to be preserved (algal gyttja). The core, however, does not include the entire organic material above the minerogenic layer (grey water-saturated sand) that was attained during subsequent coring drives (Field notes, W. Blake Jr., 1981). Most of the basal inorganic material could not be retrieved in any of the drives, but sand, silt and pebbles could be found at the base of the tubes, suggesting a full post-glacial sequence was retrieved. A moss-rich zone near the top (cm) and another basal moss concentration were also found in Proteus Lake during the 1981 coring season (Field notes, W. Blake Jr., 1981). The 260 m Lake core (BS-81-36-Core 2), originally 173 cm, was collected on June 6, 1981 in 5.4 m of water under 2.6 m of ice (total depth = 8 m; maximum depth measured = 9.8 m) and 10 cm of corn snow. The cores were preserved in their original coring tubes in the dark at 4°C until 2009, when they were extracted and sub-sampled every 1 cm for analyses. Both study cores showed signs of desiccation, and particularly the uppermost few cm of the core from 260 m Lake (~25% loss of original volume and length).

Sediment geochronology

The chronologies of the profiles were established using both ^{210}Pb and ^{14}C radioisotopic techniques (Appleby 2001; Björck et al. 2001). ^{210}Pb dating was performed using gamma counters at the Paleoecological Environmental Assessment and Research Laboratory (PEARL, Queen's University, Kingston, Canada, Ontario). The ^{210}Pb and ^{137}Cs activities were measured for the 0-8 cm intervals of both sedimentary profiles (8 samples each).

Accelerator Mass Spectroscopy (AMS) ^{14}C was performed at the W. M. Keck Carbon Cycle AMS Facility (University of California, Irvine, CA, USA) and the measurements were based on aquatic bryophyte macrofossils from 1-cm thick sediment intervals. Macrofossil remains from the ^{14}C-dated intervals were isolated using the standard method of sieving (80μm mesh size) with warm tap water, and identified by Alice Telka (*Paleotech Services,* *Ottawa, Canada*) under a binocular microscope. To avoid possible contamination by modern growth of fungal organisms during storage, the ^{14}C dating material was sub-sampled from the centre of the cores.

The dendrochronology-based calibration dataset IntCal09 (Reimer et al. 2009), recommended for non-marine radiocarbon samples from the Northern Hemisphere, was used to convert the radiocarbon ages (^{14}C yr BP) into calendar years before present (cal yr BP) in *Calib rev 6.0* (Stuiver and Reimer 1986). The calibrated ages represent the median probability estimates of the 2σ probability distribution (95% confidence interval). Even though they do not always plot where the highest probability lies, these estimates were nevertheless shown to be more stable than the intercepts with the calibration curve (Telford et al. 2004). Interpolations between ^{14}C (cal yr BP) and ^{210}Pb dated intervals and extrapolations were used to estimate the timing of changes, following the age depth models and based on linear regression between the dated intervals.

Diatoms

Diatom assemblages were analyzed in 47 and 65 sediment intervals for West Lake and 260 m Lake, respectively. Following standard techniques for diatom preparation (Battarbee et al. 2001), approximately 0.2 g of sediment was digested every second centimetre and at every 1-cm increment in the uppermost 10 cm as well as where visible lithostratigraphic changes occurred. Microscope slides were prepared on sedimentation trays and mounted using the high refraction medium Naphrax®. For most intervals, at least 400 valves were enumerated over multiple transects of the cover slip at 1000x magnification using a Leica DMR microscope with differential interference contrast (DIC) equipped with an oil-immersion objective and condenser lens, and approximately 600 valves were counted for intervals with high dominance (>50%) of small, benthic *Fragilaria sensu lato* to provide quantitative estimates of rare species. The identification of diatoms was made at the lowest taxonomic level, following Antoniades et al. 2008; Camburn and Charles 2000; Cremer and Wagner 2004; Cumming et al. 1995; Fallu et al. 2000; Foged 1981; Krammer and Lange-Bertalot 1986; 1988; 1991a, b; Lange-Bertalot 1996. Diatom data were converted into relative abundances for all analyses. The silicified chrysophycean stomatocysts were also enumerated, and are presented as a diatom frustule to cyst index (Frustule:Cyst) using the Smol index (Smol 1985). The differentiation of *Staurosira construens* var. *venter* from *Staurosirella pinnata* var*. pinata* and of the latter from *S. pinnata* var. *intercedens* using only a light microscope is often problematic, and therefore these taxa are often grouped in paleolimnological studies because of these difficulties and of their overall similar ecological preferences (Joynt and Wolfe 2001; Karst-Riddoch 2009). In the present study, *Staurosira construens* var. *venter* was generally larger than *Staurosirella pinnata*, and smaller *S. construens* var. *venter* individuals were tentatively sorted according to longer areolae length or wider valve size (Paull et al. 2008). *Staurosirella* individuals that had a length:width ratio over 2 were identified as *Staurosirella pinnata* var. *intercedens* (Antoniades et al. 2008).

Statistical methods

Species diversity, quantitatively reported as the Hill's N2 index (Hill 1973), was calculated using the *CANOCO ver. 4.5* program (Šmilauer and ter Braak 2002) and plotted against sediment depth and age as an indication of the community change through time. However, this index might not be representing changes in the abundance of the taxa at a consistent time scale throughout the cores due to changing sedimentation rate with time, water exclusion at the bottom of the cores and effect of desiccation that occurred during storage (core density and sampling resolution), and should therefore be interpreted with caution (Smol 1981).

A constrained incremental sum of squares cluster analysis (CONISS) of the complete diatom stratigraphy for each lake was performed to identify the main biostratigraphic zones representing the major changes in the communities over time. The program *Tilia ver. 2.0* was used to create the diatom stratigraphies. The diatom assemblage species changes through time were summarized using detrended correspondence analysis (DCA) (Hill and Gauch 1980). DCA sample scores from axes 1 and 2 were plotted against depth and age to compare the timing of diatom species turnover (Birks 1998) with the other proxy data inferred or measured downcore. The DCA was obtained from square-root transformed species without downweighting of rare taxa using *CANOCO*.

Diatom-inferred pH (Di-pH)

Diatom-based pH reconstructions were generated using the weighted-averaging (WA) model of Joynt and Wolfe (2001) following harmonisation of the diatom taxonomy. The model (r^2_{boot}= 0.44, $p < 0.01$, *RMSEP* = 0.34) is based on pH measurements and surface sediment diatoms from 60 lakes from poorly-buffered regions on Baffin Island, and should thus provide reasonable analogues for diatoms in our Pim Island sites. The WA model with classical deshrinking and bootstrapping was applied to the West and 260 m diatom profiles using C^2 ver. 1.4.3 (Juggins 1991). The Di-pH reconstructions were then linearly regressed against the first axis of the DCA performed on the diatom assemblages profiles described earlier in *CANOCO*, to assess if the main variation of the diatoms downcore captured in the DCA was correlated to the inferred variable.

Reflectance Spectroscopy

Spectral analysis was used on all 1-cm intervals from both the West and 260 m lake piston cores. The measurements were performed using a NIRSystems 6500 instrument (*FOSS NIRSystems Inc., Silver Spring, MD, USA*) on approximately 0.6 mL of freeze-dried, sieved (710 µm) and hand-ground sediment every 2 nm over the entire visible-near-infrared (VNIR) spectra (400-2500 nm), yielding 1050 data points. The sediment VNIRS "signature" is formed by the apparent absorbance wavelength and intensity values (*A*), according to $A = log(1/R)$, in which R is the measured diffuse reflectance, reported by the instrument as measurements of the interactions between the light in the VNIR region and the sediment sample organic components. The samples from the two cores were run over two days to avoid potential instrument drift.

Lake water DOC was inferred for the 2 lakes profiles using the Canadian Arctic Calibration Set (CACS) VNIRS model based on the entire VNIR spectra measured from 160 lake surface sediment samples and DOC measurements described in Rouillard et al. (submitted; Chapter 2). As described in Chapter 2, the VNIRS CACS-DOC model was developed from a 5-components partial least squares (PLS) regression of the spectra, cross-validated with 10 groups, providing a R^2_{CV} of 0.62 and a $RMSEP_{CV}$ of 4.4 mg·L^{-1} (11% of the DOC gradient). *Simca-P+ ver. 12.0.1* (*Umetrics AB, SE-907 91 Umeå, Sweden*) was used for the spectral analyses. The VNIRS-DOC model was applied to the West and 260 m lakes sediment samples spectral signatures that were transformed using a Multiplicative Scatter Correction (MSC) prior to the analyses to remove the influence of varying grain size, path length and measurement conditions. A principal components analyses (PCA) of the CACS spectral signatures with the passive VNIRS paleosignatures from the two study lakes was used to ascertain analogues from modern sites to those of the downcore profiles. Sedimentary chlorophyll *a* (SedChl*a*), a proxy for lake paleoproduction, was inferred using the model originally developed Das et al. (2005) and later refined by Michelutti et al. (2005). Using only the intervals where diatoms were enumerated, simple linear regressions were performed between the diatom DCA axis 1 and SedChl*a* profiles, as well as between the diatom DCA axis 1 and VNIRS-DOC profiles.

Results

Core descriptions

Visual inspection at the time of coring, during sectioning and subsampling allowed for the classification of the sediment sequences into lithostratigraphic units (Table 3.2). For West Lake, the 74-cm sediment record contained primarily organic sediment (Table 3.2a). It is likely that a small portion above the minerogenic layer was not collected during the coring effort (Field notes, W. Blake Jr., 1981). Originally measured at 105 cm, the core was subject to desiccation, especially in the most recent sediment, where up to 25% loss of the original volume was observed. Within the 134-cm 260 m Lake sediment record, the uppermost 91 cm of sediment is primarily organic-rich material (Table 3.1, b), but this is underlain with laminated, slightly angled minerogenic sediment (30 cm). This minerogenic section appeared to have dewatered on-site during retrieval, and its original volume remained unaltered despite complete desiccation, indicating material with poor water binding capacity. The minerogenic sediment section of the 260 m Lake core was lacking diatoms subfossils as well as macrofossils, as described later in this section. Such minerogenic sediment has been associated with the formation of an ice-dammed lake at Kap Inglefield (Blake et al. 1992), but could also be the result of the lake being at the glacier margin, and subsequent high energy deglaciation processes leaving minerogenic material from the receding glacier (Smith 2000). Laminated minerogenic material originating from glacier meltwater supplying high amounts of silt and clays to lakes and their catchments has been noted elsewhere (e.g. Axford et al. 2009a; Wagner et al. 2008).

No macrofossil remains of vascular plants were found in the ^{14}C-dated intervals in either sediment core (Table 3.3). However, relatively well preserved fragments of two species of aquatic mosses (bryophytes of the genera *Drepanocladus* and *Pseudocalliergon*) were found in changing abundances throughout the organic sequence of both cores (Table

3.2). The aquatic bryophyte species were also found during surveys of the Kap Inglefield Sø in nearby Greenland (Blake et al. 1992). Mosses represented up to 4 and 7 % of the sediment dry weight where they were found in the highest abundances (top of 260 m Lake core and base of West Lake core, respectively). A few limnic animal remains of invertebrates were also observed in the ^{14}C-dated intervals, including chironomids in all intervals analysed and caddisflies in the middle intervals of both lakes. The presence of several fragments of caddisfly larvae cases only made of minerogenic and chitinous material indicates that probably no organic material or plant tissue was available in their environment (Wiggins 1984). Zooplankton (ephippia of the cladoceran genus *Daphnia*) was also found in small number in both lakes, but not in the 51-52 cm deep interval of West Lake and in the most recent part of 260 m Lake.

Geochronology

Gamma spectrometry of the recent sediment samples indicated low ^{210}Pb activities in both cores, ranging from 0.03-0.3 $Bq \cdot g^{-1}$ (Fig. 3.2). The values are low, but they are comparable to other high Arctic sites (e.g. Douglas et al. 1994). The low activities, coupled with the post-coring desiccation and other potential changes in the surface sediments did not allow us to estimate ages using either constant rate-of-supply (CRS) or constant initial concentration (CIC) dating models (Appleby 2001). In particular, the first interval (originally 2 cm of watery gyttja) of West Lake core was separated and kept in a vial and was completely desiccated, so that neither the volume nor the water content could be measured. However, our contiguous ^{210}Pb dating of the recent 8-cm of sediments (Fig. 3.2) indicates that the entire unsupported ^{210}Pb inventory is contained in the upper 3 cm of West Lake core, indicating we have likely captured recent sediments in these sediment cores that can assess any post-1850 warming (e.g. Douglas et al. 1994). Since potentially only a minimum of material was lost from the top of the sediment surface during coring (watery algal gyttja from the top was preserved in a separate vial and analyzed here), we thus tentatively assigned the year of core recovery, 1981 (-31 cal yr BP) to correspond to the 0 cm depth for our age-depth model. Further, ^{137}Cs peaked during the 0-1 cm interval (West Lake), which suggests this interval probably includes the 1962-1963 peak in atmospheric fallout of this radionuclide (Schelske et al. 1994), supporting our estimated ages (Fig. 3.3). No down-core exponential decay nor ^{137}Cs peak were obtained in the most recent 8 cm of the 260 m Lake profile, possibly indicating that at least the most recent intervals where exponential decay should have been measured (~1850-1980) were not collected by the coring technique. Alternatively, extensive ice-cover at this site may have precluded sufficient radionuclide deposition in the lake. Dating lake sediments is known to present difficulties to Arctic paleolimnology. For example ^{210}Pb dating of Arctic lake sediment have often been found problematic (Wolfe et al. 2004) due to several sources of error, including disturbed sediment, altered delivery of fallout ^{210}Pb to the lake from the atmosphere or with catchment runoff from complete ice-cover or altered sediment (and ^{210}Pb) focusing from hydrological circulation patterns under the ice together with lake bathymetry. Nonetheless, accurate geochronology in Arctic lake sediment cores has been accomplished in many locations (Wolfe et al. 2004).

Four radiocarbon age determinations for each profile were obtained from the aquatic mosses macrofossils *Drepanocladus* sp. and *Psuedocalliergon* sp. (Table 3.3). Aquatic bryophytes have been shown to provide ages significantly older than terrestrial plant remains due to the "hardwater effect" in some cases (Wolfe et al. 2004). Although some calcareous till was observed on Pim Island, fewer carbonates were present in the West Lake's watershed and even less of these deposits could be seen in the surroundings of 260 m Lake, and thus the reservoir effect should be minimal in our study cores. Further, the age estimates established in our age model are consistent with the paleolimnological records on

Pim Island being constrained by the Wisconsinian glacial history ending with the retreat of the Innuitian Ice Sheet. The earlier age of the 260 m Lake profile (9255 ± 25 ^{14}C yr BP) corresponds closely to the onset of organic accumulation in the lake after deglaciation. The earlier age from the West Lake sedimentary profile is (8565 ± 25 ^{14}C yr BP) at its very base. The uppermost radiocarbon age from West Lake (3365 ± 20 ^{14}C yr BP, 11-12 cm) appears to be older than anticipated. However, this part of the core (top 35 cm) was the most affected by desiccation (25% volume loss), possibly due to original higher water content.

Age models

Although the ^{14}C dating method employed here provided ages with small errors (Table 3.3), especially when compared to many other Arctic studies where dating is very challenging (Wolfe et al. 2004), it is important to keep in mind that our interpretations based on our age-depth model-based should be considered with caution, especially given the amount of desiccation of the cores during 28 years of storage. Despite the difficulties of establishing age-depth profiles, the cores appear to be stratigraphically intact and thus suitable for paleolimnological analyses. The 260 m Lake profile provides a better resolution of the mid- to late- Holocene because 55 cm of sediment represent the last 5000 years (or even less) (36 diatom samples) while approximately the same time frame in West Lake is constrained in 20 cm of sediment (15 diatom samples) (Fig. 3.4). However, the desiccation effect does not account fully for the difference (>25%), indicating a potential higher sedimentation rate and/or larger volume occupied by mosses in 260 m Lake for that period. The non-desiccated section between 9500 and 7500 cal yr BP in West Lake comprises more than twice the amount of sediment found in the corresponding 260 m Lake section (28 versus 12 cm, respectively). Our age depth models could potentially be improved by considering desiccated sections, but the inconsistency of this effect throughout the cores would at best make the attempt approximate. Further, the changing abundance of mosses that at times represent a very significant volume of the cores sediment material makes the calculations of ^{210}Pb dates and the establishment of an overall reliable age-depth model very difficult. In 260 m Lake, the lack of chronological information for the top 12 cm and the bottom 8 cm necessitated making inferences from extrapolations, weakening the age-depth model for these periods. The top interval of 260 m Lake is conservatively estimated at 1100 cal years BP, but could range between 100 and 1100 cal years BP.

Diatom Stratigraphies

A total of 109 taxa, representing almost exclusively benthic and periphytic diatoms, were enumerated in both study cores. Similar species richness in both West Lake (81 taxa) and 260 m Lake (86 taxa) were recorded (Fig. 3.4). The species list, synonym and authority of the dominant taxa (>5% in at least one interval) are provided in Appendix E, and the counts are provided in Appendix F (West Lake) and G (260m Lake). While abundant valves could be found throughout the entire West Lake sediment record, diatom accumulation in the 260 m Lake started abruptly only from the 98 cm depth, concurrently with the onset of organic sedimentation. Only the dominant taxa are plotted in the West (23 taxa) and 260 m (21 taxa) lake core profiles (Fig. 3.3a,b). Diatom valve preservation was generally good throughout both sediment cores and no evidence of dissolution could be observed. Intervals that had undergone important desiccation contained poorly preserved valve fragments that could not be identified (maximum 4% of counted valves), but since some of the most lightly silicified taxa were present, it is unlikely that dissolution had a major influence on our counts.

CONISS differentiated three major diatom biostratigraphic zones in West Lake and four zones in 260 m Lake (Fig. 3.4). The overall variation, measured by the total sum of squares, was more important between major zones in 260 m Lake compared to West Lake.

The total variance (length of the gradient) recorded by the DCA of the diatom profiles was greater for 260 m Lake (3.3 SD units) than for West Lake (max 2.6 SD units). The main diatom changes are described below for each CONISS identified biostratigraphic zone.

West Lake

Zone 1 (Early Holocene; 9500-6000 cal yr BP; 74-27 cm)

The alkaliphilous, small, benthic fragilaroid species *Pseudostaurosira pseudoconstruens*, *Staurosirella pinnata* var*. pinata* and *Staurosira construens* var*. venter* dominate the assemblages up until ~6000 cal yr BP, at times accounting for over 90% of the subfossil assemblage (Fig. 3.4a). The Hill's N2 is the lowest for the record, expressing the simplicity of the algal community. Short-lived peaks in benthic and epiphytic *Rossithidium pusilum* (15%), *Achnanthidium minutissimum* (19%) and *Encyonema reichardtii* (26%) occur between 8300 and 7400 cal yr BP (55-43 cm) and contribute to the relatively higher Hill's N2 for that time. *Nitzschia* spp. (*N. fonticola, N. perminuta, N. inconspicua*) are also present throughout the zone, representing up to 10% of the diatom assemblage (especially around 8500 cal yr BP). This zone contains the highest Frustule:Cyst index values for the Holocene in West Lake.

Zone 2 (Mid-Holocene; 6000-4100 cal yr BP; 27-14 cm)

This zone is also dominated by *Fragilaria sensu lato* taxa (especially *Staurosirella pinnata* var*. pinata*), that form at least over 50% of the assemblage (Fig. 3.4a). A greater diatom species diversity emerges (high Hill's N2), with relative abundance of *Navicula*, *Cymbella*, *Achnanthes* and *Neidium* spp. becoming noticeable. The planktonic species *Cyclotella radiosa* appears at low abundances in the assemblage at the end of this zone (max 4 %), when relatively high abundances of *Encyonema naviculiformis* (20 %) and *Neidium* *decoratum* (10 %) are also observed with a low Frustule:Cyst index (minimum at ~4500 cal yr BP).

Zone 3 (Late Holocene; <4100 cal yr BP; 14-0 cm)

Several important and rather abrupt changes occur in Zone 3 (Fig. 3.4a). The first part of this zone (4100-1800 cal yr BP) is marked by an unprecedented co-dominance of *Sellaphora seminulum* and *Rossithidium pusillum*, with the presence of *Staurosirella pinnata* var*. intercedens* decreasing in abundance (28-6%) and a suite of low abundance epiphytic taxa (e.g. *Encyonema naviculiformis, Stauroneis anceps, Sellaphora pupula*). In the second part of Zone 3 (1800-100 cal yr BP), the small benthic fragilaroid taxon and several other taxa that were previously found only at trace levels, such as *Brachysira vitrea* and *Navicula schmassmannii*, become a more significant part of the assemblage. This follows a low in the Frustule:Cyst index was recorded here at ~1400 cal yr BP. The transition is marked by a peak in epiphytic *Gomphonema* taxa (21%).

The relative abundance of planktonic species (*Cyclotella radiosa*) remains low until the most recent sediments, the last transition of Zone 3, when it reaches up to 17% abundance. The presence of planktonic species in the most recent core intervals is consistent with the relatively high abundance of *Cyclotella radiosa* (up to 12%) found in modern epiphytic and sediment samples from West Lake (Appendix A). This major ecological change co-occurs with a sharp decline in *Fragilaria sensu lato* to the lowest levels recorded in the entire profile (1-14 %), and an increase in *Navicula schmassmannii* (24 %), *Brachysira vitrea* (25 %), *Sellaphora seminulum* (36 %) and *Achnanthes suchlandtii* (15 %).

260 m Lake

Zone 0 (>11,400-10,600 cal yr BP?; 97-92 cm)

At the onset of postglacial lacustrine sedimentation, a relatively diverse, acidophilous *Achnanthes* and *Navicula* spp. assemblage dominated the diatom community (including *Psammothidium lacus-vulani/levanderii*, *P. marginulatum*, *R. pusillum, N. schmassmannii* and *S. seminulum*), together with small benthic *Fragilaria sensu lato* taxa (max 22%) (Fig. 3.4b). The co-dominated *Achnanthes-Navicula* community found in this first zone, representing the first 5 cm of the organic section of the record (Table 3.2), is strikingly different than the following 5000 yrs. The relatively low Frustule:Cyst index could express that the chrysophycean community established earlier in the lake than the diatoms. The increase in SedChl*a* levels after the appearance of diatoms indicate that the algal community was established prior to major increases in lake primary production and organic material inputs from the catchment.

Zone 1 (10,600-5800 cal yr BP; 92-61 cm)

The acidophilous assemblage of Zone 0 (Fig. 3.4b) is replaced by a sharp shift toward a species-poor colonial alkaliphilous fragilaroid-dominated assemblage, including similar taxa as recorded at West Lake during the same interval. These taxa dominate the community for the next ~5000 yrs, with *Nitzschia fonticola* decreasing in abundance from the beginning of the period (32-0%). Similar to the West Lake profile, there are distinct peaks in the abundance of *R. pusillum* (29%), *Achnanthidium minutissimum* (16%) and *Encyonema reichardtii* (14%) between 9100 and 6700 cal yr BP (83-68 cm). The switch between the two first biostratigraphic zones marks the most pronounced species turnover of the record, as reflected by the DCA axis 1. Representatives of the *Achnanthes marginulata* complex (*Psammothidium lacus-vulcani/levanderii*) start to re-appear at significant levels in the assemblages from 6500 cal yr BP

Zone 2 (5800-2900 cal yr BP; 61-36 cm)

The species-rich diatom community enumerated in Zone 2 (Fig. 3.4b) appears to be a transitional phase where benthic and epiphytic *Achnanthes* taxa co-dominate with *Navicula* taxa and *Fragilariforma virescens*. *Fragilariforma virescens*, which reaches 37% in Zone 3, was only found at trace levels in the other zones. The biostratigraphic zone is also characterized by the appearance of the planktonic species *Cyclotella radiosa,* which remains at low abundance throughout the period (max 2%), and the tychoplanktonic *Aulacoseira tethera* that reach up to 11% at the end of the period, respectively. This peak corresponds to the highest Hill's N2 in the core. Increased levels of *Achnanthidium minutissimum* occur simultaneously with increases in planktonic taxa. *Navicula schmassmannii*, together with *A. kriegeri* and the epilithic *Psammothidium acares* all appear in large relative abundances at the beginning of Zone 2. A more acidophilous assemblage, composed of *Eunotia* spp, *Sellaphora seminulum*, *Achnanthes suchlandtii* and *Encyonema naviculiformis* appears at approximately 4700 cal yr BP

Zone 3 (Late Holocene; 2900-<1100 cal yr BP; 36-0 cm)

The acidophilous assemblage, co-dominated by *Navicula* and *Achnanthes* taxa, particularly *Sellaphora seminulum*, *N. schmassmannii* and the *A. marginulata* complex that appeared during Zone 3, remains relatively unchanged for the rest of the sediment record. Relative abundances of the small benthic *Fragilaria sensu lato* taxa are amongst the lowest on record (<2%). The DCA axes 1 scores also showed little variation during this period. The presence of the centric *Cyclotella radiosa* (up to 23 %) in all of the modern epiphytic and epilithic assemblages (This thesis, Appendix A) collected from rock scrapes and sediment between 1983-2009 and the complete absence of this taxa in the most recent increments of the 260 m Lake record indicate that the record is either incomplete at the top or that the environmental changes that allowed for planktonic taxa to thrive have started to impact the lake's limnological conditions in the last ~30 years. Chrysophycean stomatocysts were found in all sediment intervals, with many examples of highly ornamented morphotypes. The proportion of chrysophycean stomatocysts versus the diatom frustules was approximately two times higher in West Lake compared to 260 m Lake for the entire Holocene period, but low overall in both systems.

Diatom-inferred pH (Di-pH)

The correlation coefficients between the Di-pH profile and the DCA axis 1 sample scores were 0.80 for West Lake and 0.93 for 260 m Lake, indicating that pH is correlated with the main direction of variation in diatom assemblages in both study lakes. No-analogue conditions (up to 50% relative abundance of fossil assemblage missing training set) in non-Fragilarie-dominated portions of the lakes records might have caused biased Di-pH values and trends, and should therefore be considered with caution. The reconstructed Di-pH in West Lake remained alkaline around pH 8 during the first biostratigraphic Zone, with slightly lower values during the middle part (min=7.3). From the 6000 cal yr BP (Zone 2), a slightly decreasing trend was reconstructed until recent times, the lowest value attained was 7.4, and the most recent values slightly higher at 7.6. This value is slightly higher but consistent with the range of values measured since the early 80's at West Lake (7.0-7.5).

The Di-pH reconstruction of the 260 m Lake recorded values ranged from pH 6.8 to 8.6 over the organic record, representing greater variation than in West Lake. Zone 0 displayed a rather stable reconstructed pH, with a slightly alkaline mean of 7.3. At the beginning of Zone 2, the pH of the lake driven by the drastic floristic change in the diatoms, switched abruptly to become very alkaline with a value of pH 8.6 the highest pH reconstructed in the entire profile. The pH decreased again quickly in the following two biostratigraphic zones and, from the onset of Zone 3 and towards the most recent portion of Zone 4, the pH of the lake decreased gradually to reach a slightly acidic mean of pH 6.8. A slight increase in the most recent two intervals to 7.2 was inferred from the diatom assemblage, most likely driven by increases in *Navicula digitulus* and *Nitzschia* taxa. The 2009 measurements of summer pH for 260 m Lake was also slightly alkaline (7.1), while early 1980's measurements (taken through a hole in the ice) rather recorded slightly acidic values between 6.3 and 6.8.

Spectrally-inferred Chl a and DOC

A sharp rise in spectrally-inferred DOC and Chl*a* (not as sharp for DOC) marks the beginning of the organic sediment accumulation onset (10,500 cal yr BP), only captured by the longer record of 260 m Lake (Fig. 3.5). During the early- to mid-Holocene (10,500-5000 cal yr BP), both lakes recorded high SedChl*a* and DOC concentrations, with some fluctuations. The highest levels of primary production in the lake and catchment were recorded during the early- to mid-Holocene. These high early-Holocene inferred values are followed by an overall decline, well beyond the lower limits of detection for SedChl*a* and VNIRS-DOC models (0.01 mg·dry wt^{-1} and 4.4 mg·L^{-1}, respectively). The lowest values of lake water DOC and SedChl*a* are inferred during the mid-Holocene (5000-3500 cal yr BP), with an approximate 1000 years lag period between the lakes. A slight peak in lake biological production, tracked by the SedChl*a* and the inferred DOC profiles, occurred during the first part of diatom Zone 3 in West Lake (2300 cal yr BP). After 3000 cal yr BP, the lake production increased until the end of the sedimentary record (<1100 Cal yr BP; age uncertain) in 260 m Lake. The inferred DOC follows the same trend and values inferred are up to 6.8 mg·L^{-1}, with the exception of a sharp decline recorded in the most recent 3 sediment intervals. On the contrary, the values in West Lake for that period are low. The lake water DOC inferred in the most recent interval at West Lake is 2.4 mg·L^{-1}, which is slightly higher but in the same lower range of the present day value (0.5 mg·L^{-1}).

The PCA of the spectral signatures profiles from West and 260 m lakes provides us with further information on the chemical attributes of the organic compounds present in the sediment (Fig. 3.6). As expected, the clusters formed by the interval of the minerogenic bottom section of 260 m Lake falls outside 95% confidence interval of the calibration set PCA VNIRS signatures, and so do the most recent intervals from West Lake. The VNIRS sediment signature of the initial minerogenic section of the 260 m Lake record is very different from the organic portion of the core. The most similar VNIRS signatures to the minerogenic intervals are from high Arctic, unproductive lakes with mainly algal primary production (C/N ratio = 6), very low DOC (<1.7 $mg \cdot L^{-1}$) and sandy bottom sediment. The organic section of the profile almost entirely clusters together along axis 2, suggesting very little variation over time, apart from the 5700-3300 cal yr BP period when the organic compounds of the sediment appear slightly different along axis 1 (Zone 2).

The PCA biplot shows overlapping VNIRS signatures for both study lakes, suggesting similar types of organic sediment between the two cores (Fig. 3.6c). However, differences were recorded, particularly before 5900 cal yr BP, where the signature of West Lake sediments plot along axis 1 (λ_1= 0.46) at the opposite end of the PCA from the minerogenic section of 260 m Lake, possibly indicating differences in organic content between the two study cores. The PCA biplot appears to capture a gradient of catchment and aquatic production, as more productive lakes from the southern Yukon, Northwest Territories and forested regions of the subarctic all plot in the upper portion of the PCA, whereas unproductive lakes from the High Arctic plot near the opposite end of the PCA (Fig. 3.6).

West Lake's sediment VNIRS signatures for the most recent 1400 cal yr BP take a very different and abrupt trajectory along the second axis (λ_2= 0.40) and occupy ordination space that is unprecedented within the context of the entire Holocene. The VNIRS-DOC during this most recent period of sedimentation at West Lake must be interpreted with caution, because there are only poor analogues in the calibration set (Fig. 3.6, I). The most similar VNIRS signatures to this period are from very low DOC (<2.7 mg·L^{-1}), oligotrophic (Chl*a*<1.1; TP=3.5; TN=0.2 mg·L^{-1}) sites with a mixture of autochthonous and allochthonous organic matter inputs (C/N ratio = 16). The correspondence between the timing and direction of the downcore spectral signatures (Fig. 3.6) and the biostratigraphic zones (Fig. 3.3) can also be observed here, particularly the cooling trend occurring at about 6000 cal yr BP for both lakes.

Discussion

The proxy data gathered from West and 260 m lakes provide paleoenvironmental data for this region of the Arctic for the Holocene period. The data, which show the influence of climate and catchment-related processes on limnological proxies, are discussed below according to three well-documented and distinct climate periods of the Holocene (Kaufman et al. 2004; Wanner et al. 2008). These include: 1) the Holocene Thermal Maximum in the early portion of the record; 2) Neoglacial cooling and the Little Ice Age and 3) recent warming associated with the onset of the Anthropocene (past ~150 years).

Early Holocene

The early Holocene was characterized by higher insolation (Berger and Loutre 1991) and associated warmer temperatures with strong seasonality. The regional onset and ending estimates of the Holocene Thermal Maximum (HTM) in central-eastern Ellesmere Island are variable but estimates range from the onset at 9500 yrs BP with termination at 4500 yrs BP. Before the onset of appreciable amounts of organic sediment accumulation in 260 m Lake (Table 3.2), the core is characterized by the low values of SedChl*a*, suggesting minimal overall low aquatic production immediately following deglaciation (Fig. 3.5). The diatom community during this initial period of lake formation was dominated by slightly acidophilous, benthic *Navicula* and *Achanthes* taxa (Fig. 3.4). Such acidophilic diatom assemblages were also observed early after deglaciation on Baffin Island (Axford et al. 2009a; Michelutti 2007; Wolfe 1996). The pioneering assemblage found in this early period of the lake's history are markedly different from the small benthic fragilarioid assemblages that typically dominant postglacial assemblages in Arctic lakes. These acidophilous assemblages may reflect a still largely ice-covered catchment, where the dominant inflows into the lake are from snow melt and rainwater, with little contribution of base cations from fresh glacial tills. The favourable conditions for primary production of the early to mid HTM are reflected in our sedimentary profiles by high abundance of aquatic bryophyte macrofossils remains in the lakes sedimentary profiles (Table 3.2), high spectroscopically-inferred levels of DOC and SedChl*a* (Fig. 3.5) and organic-rich VNIRS signatures (Fig. 3.6). Relatively high primary production in the early stages of lake development has been shown elsewhere in the Arctic (e.g. Pienitz et al. 2000; Reuss et al. 2010).

The appearance of aquatic mosses (*Warnstorfia* sp.) in the early- to mid- Holocene was also recorded at Hjort Sø, central-eastern Greenland (Wagner et al. 2008). However, a rich moss layer was found in Northern Baffin Island sediment intervals corresponding also with peaks of temperature reversal during the HTM (Axford et al. 2009b). The variation under climatic shifts of aquatic moss abundance in shallow Arctic lakes has received little attention in the literature, despite their influence on biological lake structure and primary production (Anderson et al. 2004; Willemse 2002)

The highest lake water DOC inferred values in this study are recorded at West Lake in the early-Holocene (Fig. 3.5). These peaks in VNIRS-DOC correspond to VNIRS signatures that have their best analogues in the forested catchments of the Yukon, rich in coloured DOC from humic acids originating from the terrestrial vegetation and/or adjacent wetlands (Fig. 3.6). The application of the VNIRS technique that we employ in this study was used to infer lake water DOC and TOC content from Swedish Subarctic Holocene paleolimnological records and the inferences were linked to climatic changes through catchment biological production and other processes (Reuss et al. 2010; Rosén 2005; Rosén et al. 2001).

The similarities of early Holocene VNIR signatures in West Lake to that of productive forested sites in the PCA biplot (Fig. 3.6) suggest that a source of coloured DOC, most likely from complex organic compounds of terrestrial origin, influenced the light environment in the lake system during the early Holocene (Saulnier-Talbot et al. 2003). Catchment vegetation would have been most abundant during the HTM given the warmer temperatures and higher insolation (Berger and Loutre 1991). The high moss content found in the of both study cores during this period (Table 3.2) could have, at least in part, originated from the surrounding lush catchments, or a potential wetland community around the lakes. With the presence of a wetland-type vegetation in the catchment, the input of a relatively high amount of fulvic acids to the lake would have been likely. The alkaliphilous diatom taxa that dominated this portion of the record suggest that base cation inputs from recently deposited glacial tills overrode the effects of any acidic contributions from catchment organic inputs on diatom assemblages. The Frustule:Cyst index is higher during the early-Holocene as compare to the rest of the sedimentary profiles in the two records, but do not overall show any apparent relationship to climate conditions or habitat availability (Fig. 3.4). Chrysophytes were suggested to present both planktonic and epiphytic life forms in the Arctic, but Douglas and Smol (1995) suggested that Chrysophytes cysts are potentially not dispersed and deposited uniformly at the bottom of the lakes from their various microhabitats in the Arctic.

The dominance of small benthic fragilarioids diatoms during the HTM portion of our sediment records (Fig. 3.4 zones 1) is not necessarily consistent with warm temperatures and extended growing seasons. Fragilarioid taxa can thrive in rather deep benthic habitats and some species such as *Staurosirella pinnata* are described as low light specialists (Lotter and Bigler 2000). These opportunistic, R-strategists species usually characterize cold, largely ice-covered Arctic lakes (Smol et al. 2005). However, these *Fragilaria sensu lato* taxa dominate the early portion of our record most likely because they are early colonizers that thrive in carbonate-rich waters of recently deglaciated terrain (e.g. Reuss et al. 2010), including those of Cape Herschel's ponds (Douglas et al. 1994). Similar to West and 260 m lakes, the Arctic widespread *Nostoc commune* (Croasdale 1973) was also found during the first half of the deglaciated Holocene in high abundances at Kap Inglefield Sø (north-western Greenland), located just across Smith Sound from Pim Island. Decreasing relative abundance until 4200 (7210-4170 ^{14}C BP) was recorded and associated with the local expression of the *HTM* (Blake et al. 1992). *Achnanthidium minutissimum* and *Nitzschia perminuta*, both present during the mid HTM period, were also associated to a warming signal (Keatley et al. 2006).

The highest values of production-related variables including SedChl*a* and DOC occur in early Holocene, and this signal is particularly strong for West Lake. This suggests that warm conditions during this period allowed for enhanced aquatic production. The lack of planktonic taxa during the HTM is somewhat surprising, as planktonic diatoms are currently present in both study lakes and are associated with warming induced lengthening of the summer growing season and ice cover reduction. The occurrence of planktonic taxa in recent times, but their absence during the HTM, suggest that present-day conditions may be the warmest since deglaciation. Alternatively, it may be that the greater solar insolation during the HTM led to stronger seasonality (which has also declined throughout the Holocene), but the growing season was shorter compared to the CO_2-enhanced warming of present day, thereby precluding the establishment of large planktonic populations. Similar conclusions regarding enhanced seasonality were reached by Briner et al. (2006) in a paleolimnological study from east-central Baffin Island.

Abundant mosses (Table 3.1) and shallow water diatom specialists (e.g. *Achnanthes* spp. and *Encyonema reichardtii* (Cremer et al. 2001)) are observed in both the West Lake and 260 m Lake cores during the early Holocene (Fig. 3.4). These increases would be best explained by an increase in littoral habitat availability (Cremer et al. 2005; Douglas and Smol 1994). Considering the relatively steep but closed basins of the lakes (particularly 260 m), there are two possible mechanisms that would have led to larger littoral zones, both related to changes precipitation/evaporation ratio that could have occurred during the early Holocene as a result of stronger seasonality. Drastic changes in water levels have been witnessed at Cape Herschel in response to recent climate warming (Smol and Douglas 2007).

First, the entire lake bottoms could have become "littoral" following a major decrease in water level. Higher temperatures and/or low precipitations could cause such a decrease. The second potential mechanism for a more important littoral zone is an increase of the water level into the more gentle catchment slopes. Black marks from boulders surrounding 260 m Lake indicate past higher water levels at the site, and could be supporting this hypothesis. Under this hypothesis, the early-Holocene would have been wetter and/or cooler. The difference in span over time of this peak between lakes is difficult to explain, and could be the result of differences in drainage area size and hydrology as well as lakes' bathymetry. A detailed bathymetric survey and lake transect study for diatom composition and depth preferences of the lakes could provide more insights on the relationship of observed changes to lake water depth. It is unclear whether the probable changes in lake water levels would be directly (changes in precipitation patterns) or indirectly (evaporation) related to climate forcings. However, these peaks in shallow waters periphytic taxa are minor as compared to the overall dominance of small benthic *Fragilaria sensu lato* taxa.

Combining the evidence from our proxy data, we suggest that the main diatom community response during the early- to mid-Holocene was driven by the well-buffered nature of the catchment at this early stage, but could also have been influenced directly and indirectly by the warmer climate to a certain extent (e.g. water level change, more substrate availability).

Mid- to late-Holocene

The mid- to late-Holocene at Pim Island is characterized by shifts in diatom assemblages as well as changes in the inferred DOC and SedChl*a* profiles, suggesting changing environmental conditions. However, the timing and trends inferred by our different proxies are not completely coherent. The combined evidence from our sediment core data is consistent with cooling conditions during this period (i.e., 5300-4000 cal yr BP). This includes a marked drop in the presence of moss remains, declines in the Frustule:Cyst index (Fig. 3.4), and low inferred values of SedChl*a* and DOC (Fig. 3.5). Taken together all of these proxy data indicate a directional shift from more productive to less productive systems. As a result of decreasing summer insolation from the mid- to late-Holocene (Berger and Loutre 1991), the Northern Hemisphere has been shown to have experienced an overall cooling during the mid Holocene, also referred to as the "Neoglacial cooling" (Wanner et al. 2008).

The onset of cool conditions at ~5300 yr BP reflected by our multiple sedimentary proxies in both lakes (Fig. 3.6) is amongst the earliest recorded for Neoglacial cooling in this region of the Arctic. For example, at nearby Rock Basin Lake, shifts in diatom assemblages and reductions in biogenic silica suggest the onset of Neoglacial cooling at approximately

3000 yrs BP. This is supported by declining $\delta^{18}O$ and percent melt records from the Aggasiz ice Cap around this same time (Fisher et al. 1995). Pollen (Hyvärinen 1985) and diatom (Smol 1983) evidence suggested that the warm conditions of the HTM were ongoing until ~4000 years ago at Rock Basin Lake, and that the effects of the warming trend could be observed in the diatoms and biogenic silica content as late as 2500 cal yr BP (Michelutti et al. 2006). Differences in the inferred onset of Neoglacial cooling highlights the differing sensitivities among lakes and other natural archives to climatic fluctuations, or it suggests a spatially variable climate.

The most notable diatom shift recorded in both study lakes during the Neoglacial cool periods is the shift in dominance from small benthic *Fragilaria* spp. dominance (Fig. 3.4 zones 1) to a more diverse assemblage of small benthic and periphytic *Achnanthes* and *Navicula* taxa (Fig. 3.4 zones 2 and 3). *Psammothidium marginulatum* has been previously identified in the few softwater, slightly acidic ponds at Cape Herschel (Douglas and Smol 1994). *S. seminulum* has been found dominating the assemblages in Arctic latitudes sites also during the Holocene, but not during colder periods (Wagner et al. 2008). *N. schmassmannii*, has also been recorded in the early Holocene sediments of a low Arctic lake (Paul et al. 2010), and was associated with mosses and shallow waters. Although both study cores record a similar diatom transition, the timing of the shift differs by nearly two millennia according to our sediment age estimates (Fig. 3.4). This offset may be the result of an earlier depletion of carbonate-rich glacial tills in the catchment of 260 m, relative to West Lake. The more variable and diverse diatom assemblages that has been observed in poorly-buffered sites are attributed to their heightened sensitivity to climate-driven pH dynamics (Axford et al. 2009a; Michelutti et al. 2006, 2007; Wolfe 2002). Although including only the most recent portion of the Holocene, several other sediment records from poorly-buffered Arctic sites also had a relatively diverse diatom assemblage preceding the most recent anthropogenic-related climatic forcing, such as in ponds I-F and I-O at Isachsen, Ellef Ringnes Island (Antoniades et al. 2005), Sanagak Lake on the Boothia Peninsula (Stewart et al. 2008) and Lake BC01 on Melville Island (Peros et al. 2010).

In contrast, well-buffered Proteus Lake, located only a few kilometres away, slightly higher in elevation from our two study lakes and of similar size (Fig. 3.1), maintained an alkaline *Fragilaria*-dominated community over its 9000 cal yr BP deglaciated environmental history, with only minor variation in species composition (Howard 1989). Diatom assemblages in sediment cores from well-buffered sites such as at Cape Herschel (Douglas et al. 1994), but also in several other high Arctic sites (Blake et al. 1992; Finkelstein and Gajewski 2008; Howard 1989; Perren et al. 2003; Podritske and Gajewski 2007; Smith 2002; Wolfe 2000), typically are dominated by small benthic fragilarioids up until the late twentieth century when human-induced warming resulted in more diverse assemblages (Smol et al. 2005). Shorter sediment records also from well-buffered sites show the same trend (e.g. Self Pond (Antoniades et al. 2005); Elison Lake, Camp Pond, Col Pond (Douglas et al. 1994); Skeleton Lake, EP2 and EP3 (Keatley et al. 2008); BK3, BK5, BKAH (Lim et al. 2008)). This trend appears independent of whether sites are ponds (>2m) or lakes (>2m). A limited number of sites do not illustrate this trend (e.g. MV-AT (Keatley et al. 2006)).

Another notable change in the subfossil diatom record of 260 m Lake is the appearance of the large, heavily silicified, tychoplanktonic *Aulacoseira tethera* (Fig. 3.4b). Its presence in the lakes of north-eastern Greenland was interpreted to reflect relatively warm, turbulent waters, with higher pH and lower than normal water levels (Cremer et al. 2005). *Aulacoseira tethera* was also found at high abundances (up to 13%) in alkaline lakes from Store Koldewey, north-eastern Greenland, (Cremer et al. 2005), but was not common in other Arctic surveys. In the present study, its relative abundance peaked at the end of the zone (2900 cal yr BP), potentially indicating somewhat warmer conditions at that time.

For West Lake, the good correlation between the DCA axis1 and SedChl*a* (r^2=0.76) and VNIRS-DOC (R^2=0.71) suggests covariance between the DOC and SedChl*a*. The diatom assemblages at West Lake, though, do not appear to have been particularly affected by the coloured DOC recorded in the early Holocene (Fig. 3.4), even though several lines of evidence have shown the importance of the optical environment to aquatic primary producers (Pienitz and Vincent 2000), including diatoms (Fallu and Pienitz 1999; Saulnier-Talbot et al. 2003). Large changes in the underwater optical environment of subarctic lakes have been shown to have occurred over the Holocene period (Reuss et al. 2010; Saulnier-Talbot et al. 2003). For instance, an increase in diatom-reconstructed DOC of 5 $mg{\cdot}L^{-1}$, associated with increase in catchment vegetation, reduced significantly the UV penetration in the aquatic system (Saulnier-Talbot et al. 2003).

The profiles for SedChl*a* and inferred DOC show opposite trends in 260 m Lake and West Lake over the past 2000 years (Fig. 3.5), however, both cores show similar diatom assemblages (Fig. 3.3). In addition, the very different diatom assemblages (Fig. 3.4, zones 1 versus zones 2) recorded between the early and mid-Holocene suggest that there is no relationship between the diatom community species composition and the type of organic matter present in the sediment. Overall, despite important changes inferred in the light environment our study sites over the Holocene, no clear response from the diatom community to these changes was recorded. Rather, the subfossils assemblages responded to lake pH, and varied in correlation with overall changes in biological production.

Most recent environmental history at Pim Island

The post-1850 AD portion of the diatom record from West Lake shows a significant ecological change of the Holocene, namely the onset of appreciable abundances of planktonic *Cyclotella radiosa* (Fig. 3.4a). Widespread increases in planktonic diatoms have been observed in post-1850 sediment records throughout the Northern Hemisphere, and reflect the anthropogenic-related global warming trends affecting ice cover dynamics and thermal stratification (Rühland et al. 2008).

The presence of planktonic taxa in post-1850 sediment, such as *Cyclotella* species, has been observed in several paleolimnological records from lower Arctic latitudes, in northeastern Greenland, Svalbard and in the Russian Polar Urals (Cremer and Wagner 2004; Rühland et al. 2008). To our knowledge, though, sizeable populations of planktonic taxa have rarely been observed within the Canadian High Arctic Island Archipelago, and these rare records are from exceptional sites such as the large and deep Lake Hazen (Antoniades 2005) on north-eastern Ellesmere Island and a nutrient-enriched Thule whalers site on Bathurst Island (Hadley et al. 2010). However, the recent warming has also been expressed in the nearby ponds at Cape Herschel's ponds, which showed an unprecedented diversification of the benthic and epiphytic diatom assemblages, resulting from a lengthened growing season (Douglas et al. 1994). In addition, analyses of nearshore sediment and rock scrapes recovered from 1983 to 2009 well-buffered Proteus Lake on Pim Island sediment and rock scrapes revealed still no planktonic taxa in the lake (This thesis, Chapter 2).

Summary

We utilize primarily diatom assemblages as proxies for climate and other limnological changes in two poorly-buffered shallow lakes on Pim Island, central-eastern Ellesmere Island. Our diatom-based Holocene reconstructions and assessment of the aquatic conditions in the lakes were supported using spectroscopically inferred DOC and sedimentary Chl*a*. Consistent with other high Arctic studies, the diatom assemblage characterizing our poorly-buffered sites displayed a heightened response to some of the main Holocene climatic trends observed in our other proxy data versus well-buffered sites.

During the early Holocene, when more favourable conditions for primary production at the sites were inferred by our other proxies and supported by the regional trends, the algal assemblages were still dominated by alkaliphilous *Fragilaria sensu lato* taxa taking advantage of the calcareous tills left by the retreat of glaciers in their catchments. At both West Lake and 260 m Lake, the fragilaroid-dominated assemblage of the early Holocene shifted abruptly in the mid Holocene to become co-dominated by slightly acidophilous *Achnanthes* and *Navicula* taxa.

The different timing within West Lake and between lakes (~2000 years) and nature of that community shift cannot be explained by the regional cooling trends (supported by low moss content, SedChl*a* and VNIRS-DOC as well as organic-poor-like VNIRS signatures). We suggest that this threshold response was triggered by a loss of the lakes catchments buffering capacities, and that climate-related processes become the main forcings on diatom communities when the lake is in equilibrium with its abiotic surroundings.

The variable benthic and periphytic littoral diatom assemblage characterized the lakes until the most recent sediments, after which a centric (*Cyclotella radiosa*) planktonic community became a larger part of the community and is still present today. The post-1850 Hemispheric-scale appearance of planktonic diatoms, attributed to anthropogenic-induced warming, had not yet been recorded in central Ellesmere Island, and only a few studies have observed the phenomena thus far in the high Arctic. The absence of planktonics from our records during the early Holocene perhaps suggests that the HTM warming was of a different nature to the recent warming despite a similar or even greater magnitude.

A better estimate of the difference in timing of the ecological response to the post-1850 warming between poorly-buffered and well-buffered sites could be attained by further high-resolution analysis of sedimentary records from West Lake and 260 m Lake versus Cape Herschel's well-buffered ponds, in which a more diverse littoral flora has succeeded to a small benthic *Fragilaria*-dominated assemblages around 1850 A.D. We conclude from this first application VNIRS-based DOC inferences and use of spectral signatures, that this fast and non-destructive technique has the potential to increase our understanding of long-term processes on the carbon cycling in lakes of high latitudes, of past optical aquatic environments and of catchment influences.

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Table 3.1. Select geographical (coordinates), topographical (altitude, lake depth (Depth), surface area (Area)) and limnological properties (i.e., water temperature (Temp), pH, specific conductivity (Conductivity), total phosphorus unfiltered (TPU), dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), total nitrogen unfiltered (TNU), silica (SiO_2), ions of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chlorine (Cl) and sulfate (SO_4), as well as nitrogen pentoxida (NO_2NO_3), nitrites (NO_2), and ammonium (NH_3)) and main metallic nutriments (alumninum (Al), iron (Fe), manganese (Mn)) from West Lake and 260 m Lake from the 1980-2009 surveyed period (mean values).

Variable	**Units**	**West Lake**	**260 m Lake**
Latitude	(N)	78˚44.283'	78˚41.825'
Longitude	(W)	74˚37.983'	74˚22.557'
Altitude	(m a.s.l.)	315	260
Depth	(m)	12	9.8
Area	(m^2)	110,000	43,600
pH		6.5	6.6
Conductivity	($\mu S \cdot cm^{-1}$)	29	36
Water temp	(˚C)	4	2
TPU	($mg \cdot L^{-1}$)	0.0143	0.0094
TNU	($mg \cdot L^{-1}$)	0.133	0.176
DOC	($mg \cdot L^{-1}$)	0.5	0.8
DIC	($mg \cdot L^{-1}$)	2.2	1.0
Alk $CaCO_3$	($mg \cdot L^{-1}$)	9.2	4.1
Cl	($mg \cdot L^{-1}$)	4.2	6.7
SO_4	($mg \cdot L^{-1}$)	1.4	1.9
SiO_2	($mg \cdot L^{-1}$)	0.5	0.6
Ca	($mg \cdot L^{-1}$)	1.9	0.9
Mg	($mg \cdot L^{-1}$)	1.1	0.7
Na	($mg \cdot L^{-1}$)	2.5	3.5
K	($mg \cdot L^{-1}$)	0.3	0.5
NO_3NO_2	($mg \cdot L^{-1}$)	0.01	0.05
NH_3	($mg \cdot L^{-1}$)	0.022	0.042
NO_2	($mg \cdot L^{-1}$)	0.001	0.001
Al	($mg \cdot L^{-1}$)	0.34	0.10
Fe	($mg \cdot L^{-1}$)	0.379	0.122
Mn	($mg \cdot L^{-1}$)	0.0076	0.0037

Table 3.2. Core descriptions for West Lake (a) and 260 m (b) Lake.

a) West Lake

Depth (cm)	Age (Cal yr BP)	Core description
0-1	~-12-63	Homogenous algal gyttja
2-6	~100-1400	Grey banded sediment/more grey-brown zone (organic-rich sediment)
7-37	1800-6900	Beige-grey organic clay (buff sediment) with few mosses and thick moss layers at 7-13 cm and 24-27 cm
38-74	7000-9500	Greenish-grey clay/buff-increasing brown towards base with few mosses and thick moss layers at 45-51 and 68-74 cm

b) 260 m Lake

Depth (cm)	Age (Cal yr BP)	Core description
0-47	<2900-4300	Organic clay with very gradual change from a few mosses to very mossy; 2-3mm pebbles found at 45 cm
48-67	4500-6600	Homogenous clay with fine sand, no mosses or very few
68-81	6700-8800	Clay with silt, mosses (peaks: 70, 73 cm) and other macrofossils
82-91	8900-~10,400	Clay with silt and fine sand, small gravel and pebbles, up to 8 mm (peaks at 86 and 89 cm intervals; transition to sand and silt transition before 90 cm, mosses at 89 cm only
92-98	~10,700-~11,500	Homogenous silt and fine sand
98-134	> ~11,700	Laminated minerogenic (sand and silt)

Table 3.3. Radiocarbon ages from West and 260 m Lake cores provided as radiocarbon years before present (^{14}C yr BP) and the median probability estimate (Cal age) in calibrated calendar years before present (Cal yr BP), including the two sigma ranges (95.4% confidence intervals), the δ^{13}C correction for isotope fractionation (δ^{13}C) obtained from aquatic bryophyte macrofossils.

	Depth (cm)	**UCIAMS number**	**^{14}C age (^{14}C yr BP)**	**δ^{13}C**	**Cal age (Cal yr BP)**	**2σ ranges (Cal yr BP)**
West Lake	11-12	83946	3365±20	-31.2	3609	3560-3644* 3659-3686
	26-27	83947	5190±20	-29.4	5940	5912-5952* 5961-5990
	51-52	83948	7220±30	-28.0	8022	7965-8065* 8087-8157
	73-74	83949	8565±25	-31.0	9536	9500-9511 9516-9550*
260 m Lake	12-13	83950	1805±20	-25.0	1745	1638-1644 1696-1817*
	36-37	83951	2840±20	-25.0	2943	2869-3003
	70-71	83952	6235±25	-26.9	7181	7025-7060 7065-7116 7154-7251*
	89-90	83953	9255±25	-28.3	10,442	10,295-10,364 10,366-10,517*

*2σ range with the highest relative area under the probability curve

Fig. 3.1: Topographic map of Pim Island and the Cape Herschel with 100m elevation contour lines and areas with permanent snow and ice-cover (grey-shaded), located on the east-central coast of Ellesmere Island (Nunavut, Canada). The study sites (West Lake and 260 m Lake) and the other waterbodies under study in Appendix A on Pim Island are marked by a black dot. Original geographic data scale 1: 50 000 (source: National Topographic Data Base). Generated with Arc-GIS Desktop ver. 9.2.

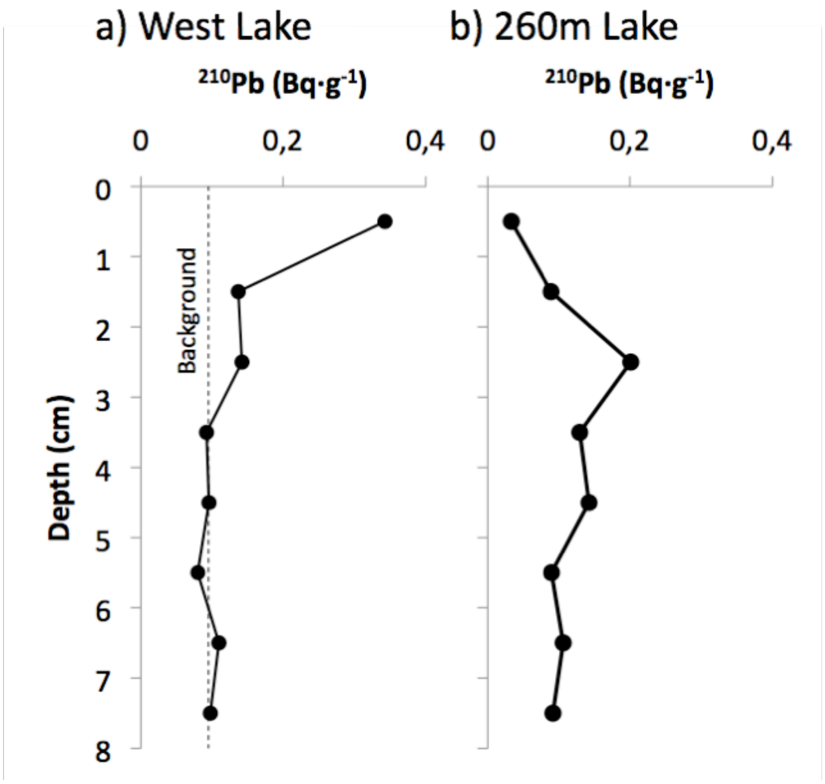


Fig. 3.2: Relationship between total ^{210}Pb activity in becquerels per gram (Bq·g^{-1}) measured with gamma spectrometry and core depth for the uppermost 8 cm of (a) West Lake and (b) 260 m Lake Holocene cores. Background in West Lake (dashed line) was reached between 3 and 4 cm.

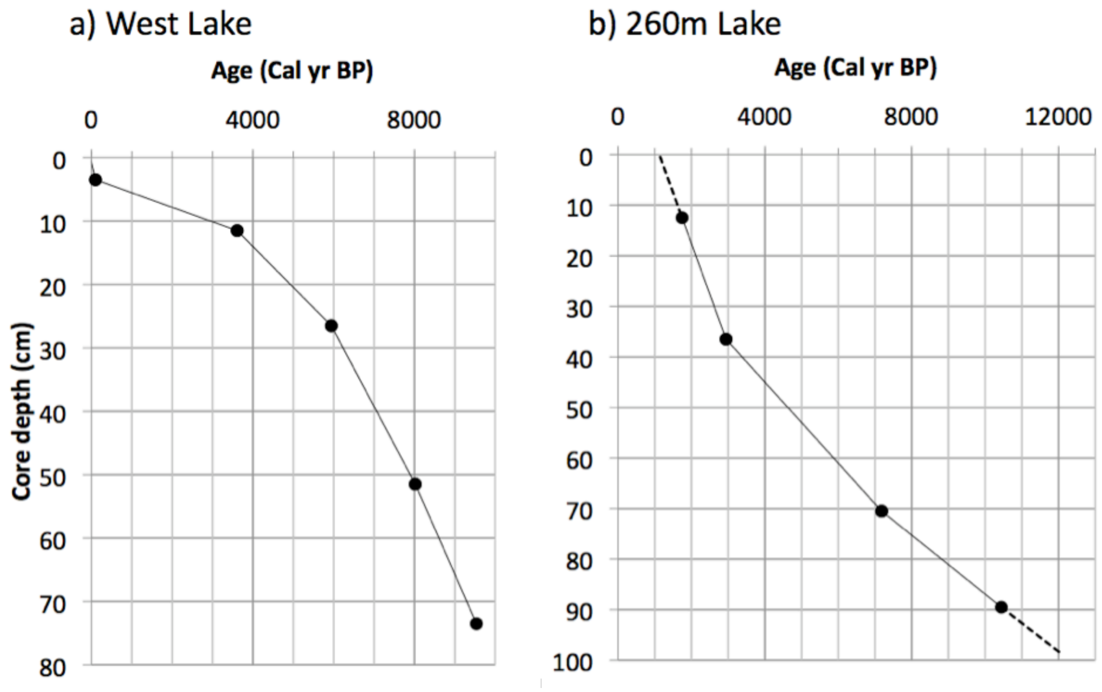
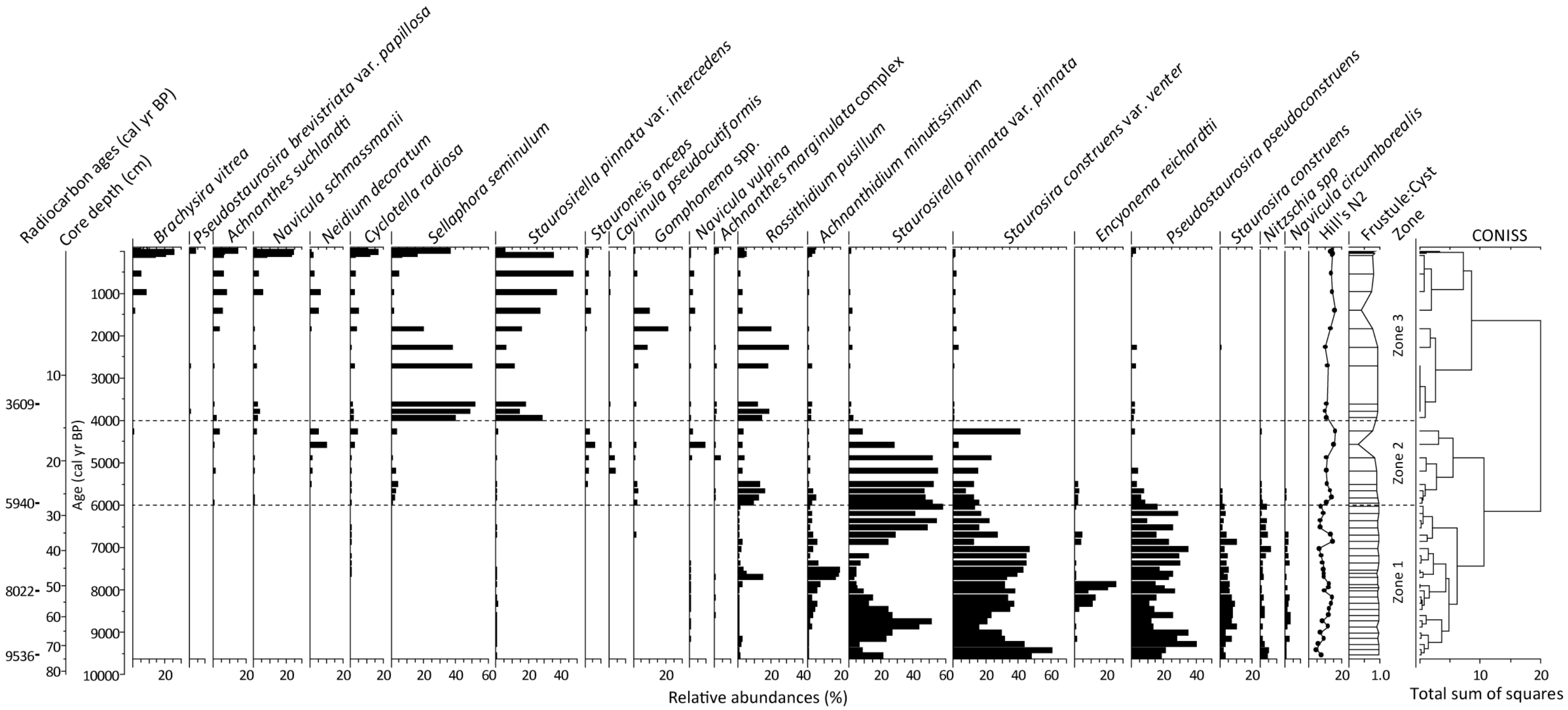


Fig. 3.3: Linear regression-based age-depth models used for the chronology of (a) West Lake and (b) 260 m Lake piston cores based on the approximated background ^{210}Pb approximative time horizon and coring date obtained for West Lake and 4 calibrated radiocarbon ages (black dots) obtained on aquatic bryophytes for each lake. Interpolations between dated intervals (solid line) and extrapolations beyond (dashed line) were used. The ages are reported in calibrated years before present (cal yr BP) and were converted from radiocarbon ages in *Calib rev 6.0* (Stuiver and Reimer 1986) using the standard calibration dataset IntCal09 (Reimer et al. 2009).

a) West Lake


Radiocarbon ages (cal yr BP)
Core depth (cm)
Brachysira vitrea
Pseudostaurosira brevistriata var. papillosa
Achnanthes suchlandti
Navicula schmassmanii
Neidium decoratum
Cyclotella radiosa
Sellaphora seminulum
Staurosirella pinnata var. intercedens
Stauroneis anceps
Cavinula pseudocutiformis
Gomphonema spp.
Navicula vulpina
Achnanthes marginulata complex
Rossithidium pusillum
Achnanthidium minutissimum
Staurosirella pinnata var. pinnata
Staurosira construens var. venter
Encyonema reichardtii
Pseudostaurosira pseudoconstruens
Staurosira construens
Nitzschia spp
Navicula circumborealis
Hill's N2
Frustule:Cyst
Zone
CONISS
3609
5940
8022
9536
10
20
30
40
50
60
70
80
Age (cal yr BP)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Zone 3
Zone 2
Zone 1
20
20 20
20 20
20 40 60
20 40
20
20 40 20
20 40 60
20 40 60
20
20 40
20
20
1.0
10 20
Relative abundances (%)
Total sum of squares

b) 260 m Lake

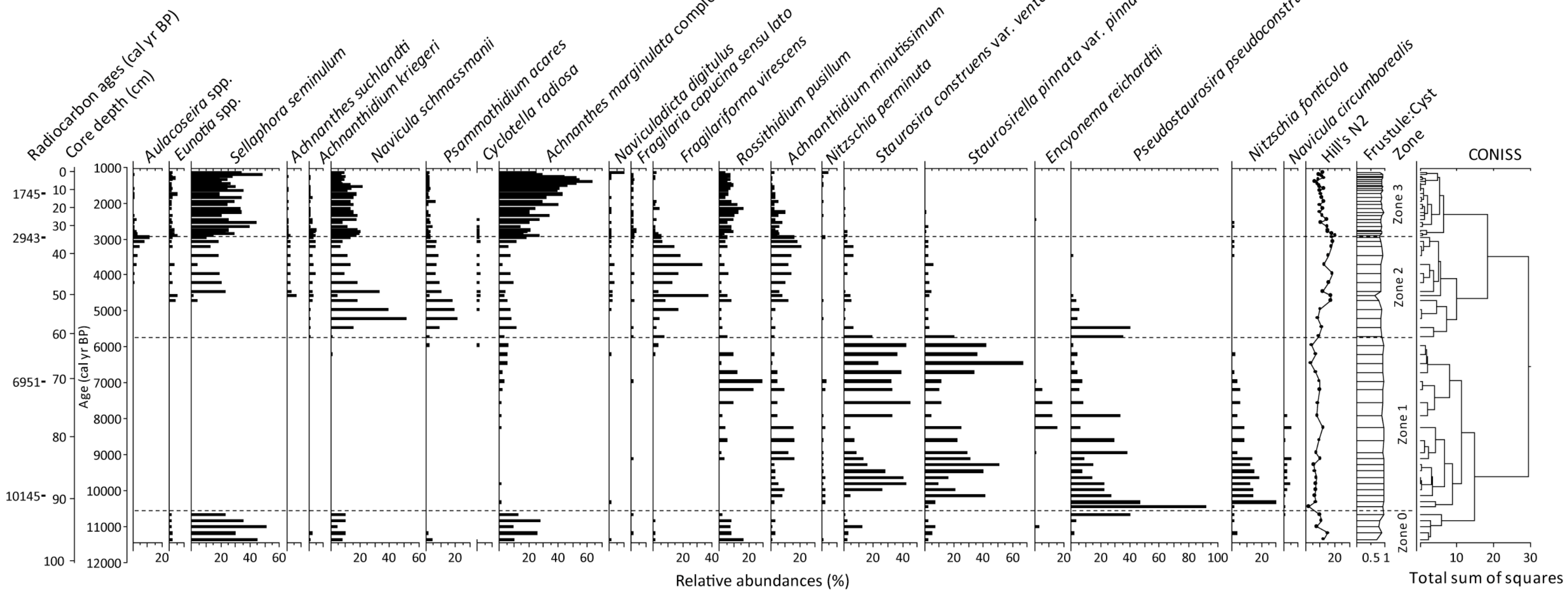


Fig. 3.4: Holocene diatom records stratigraphies for West (a) and 260 m Lake (b), showing relative frequencies of the most abundant taxa ordered by increasing DCA axis 1 species scores (left to right). The Hill's species diversity index (Hill's N^2) and the diatom frustule to chrysophyte stomatocyst index (Frustule:Cyst) are plotted against age (Cal yr BP) and core depth (cm) on the diatom stratigraphy. The records are separated (dashed line) in biostratigraphic zones (Zone) following the main changes in the communities identified by a constrained incremental sum of squares cluster analysis (CONISS).

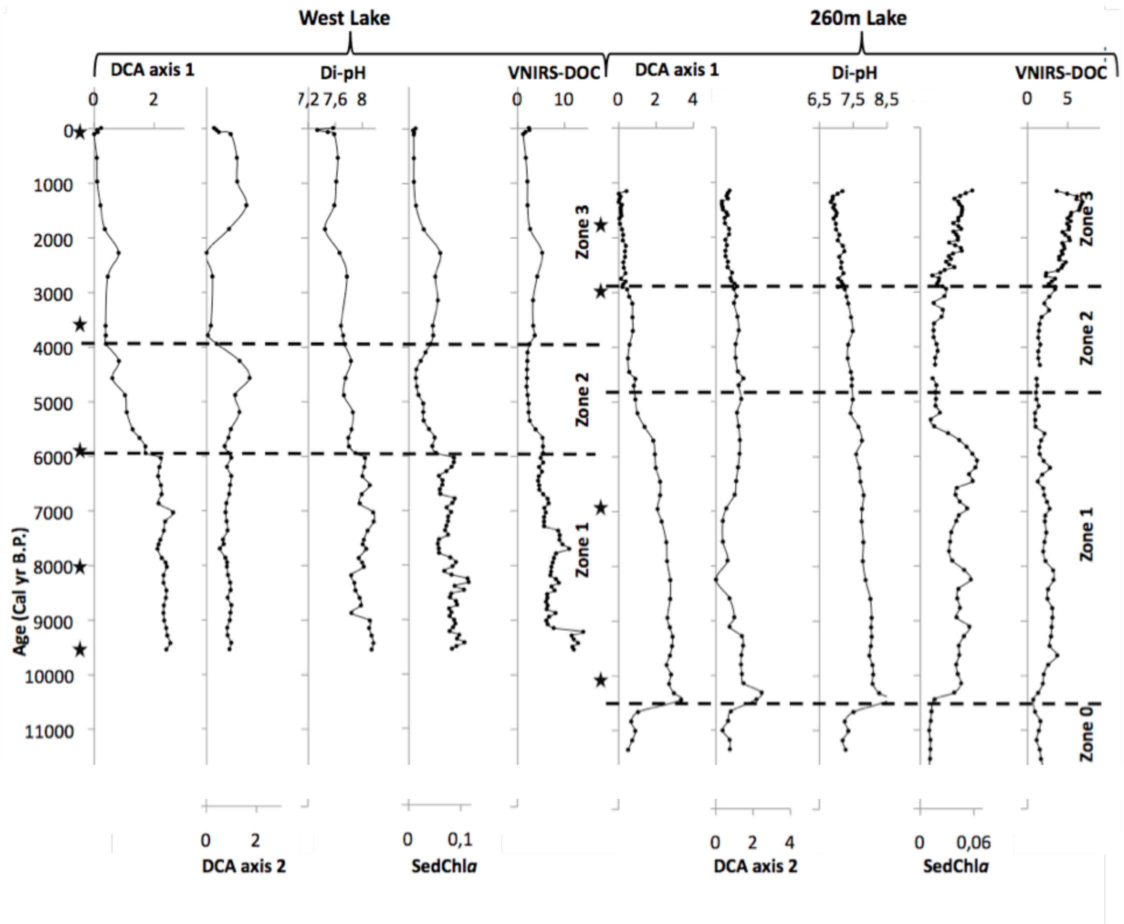
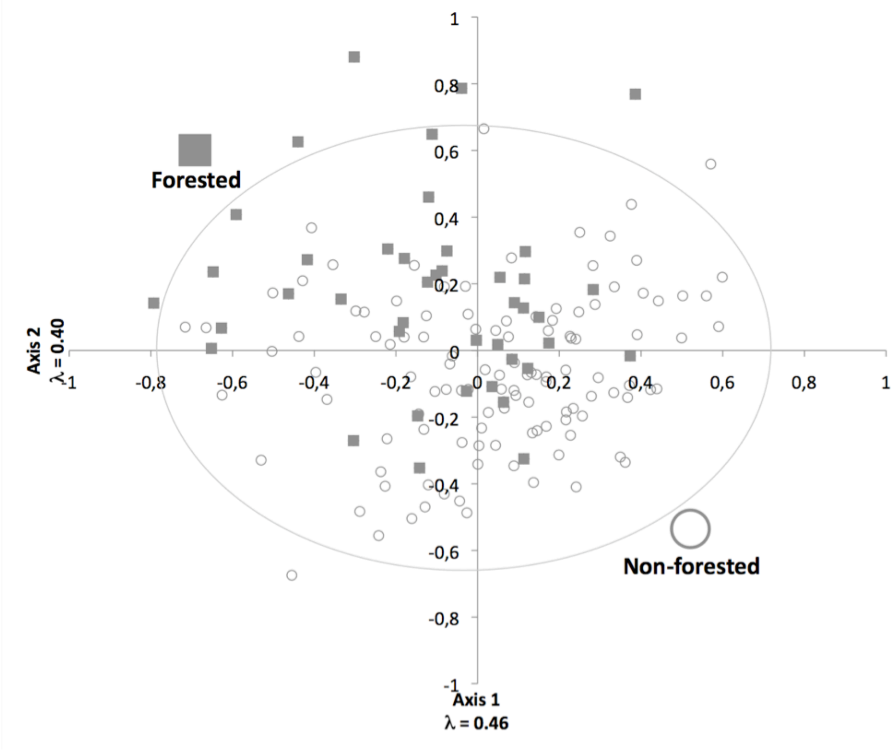


Fig. 3.5: West and 260 m lakes Holocene records of the diatom downcore assemblage first 2 DCA samples score axes (West Lake: λ_1=0.54, λ_2=0.13) and 2 (260 m Lake: λ_1=0.59, λ_2=0.13), diatom-inferred pH (Di-pH), sedimentary Chl*a* (SedChl*a*) and VNIRS-inferred DOC (VNIRS-DOC) plotted against time. The records are separated (dashed line) in the diatom biostratigraphic zones (Zone) to facilitate interpretation. The stars indicate dated intervals.

I)


Forested
Non-forested
Axis 1
λ = 0.46
Axis 2
λ = 0.40
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1

II)

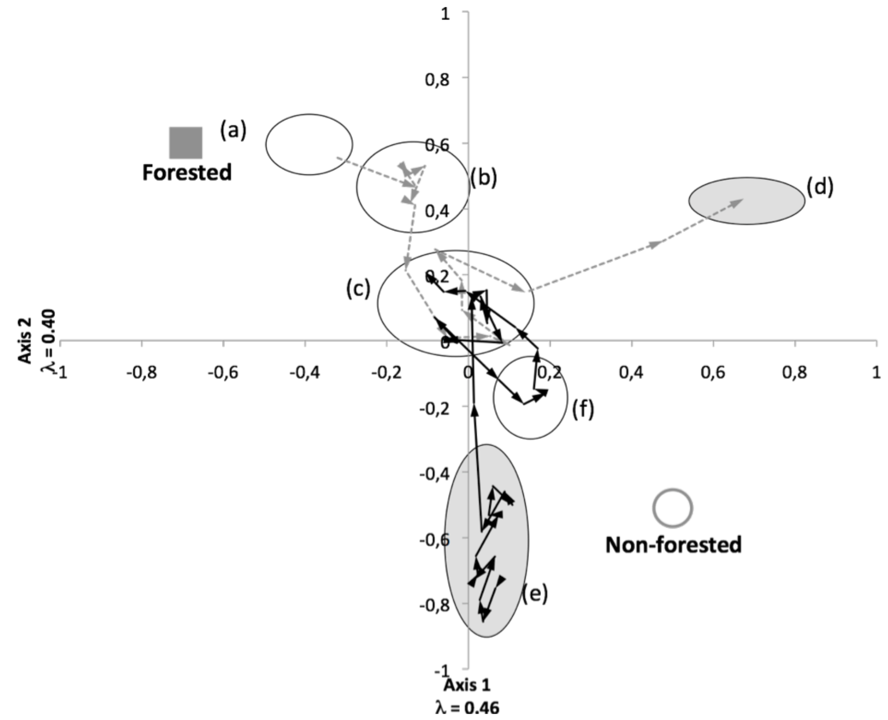

(a)
(b)
(c)
(d)
(e)
(f)
Forested
Non-forested
Axis 1
λ = 0.46
Axis 2
λ = 0.40
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1

Fig. 3.6: (I) Principal component analysis (PCA) of the VNIRS signatures from the 160 Canadian Arctic surface sediment calibration set including lakes located in forested (filled squares) and non-forested (empty grey circles) catchments (grey circle = 95% confidence interval) and their centroids. (II) The VNIRS dowcore spectral profiles from West (dashed grey line) and 260 m (black solid line) Lakes are plotted passively to the PCA and represented as ~500 cal yrs BP running mean (arrow heads pointing towards top of the cores). The first 2 axes represent 86% of the variation (46 and 40%, respectively). The analyzed samples cluster time periods captured by both (no filling) or only one (grey filling) of the lakes sedimentary profiles represent the following ages (cal yr BP): (a) >9200, (b) 9100-6000, (c) 5600-1400 and (d) >1000 in West Lake, and (e) >10,300 (c) 10,100-5500 (f) 5500-3500 (c) <3300 and in 260 m Lake. All spectra have been centred and applied a MSC prior to analysis.

CHAPTER 4

General Discussion

In this thesis, paleolimnological techniques were used to study the local and regional influences of climatic change and related catchment processes on high Arctic aquatic environments over the scale of the Holocene. In the first manuscript (Chapter 2), we developed a Canadian Arctic model based on a novel technique in reflectance spectroscopy for inferring lake water DOC from lakes sediment, and we compared its Holocene reconstructions to a diatom based DOC model and a VNIRS-TOC model. In my second manuscript (Chapter 3), we employed a multi-proxy approach to assessing Holocene environmental change including the use of subfossil diatom assemblages and spectroscopically-based VNIRS-DOC model and sedimentary Chl*a*. As a qualitative exploratory attempt (Appendix A), we documented the available modern biological and limnological characteristics of lakes and ponds from Pim Island (Nunavut, Canada). We used subfossil diatom assemblages preserved in modern littoral sediments and rock scrapes to make inferences on the main drivers of environmental change at these sites over the Holocene. Some of the general conclusions from these studies are described below.

Tool development for high Arctic paleoenvironmental studies

Diatom assemblages have been used to successfully infer past lakewater DOC concentrations in paleolimnological studies (Saulnier-Talbot et al. 2003). However, diatom-based DOC inferences have the potential to be confounded by the influence of lakewater pH, which is often identified as the main variable influencing diatom assemblages. To avoid potential complications with diatom-based DOC models, we utilized a relatively new, VNIRS technique. Previously, a calibration set of Swedish Subarctic lakes was used to develop a VNIRS DOC model and consequently was applied to lake sediment cores to infer changes in climate and catchment-related processes over the scale of the Holocene (Rosén et al. 2001; Rosén 2005; Reuss et al. 2010).

Our results from Chapter 2 suggest that the history of lake catchment changes is partly preserved in sediment cores (reflected in sediment profiles) in the form of a geochemical "fingerprint" that can be recorded using VNIRS and modelling approaches. Our analyses also suggest that VNIRS-based models to infer past lake water DOC have no major geographic limitation, and thus offer a wide scale of applicability. In general, the DOC model developed here allows for the reconstruction of overall trends in lake water DOC from lake sediment cores, highlighting the usefulness of VNIRS as a time- and cost-effective tool for the investigation of long-term changes in the optical environment and C cycle of freshwater ecosystems.

In the future, the utilization of the CACS-based VNIRS model for DOC inferences on sedimentary records from different regions of the Arctic should provide further testing of the method's capabilities, and potentially our understanding of long-term catchment processes at high latitudes in lake optical conditions and biological response. An analogue-based selection of calibration sites could improve our lake water DOC inferences. For instance, more reliable VNIRS-DOC values could be attained by extending the Canadian calibration set with analogue sites from northern Sweden described in Rosén (2005).

Local influence to Holocene climate response from poorly-buffered lakes

The Arctic VNIRS-model for DOC lakewater inferences developed in Chapter 2 was applied to assess potential catchment influences and variation in light penetration in two limnetic systems from high latitude Pim Island, Nunavut, over the Holocene. The spectrally-inferred variables appeared to follow some of the main trends in climate during the Holocene (HTM, Neoglacial Cooling), and some large variations were observed in the absolute values. However, the diatom community appeared to be only marginally related to the variations in VNIRS-DOC. Rather, our data suggest that the geological setting of our study region strongly influenced the diatoms as climate-driven pH dynamics governed the acid-base equilibria of these sites. Following deglaciation our sites appeared to be mainly influenced by alkalinizing inputs from abundant glacial tills. However, as the base cation inputs from glacial tills declined over time, climate appeared to have a first order influence on diatom assemblages via control over limnetic DIC dynamics.

The information gathered on present-day limnological variables, diatom species composition and their ecological preferences was used to help interpret the paleolimnological inferences from the Holocene lake records of two lakes on Pim Island, as discussed in Chapter 4. Based on previous Arctic paleolimnological studies, the dominance by benthic taxa was expected (Smol et al. 2005). However, the observation of planktonic species, especially at such high relative abundance, in present-day samples is, to our knowledge, rare in the Canadian high Arctic Archipelago. In the low Arctic and a few high Arctic sites of Greenland and Norway, planktonic diatom taxa have been shown to increase in response to longer ice-free seasons and increased thermal stratification (Rühland et al 2008). The effect of catchment buffering capacity, lake depth and habitats preference that could explain such unique record are explored further in Chapter 4, in relationship to other high Arctic calibration set studies.

The data presented in this thesis illustrate the importance of the integrated study of lake ecosystems and ontogeny from a catchment point of view, even in the High Arctic where watershed processes are generally limited today (Vincent and Laybourn-Parry 2008). Climatic changes during the Holocene had major changes on the lakes' catchments at high latitudes (e.g. Reuss et al 2010). Our indicators suggest that the main drivers of communities and productivity over the deglaciated Holocene in our study sites came from both the global climate-driven changes in ice cover and local catchment processes, which are also climate-driven. This highlights the importance of using multiple proxies tracking the different catchment and in-lake components influencing aquatic systems for the reconstruction of past environmental change. Further, the opportunity provided by the 25+ years of monitoring and sample collection from the original Cape Herschel project allowed us to highlight once more the local and regional variations in response to global climatic trends can have major influence on aquatic systems sensitivity. This research also emphasizes the importance of long-term studies in understanding the influence of global environmental changes on aquatic systems.

The timing of major Holocene fluctuations in the central-eastern part of Ellesmere Island was not completely coherent between our proxy data and regional studies (e.g. Neoglacial Cooling). The availability of several other Holocene records from this region retrieved during the early 1980's by the Geological Survey of Canada (Blake 1987) from potentially poorly-buffered lakes could help resolve some of the discrepancies discernable from our data during the late-Holocene. The high-resolution analysis of recent sediment from West and 260m lakes and other poorly-buffered sites in the region could definitely improve our understanding of the late Holocene variations recorded in the diatom assemblages, as well as of other local influences. For instance, better temporally-resolved and dated records could help determine the earliest signs of the post-1850 global warming signal and potentially contribute to improve regional predictions for the future. Finally, the geographical survey of the presence of planktonic species in the high Arctic could become an important approach to assessing regional trends of the current warming.

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CHAPTER 5

Summary and Conclusions

Taken together, these results improved our understanding of the mechanisms driving regional and local climatic fluctuations of the Holocene at high latitudes. The main findings reported here can by summarized in a few major points:

1) A VNIRS predictive model for inferring trends in lake water DOC was developed from a Canadian Arctic lake surface sediments calibration set, and the multivariate PLS model yielded good statistical performances.

2) The Canadian model was applied to two sediment records from Canada and Sweden, and used to reconstruct similar trends in both a Swedish VNIRS-based total organic carbon (TOC) model and a Canadian diatom-based DOC inference model. The reconstructions are also consistent with other published proxy records from the Holocene cores, suggesting that the geochemical proxy can by used to infer DOC in various high latitudes geographical settings.

3) The multi-proxy investigation (diatoms, diatom-inferred pH, spectroscopically-inferred DOC, VNIRS signatures, sedimentary chlorophyll *a* (SedChl*a*)) of two High Arctic long-term sedimentary records from Pim Island, Nunavut, was used to track some of the main regional Holocene climatic fluctuations, namely the Holocene Thermal Maximum (10,000-6000 cal yr BP), the Neoglacial Cooling (starting ~6000 cal yr BP) and the most recent warming (~post-19th century).

4) The pre-19th century diatom assemblages were dominated by benthic and littoral species (*Fragilaria, Achanthes, Navicula*). The early- to mid-Holocene diatom assemblages, dominated by alkaliphilous *Fragilaria sensu lato*, were replaced by the small, slightly acidophilous *Achnanthes* and *Navicula* taxa during the mid-Holocene. The abrupt

community response recorded in the diatom assemblages during the mid-Holocene (~4000 and 6000 cal yr BP) suggests a strong influence of local catchment processes, primarily buffering capacity, in affecting lake ontogeny.

5) The limnological and biological responses of our two poorly-buffered High Arctic lakes during the Holocene were more dynamic than that of well-buffered sites, suggesting that they provide the most sensitive records to paleoclimate.

6) The VNIRS technique to infer lake water DOC was applied for the first time to High Arctic records. No relationship was evident between the spectroscopically inferred paleo-optic variable and the diatom species assemblages throughout the Holocene.

7) The poorly buffered lakes singularly recorded planktonic diatoms, post-1850, in the sedimentary records as well as in modern littoral sediments. Such free-floating diatoms had previously not been reported at sizable populations in High Arctic lakes.

8) Modern littoral algal assemblages demonstrated the importance of local charactacteristics, (such as catchment, elevation, depth etc.) on diatom response to recent global climate change, and helped support our Holocene climatic inferences.

Nevertheless, much remains to be described on the influence of local edaphic factors, lake physical properties and the ongoing modifications of catchment processes on high Arctic freshwater systems. Continuing monitoring and further paleolimnological studies in the Cape Herschel region will most likely continue to contribute to our knowledge of the effects of climate on the high latitude systems of our planet. The acceleration of the warming in the Arctic compared to the predicted trends from global climate models (ACIA 2005; IPCC 2007) should prompt new research to be undertaken to understand further the potential impacts on biological systems.

APPENDICES

APPENDIX A: Modern diatom assemblages and their relationship to environmental variables from lakes and ponds on Pim Island, Nunavut, High Arctic Canada

Abstract

We documented modern limnological variables and diatom assemblages from three lakes and six ponds surveyed from 1979 to 2009 on Pim Island (Nunavut, Canada). Pim Island is a region of interest because many of its surface waters have relatively lower pH and alkalinity compared to most previous paleolimnological studies in the high Arctic, and especially the very near-by, well-studied ponds on Cape Herschel, Ellesmere Island. Over the 1980-2009 period, the lakes and ponds were clear, oligotrophic, and slightly alkaline and poorly buffered (two lakes) to well-buffered (one lake and all ponds). No striking trends were observed in the water chemistry nor in the diatom assemblages over the 30-years study period, suggesting that ecological thresholds had already been crossed prior to the initiation of sampling at most sites. The diatom communities were dominated by benthic and littoral epilithic and ephiphytic pennate taxa. Interestingly, the planktonic *Cyclotella radiosa* (up to 23%) was present in the epilithic samples in the two poorly-buffered lakes, but not at any other site. To our knowledge, this is amongst the first records of sizeable populations of present-day planktonic species in high Arctic lakes.

Key Words: Diatoms, High Arctic, Pim Island, Poorly-buffered, autoecology, habitat preferences

Introduction

Studying extreme ecosystems is an important research initiative because of the simplified species-habitat relationships and the fact that polar regions are especially sensitive to the effects of climatic and other environmental changes (ACIA 2005). At high latitudes, harsh environmental conditions hinder the survival and reproduction of most organisms. High Arctic environments are characterized by low primary biological production, both on land and in the freshwater (Vincent and Laybourn-Parry 2008). The lakes and rivers found at these high latitudes are typically dilute and oligotrophic. The high Arctic provides scientists with valuable study systems because of their simplified ecological interactions, coupled with a high sensitivity to climate-induced environmental changes (Smol and Douglas 2007a).

Polar aquatic ecosystems are particularly vulnerable to climatic changes (Rouse et al. 1997). For example, the ice-covered Arctic freshwater systems have been closely linked to climate changes over the Holocene owing to the relationship of climate with snow and ice cover (Michelutti et al. 2007). Many high Arctic aquatic primary producers are adapted to take advantage of the ice-free littoral zones that, in the summer, surround the perennial or near perennial ice. It is in these moats that most of the lakes' production occurs (Schindler and Smol 2006). Any modification on the availability of these habitats will lead to changes in lake properties and cause community shifts among biological assemblages (Livingstone et al. 1999; Schindler and Smol 2006). The Anthropocene's warmer climatic conditions have already shortened the duration and extent of ice cover (Smol et al. 2005). The resulting increase in profundal habitat availability is mainly characterized by changes in nutrients and light regimes, longer growing season, and increased abundance of aquatic mosses that become a new available substrate (Lotter and Bigler 2000; Smol et al. 2005; Schindler and Smol 2006). Increases in lake primary production are already being documented in the Canadian high Arctic from recent sediments (Joynt and Wolfe 2001; Axford et al. 2009) and in some instances have resulted in increased organic matter (OM) content (Antoniades et al. 2007).

One of the best documented regions for paleolimnological research in the Arctic is the Cape Herschel region of central-eastern Ellesmere Island (Smol and Douglas 2007a, b). Monitoring at Cape Herschel on a semi-regular basis since the early 1980's represents the most extensive monitoring program at this latitude, and coupled with detailed paleolimnological investigations (Douglas and Smol 1994; Douglas et al. 1994; Smol and Douglas 2007a, b), provides an important reference site for long-term environmental research. The study of the Cape Herschel ponds (Douglas and Smol 1994) was also amongst the first to provide a comprehensive characterization of the environmental optima of high Arctic diatom taxa, as well as habitat preferences in relationship to high Arctic limnological characteristics. Following the early Cape Herschel studies, a suite of autoecological studies have been conducted on over 400 high Arctic lakes and ponds of the Canadian Arctic Archipelago, which is summarized by Michelutti et al. (2007). Water pH, which is influenced directly by catchments' buffering capacities and indirectly climatically controlled by ice-cover and DIC speciation dynamics, is often identified as the measured limological variable that most closely tracks diatoms assemblage composition of Arctic diatom floras (Michelutti et al. 2006; 2007; Wolfe 2002; This thesis, Chapter 3). In lakes with calcareous bedrock, the leaching of the carbonates buffers the system, and thus it remains less sensitive to climate-related shifts in pH. Conductivity, nutrients, DOC, water temperature and habitat specificity also influence the algal community (Saulnier-Talbot et al. 2003; Smol et al. 2005; Rühland et al. 2008). Topographical and morphological characteristics, such as water depth, can also have an overriding influence on the algal community, as illustrated by the shallow ponds of Cape Herschel, where evaporation have been changing the ionic concentrations and, in some cases, has led to complete desiccation (Smol and Douglas 2007a).

Pim Island is a region of limnological interest because of its relatively low pH and alkalinity as compared to most previous calibration studies in the high Arctic, and especially to the very near-by, well-studied ponds on Cape Herschel, Ellesmere Island. In addition, the broad range of natural variation in waterbody size and depth, elevation, bedrock, and substrate across the island, provides an opportunity to identify the main environmental influences on diatom communities in the face of the current climatic change. The extensive paleolimnological studies that have been conducted in the region also permits the comparison between the present-day communities and the Holocene paleolimnological records (Smol 1983; Blake et al. 1992; Douglas et al. 1994; Michelutti et al. 2006; This thesis, Chapter 3) that may help understand some of the main drivers of change. In this study, we provide modern time-series of limnological and diatoms characteristics from different lacustrine habitats for 3 lakes and 6 ponds of Pim Island varying in topography, catchment buffering capacities and elevation. We will qualitatively document: 1) the differences captured within lakes and ponds over our monitoring period (1979-2009): and 2) between waterbodies; as well as 3) how they compare to nearby Cape Herschel and to other high Arctic regions.

Study area

Pim Island (78°41'N; 74°25'W)(Fig. A.1) is a small (~86 km^2) island located near the confluence of Kane Basin and Smith Sound on the east-central coast of Ellesmere Island in the Canadian high Arctic, Nunavut, and is across from Inglefield Land, Greenland (Fig. A.1). Cape Herschel and Pim Island are influenced by the same sub-regional climatic system (Maxwell 1981), although the higher elevation and the fact that it is an island often surrounded by ice makes its local climate somewhat colder. The island is separated from Cape Herschel by Rosse Bay (~10 km apart). The island's maximum elevation is 550 m a.s.l.

Pim Island bedrock geology is dominated by the crystalline Canadian Shield composed of granites, migmatites, and associated rocks that is overlain with thin layers of calcareous till forming a discontinuous pattern (Blake 1992). Large outcrops of calcareous siltstones and shales were observed on Cape Herschel, and this difference in the geology of lakes and ponds drainage basins largely controls the buffering capacities of lakes, which then also affects the aquatic biological communities. For further details on glacial history, climate and vegetation in the area, refer to Chapter 3.

Several relatively shallow yet rather large surface area lakes and ponds are found on this island at different elevations (Table A.1) and limnological characteristics (Table A.2). Proteus Lake, the only officially named lake on Pim Island, is the largest-sized and one of the highest lakes surveyed on the island (390 m a.s.l) (Fig. A.1). It is a relatively shallow lake (6.9 m) and its basin drops abruptly after 1 m depth. Although rather exposed and windy, Proteus Lake is still surrounded by hills on all sides. No vegetation was observed in the soft slopes surrounding the lake, nor within the lake, but filamentous green algae grow in the slow flowing outlet. Our records indicate that the lake was almost completely ice-covered during the summers of the last three decades. The westernmost lake sampled on the island, West Lake (Fig. A.1), is located on the main plateau and sheltered by hills (315 m a.s.l.). 260 m Lake (Fig. A.1) is situated on the south-central coast of the Island (260 m a.s.l.). The small lake is surrounded by high hills and constituted of two basins separated by a sandy isthmus generally free of ice during the summer. The main basin, where the sampling was conducted, deepens rapidly.

Field observations on North Pond (Fig. A.1), constituted of a chain of ponds, indicate a very windy and exposed site on the north plateau. Pond H is located at the edge of the North Plateau (Fig. A.1). Ponds P1 and P3 are located near from one another (Fig. A.1). Greely Pond, a relatively deep pond (2 m depth), is located at sea level and has an outlet. The very lush system is characterized by the presence of filamentous algae in the water and aquatic mosses between rocks. The catchment has a ~5% vegetation cover with mosses lichens and Arctic willow and cushion forbs of purple saxifrage and Arctic poppies. Vegetation cover at all other sites is less than 5%.

Lakes and ponds on Pim Island currently have an open water season that last on average less than three months, but the lakes never reached complete ice melt during our monitoring seasons, and remained even completely ice-covered during the summer of 2004, which precluded sampling, with the exception of Greely Pond, indicating that somewhat more favourable conditions prevail at this site. The patchy presence of calcareous tills in varying densities was observed at all sites but two, West and 260m lakes, where no till was evident in the catchment.

Methods

Limnological Survey and Sample collection

Water collection and sampling of lacustrine habitats occurred in the summer months (beginning of June to mid-August) between 1980 and 2009, following standard methods described in Douglas and Smol (1994). The water samples were collected from the surface using plastic *Nalgene* bottles. All habitats and water samples were preserved at 4°C in the dark until further analyses. Water chemistry analyses were performed at the National Laboratory for Environmental Testing (NLET) at the National Water Research Institute (Burlington, ON, Canada) following standard protocols. Protocols for the analyses of major and minor ions, trace metals, phosphorus, nitrogen, carbon, and chlorophyll-a can be found at Environment Canada (1979; 1994a, b). Characterisation of the catchment and water temperature, pH and specific conductivity measurements were made on location.

For certain sites, only pockets of sediment could be found between rocks (e.g. 260 m Lake, West Lake). Thick organic crust on rocks could be found in Proteus and West Lakes and Greely Pond, but not in 260 m Lake (rocks appeared clean). Sediment sample in Greely Pond is essentially algal crust. Briefly, epipelic samples consisted of the top cm of sediment was collected as far away from the shore as possible (closer in some instances). Epiphytic samples were collected on typically three representative rocks collected from different areas and depth of the lake by scraping the algal material into a vial using a brush and lake water.

Diatom preparation

Diatoms assemblages were analyzed in 65 littoral sediment and 19 rock scrapes samples for the three lakes and six ponds. Standard techniques for diatoms preparation were applied (Battarbee et al. 2001), involving acid digestion and the mounting of the microscope slide on sedimentation trays using the high refraction medium Naphrax®. Approximately 500 valves were enumerated along multiple transects of the cover slips for each sample, at 1000x magnification using a Leica DMR microscope with differential interference contrast (DIC) equipped with an oil-immersion objective and condenser lens. The identification at the lowest taxonomic level was harmonised with Douglas and Smol (1994), and followed Antoniades et al. (2008); Cumming et al. (1995); Camburn and Charles (2000); Cremer and Wagner (2004); Fallu et al. (2000); Foged (1981); Krammer and Lange-Bertalot (1986; 1988; 1991a, b); Lange-Bertalot (1996). The diatoms counts were transformed in relative abundances for all analyses. The chrysophycean stomatocysts were also enumerated, and the cyst to diatom frustule index was calculated using the Smol index (Smol 1985).

Statistical analyses

The diatom species assemblage recorded in the lakes and ponds for the available years of sampling were separated into littoral sediment and rock scrapes samples for the multivariate analyses. Given community turnovers of the assemblages (SD=~2.5), detrended correspondence analysis (DCA) (Hill and Gauch 1980) was performed on the two groups of samples. The main taxa (relative abundance ≥4%) were plotted using *Tilia ver. 2.0.* in increasing order of DCA axis 1. The Hill's N2 species diversity index (Hill 1973) was calculated in *CANOCO ver. 4.5* (Šmilauer and ter Braak 2002).

Results

Limnological characteristics

The lakes and ponds monitored on Pim Island (Fig. A.1) since 1979 seem to display some of the typical characteristics observed in high Arctic lacustrine environments, i.e. oligotrophic (Chl*a*<3.7, TP < 0.120 mg·L^{-1}), very dilute (specific conductivity < 160 µS·cm^{-1}, Na^+, K^+, Mg^{2+}, Ca^{2+} concentrations < 19 mg·L^{-1}) (Table A.1). Greely Pond appears to be the most productive amongst the lakes surveyed, based largely the presence of an algal crust on the rocks, which were less notable in the other lakes and ponds. Some organic material was observed on the rocky bottom of West Lake as well as P3 Pond, and in greater amount in Proteus Lake, but virtually none was observed on 260m lake's rocks and sandy bottom.

The water chemistry of the surveyed waterbodies is also characterised by a gradient in alkalinity from the most poorly buffered sites (West and 260m lakes) to the most well buffered site (Greely pond) ($CaCO_3$: 1.7-65 mg·l^{-1} and DIC: 1.2-8.5 mg·l^{-1}) (Table A.1; Fig. A.2d). The lakes with the lowest pH (< 6.8) were West and 260 m lakes (measurements through ice from early 1980's) and were both the focus of a multi-proxy long-term study (Chapter 3). As expected for this region given the very sparse vegetation, lakeand pond water DOC levels measured on Pim Island since 1983 are low (<4 mg·L^{-1}). The limnological characteristics of ponds over the monitoring period fluctuated more than deeper lakes (Fig. A.2)

The lowest pH values were measured in West (4.3) and 260 m lakes (6.3) in the early 1980's. The other lakes and ponds pH values ranged between 6.7 and 8.73. Over the monitoring period, the highest pH values (Proteus Lake and Greely Pond) were obtained in the 2007 field season (Fig. A.2 (b)), and have increased by one order of magnitude from the first sampling season in (1979 and 1983, respectively) to the warmer 2007 (7 to 8.6 and 7.6 to 8.7, respectively). The lake-water concentrations of the macronutrient and the main metallic micronutrients (aluminum, iron, manganese) were generally low (Table A.1; see Appendix D for full water chemistry).

Algal communities

104 diatom taxa were identified from the sampled analyzed. The diatom communities collected from littoral sediment (31 taxa) and rock scrapes (28 taxa) at varying depth are dominated by small, benthic, epipelic and periphytic taxa (Fig. A.3; Appendix H and I). The overall dominance of a benthic versus planktonic diatom flora was expected and observed in most calibration sets, since the prolonged lake ice-cover of high Arctic systems has been shown to preclude the development of extensive planktonic communities (Smol and Cumming 2000) and our sampling protocol was restricted to littoral samples.

The species diversity, measured as the Hill's N2 index, from rock scrapes samples was higher than for the littoral sediment samples (Fig. A.3a, b). Species composition between the two types of samples differs, but many taxa are common to both. Sediment generally contained an integrated sample of diatom communities from lakes, but habitat preferences can alter this relationship, especially when sediment comes from the littoral zone (Douglas and Smol 1994). The species diversity in the lakes was higher than in the ponds (Fig. A.3a, b) (rock scrapes and littoral sediment confounded), possibly due to the higher diversity of habitats present. P3 Pond, the closest site to the remaining ice cap on Pim Island (Fig. A.1) was a remarkably species-poor site, with only eight taxa identified, and *Achnanthidium minutissimum* representing 56% of the total count.

A planktonic community, essentially formed by *Cyclotella radiosa* and *C. ocellata* (maximum 23%), was identified in the West (0-12%) and 260 m (0.4-23%) lakes, but at no other sites. The centric taxa were identified in greater abundances in the rock scrapes, while they were almost at trace level in the littoral sediments (<3%). The epipelic, acidophilous

Psammothidium marginulatum and *P. kryophilum* are present in higher abundances, with other circumneutral *Achnanthes* taxa.

All samples compounded, the most abundant and common species are the cosmopolitan *Achnanthidium minutissimum* and *Nitzschia perminuta* (Fig. A.3). *Cymbella* spp. (e.g. *Cymbella botellus, Encyonema minutum, E. fogedii, Encyonopsis microcepha*) and other genera (e.g. *Denticula tenuis, Diatoma tenuis*) plot on the right hand side of the biplot (high DCA axis 1 values) (Fig. A.3). This assemblage is found in the ponds (particularly at Greely), but also in certain samples of Proteus Lake. The proportion of chrysophytes stomatocysts was generally low, and was slightly higher in lakes versus ponds, and the Frustule:Cyst index was higher in littoral sediment versus rock scrapes (Fig. A.3).

Exploratory interpretations

Within-site temporal changes and habitat preferences

It is important to keep in mind that, unlike other calibration studies conducted in the high Arctic (summarized in Michelutti et al. 2007), the small number of sites of our sampling (n =8) and the important differences between the study lakes and ponds allow us to only consider the most ecologically significant patterns, and that the data presented here are qualitative and exploratory. When considering all the samples together, it is not possible to identify any clear trend in the limnological characteristics analyzed at Pim Island over the monitored period (Fig. A.2), but some patterns can be determined.

Increases in pH have also been observed in Cape Herschel ponds during the same time frame. The sampling of the early 1980's values was taken through ice and occurred earlier in the season (June), and the acidic waters of snow melt probably decrease the measurements. However, our ice cover records (decrease in ice cover to ~30% versus 90% in the early 80's) suggest that the 2007 summer was particularly warm (Table A.1), with corresponding changes to the DIC pool, while the 2009 summer was particularly cold.

In contrast to our sites, the monitoring at Cape Herschel records an increasing trend in specific conductivities since the early 1980's (Smol and Douglas 2007a). This trend was attributed to a warming climate, resulting in the evaporation of the ponds water, and was severe enough to cause complete disappearance of some aquatic ecosystems. Signs of past higher water levels (black marks on boulders and cliffs surrounding the lakes) were also observed for 260 m, West and Greely sites. However, the specific conductivity observed in the Pim Island lakes and ponds ($< 88\ \mu S \cdot cm^{-1}$) is low compared to the average that has been reported from Cape Herschel's ponds (Smol and Douglas 2007a). The higher elevation of the Pim Island sites (Fig. A.1) may have dampened the warming signal, including maintaining steady rates of evaporation. Also, the monitoring frequency was not as high at Pim Island than at Cape Herschel, and trends might have been not expressed as clearly.

The diatom flora recorded on Pim Island appears to spread along a gradient of pH and/or productivity (Fig. A.3a, b). The trend is most obvious from the rock scrape samples (Fig. A.3b). The planktonic Cyclotella taxa and small periphytic *Achnanthes* spp. and *Navicula* spp. plot on the left hand side (low DCA values on axis 1). High pH values have been recorded during the warm year of 2007 at the well-buffered Proteus Lake and Greely Pond (Fig. A.2), and are expected with the contemporary rise in temperature (Smol et al. 2005; Michelutti et al. 2007). Despite the present extensive ice-cover (Table A.1), a relatively diverse diatom assemblage has been observed in all of the modern samples analyzed, as compared to post-glacial assemblages from Pim Island (Howard 1989); this thesis, Chapter 4) and Cape Herschel (Douglas and Smol 1994). A decreased duration of ice-cover provides favourable conditions over a long enough period of time for more diverse and complex diatom assemblages to develop, including species characterized by secondary growth forms (stalked) (Douglas and Smol 2010). At Cape Herschel, as in many other well-buffered high Arctic sites, paleolimnological investigations studies recorded more diverse diatom assemblages in recent sediment, which is unprecedented given the very-stable, *Fragilaria*-dominated long-term paleolimnological histories of these waterbodies (Smol et al. 2005). Species that had previously only been reported in trace numbers in some of these aquatic systems were now abundant in the most recent sediments (~150 years to present) (Smol et al. 2005).

Lower Diatom:Cyst index observed from the rock scrapes samples suggests the presence of periphytic life forms of chrysophytes in our sites (Fig. A.3). A greater proportion of cysts in the siliceous algal community from epiphytic samples was also found at Cape Herschel (Douglas and Smol 1994), indicating that chrysophycean periphytic life forms could thrive in the Arctic compared to the more planktonic communities typically recorded at southern latitudes (Zeeb and Smol 2002).

Between-site variability

Several variations in limnological characteristics and diatom assemblages were recorded between our study sites. The ponds displayed overall more fluctuations in temperature than the lakes (Fig. A.2), a result that was expected as compared to the findings at Cape Herschel (Douglas and Smol 1994; Smol and Douglas 2007b). Unlike ponds (< 2 m deep), lakes (>2 m) do not freeze solid in the winter due to a greater water volume, and experience less water temperature change during the summer (Cremer et al. 2005; Smol and Douglas 2007b).

The above temperature differences (linked to the lake's morphology) could, in turn, have an impact on the summer primary production. Only one site, Greely Pond, appears to support a more productive system on Pim Island, as suggested by its lush lake bottom and somewhat more vegetated catchment. A higher relative abundance of taxa particularly associated with aquatic vegetation, such as *Cymbella* spp, *Denticula tenuis* and *Diatoma tenuis* (Fig. A.3a), is recorded at Greely Pond, particularly in the rock scrapes samples (organic crust). *Denticula tenuis* was found in alkaline ponds at Cape Herschel, while the cosmopolitan *E. microcephala* was found at more circumneutral sites (Douglas and Smol 1994). *Diatoma tenuis* is a cosmopolitan species has been associated with high pH and relatively high conductivity (Antoniades et al. 2008). The ecologically distinct assemblage of this pond and the higher primary production is probably a combination of factors related to the low elevation of Greely Pond (and therefore draining a larger catchment area) and its location by the ocean (Fig. A.1), as it is usually recorded from Arctic catchment in this bioclimatic zone (CAVM 2003). A combination of the calcareous bedrock and the potentially longing growing season could contribute to the high pH recorded at the site (Fig. A.2a). Its proximity to the ocean (Fig. A.1), in addition to influence the input of wind-derived sea salts contributing to the higher conductivity levels recorded at the site (Fig. A.2b), could also contribute to an enhanced nutrient loading into the system (Keatley et al. 2009). In fact, although no major bird colonies were observed in the pond catchment during sampling, the effects of sea-bird related enrichments have been shown to result in marked increases in productivity in typically nutrient poor Arctic ponds, and may be contributing to the observed nutrient load in Greely pond (Keatley et al. 2009).

The more productive system at Greely Pond, that may be deep enough to support a planktonic habitat (Table A.1), could be the result of an extended growing season as compared to the lakes on Pim Island, representing favourable conditions for planktonic taxa (Smol et al. 2005). *Diatoma tenuis,* present at low relative abundance in Greely Pond*,* was also recorded to have potentially planktonic life forms (Antoniades 2008), but the low relative abundances (<4%) (Fig. A.3) do not allow us to draw strong conclusions.

The most striking ecological difference recorded between our sites on Pim Island in our diatom communities is the presence of the planktonic taxa *Cyclotella radiosa* in all samples from poorly-buffered West (1987-2009) and 260 m lakes (1983-2009) (Fig. A.3).

These results contrast with the exclusively benthic and littoral periphytic species record from Cape Herschel (Douglas and Smol 1994). At Cape Herschel, ponds are all <2 m deep (Douglas and Smol 1994). Due to their limited pelagic zones, the shallow ponds at Pim Island and Cape Herschel would most likely not provide a suitable habitat for planktonic species to thrive, or at least in the same structure as those recorded in deep lakes.

In fact, even though they are common in the subarctic and at more southern latitudes, sizeable communities of planktonic diatoms (>5%) from surface sediment in high Arctic modern calibration sets covering wide limnological gradients (including pH and depth) and have thus far only been recorded in a few Canadian Arctic sites, northeastern Greenland and Svalbard (Norway) (Cremer and Wagner 2004; Rühland et al. 2008), suggesting that lake depth cannot completely explain the absence of theses free-floating taxa. A relative abundance >5% of *Stephanodiscus minutulus* was recorded in a sedimentary record from pond B-AT on more sooouthern Bathurst Island, and attributed to a nutrient enrichment signal from Thule whalers impact on the pond that were estimated to occur approximately over the past millennia (Hadley et al. 2010). Large populations of centrics were recorded in the very large and deep Lake Hazen, northern Ellesmere Island, represented by *Cyclotella stelligera, C. comensis* and C. *bodanica* forming up to 75% of the most recent diatom assemblage (Antoniades 2005; Douglas 1993 (PhD Thesis Appendix)). These centric species and other planktonic and/or tychoplanktonic species (e.g. *Stephanodiscus* spp., *Cyclotella antiqua, Tabellaria flocculosa*) were recorded in several sites of the low Arctic Prince of Wales Islands, but were generally represented less 1% of the assemblages (D. Antoniades, personal communication).

However, because they are under the same climatic forcings (Smol et al. 2005), we would expect planktonic species to also have been found in the nearby similar sized Proteus Lake (Fig. A.1). At Proteus Lake no centric, planktonic species such as the ones from West and 260 m lakes were recorded (2009) in our study samples (Fig. A.3). In addition, even though the littoral samples from Proteus Lake recorded rather diverse assemblages of small epiphytic *Achnanthes*, *Nitzschia* and *Navicula* spp., the small, benthic *Fragilaria sensu lato* (mostly *Staurosirella pinnata sensu lato*) dominated the deep water assemblage of surface sediment collected with a mini-Glew corer from the central zone of Proteus Lake (Appendix H). This present-day diatom assemblage in Proteus Lake represents a good analogue for early post-glacial environments, and is very similar to the *Fragilaria sensu lato*-dominanted assemblages from its entire Holocene record history (Howard 1989) and from pre-19th century records from ponds at Cape Herschel. This record indicates that Proteus Lake, due to its elevation and morphometry, has not experienced the limnological changes related to climate warming noted in less ice-covered sites. In Chapter 3, the study of lake ontogeny, at the Holocene scale from the poorly buffered West and 260 m lakes sedimentary profiles suggest that the delay in lake diatoms community response to climatic changes is strongly influenced by alkalinizing edaphic processes. Alkalinity was further identified as a main factor driving the composition of modern diatom assemblages at Cape Herschel (Douglas and Smol 1994).

The highly alkaline waters and, to a lesser extent, the harsher conditions resulting of the topography of this site probably explain the muted response of the diatom community to recent climatic warming observed in the similar sized, poorly-buffered West and 260m lakes located only 2 km apart (Fig. A.1).

Briefly, no clear trend in the limnological data or in the diatom composition over the last 30 years could be documented with certainty, suggesting that ecological thresholds have already occurred in the lakes and ponds 30 years ago, or are still yet to be crossed. The observation of planktonic species at such high relative abundance in present-day littoral samples is, to our knowledge, relatively rare in the high Arctic, and particularly in the

Canadian high Arctic Islands Archipelago. From our collection of sites, it is unclear if buffering capacity of lakes (chemical control) was the main control on diatoms floristic response to recent climatic warming, or if depth and local topography also had a role (physical control), but it appears that local modulation has a major role to play in that response.

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Table A.1. Summary of the available geographical, topographical and morphological properties, ice cover at sampling and collection periods for 3 lakes and 5 ponds on Pim Island, Ellesmere Island, Nunavut.

Site	Latitude (N)	Longitude (W)	Altitude (m a.s.l.)	Depth (m)	App. Area (m^2)	Sampling years	n	Sampling months	Summer ice-cover (%)
Proteus Lake	78˚41.622'	74˚22.292'	379	6.9	114,000	1979-2009	11	June-August	30-100
West Lake	78˚44.283'	74˚37.983'	315	12.1	110000	1981-2009	4	June-August	90-100
260 m Lake	78˚42.300'	74˚31.000'	260	9.8	43600	1981-2009	7	June-August	90-100
Greely Pond	78˚44.379'	74˚16.201'	0	2.0	2375	1998-2009	5	July	0
P1 Pond	78˚42.306'	74˚25.269'	415	0.1	16	1998	1	July	25
P3 Pond	78˚42.444'	74˚25.797'	460	0.6	1500	1998	1	July	0
H Pond	78˚44.262'	74˚22.125'	170	-	-	1983	1	July	0
North Pond	78˚42.703'	74˚9.971'	265	0.4	14000	1983-2009	2	June-July	0

Table A.2. Summer water chemistry -pH, specific conductivity, water temperature, Chl*a*, total phosphorus unfiltered (TPU), total nitrogen unfiltered (TNU), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), water alkalinity (as $CaCO_3$) of lakes and ponds on Pim Island, Ellesmere Island, Nunavut (mean values 1979-2007).

Site	pH	Cond (µS·cm^{-1})	Temp (˚C)	Chl a (µg·L^{-1})	TPU (mg·L^{-1})	TNU (mg·L^{-1})	DOC (mg·L^{-1})	DIC (mg·L^{-1})	Alk $CaCO_3$ (mg·L^{-1})
Proteus Lake	7.4	71	2	1.1	0.0041	0.118	1.3	3.8	25.4
West Lake	6.5	29	4	-	0.0143	0.133	0.5	2.2	9.2
260 m Lake	6.6	36	2	-	0.0094	0.176	0.8	1.0	4.1
Greely Pond	8.0	75	9	1.7	0.0052	0.144	1.9	6.7	-
P1 Pond	7.5	25	8	3.7	< 0.0002	0.11	1.2	1.2	-
P3 Pond	7.4	27	9	0.3	< 0.0002	0.104	1.5	1.7	-
H Pond	7.26	21	-	-	-	-	-	-	-
North Pond	7.6	52	10	-	0.0087	0.271	0.9	4.6	-
Tot (min)	**4.3**	**18**	**1**	**0.1**	**< 0.0002**	**0.003**	**0.4**	**1.0**	**1.7**
Tot (max)	**8.7**	**163**	**16**	**3.7**	**0.0170**	**0.287**	**3.3**	**8.5**	**65.0**
Tot (mean)	**7.2**	**52**	**6**	**1.6**	**0.0062**	**0.146**	**1.3**	**4.3**	**16.1**

Table A.2. (continued)

Site	Cl (mg·L^{-1})	SO_4 (mg·L^{-1})	SiO_2 (mg·L^{-1})	Ca (mg·L^{-1})	Mg (mg·L^{-1})	Na (mg·L^{-1})	K (mg·L^{-1})
Proteus Lake	7.5	1.7	2.3	6.1	2.3	4.2	0.5
West Lake	4.2	1.4	0.5	1.9	1.1	2.5	0.3
260 m Lake	6.7	1.9	0.6	0.9	0.7	3.5	0.5
Greely Pond	9.6	4.9	0.4	9.0	2.6	5.5	0.6
P1 Pond	6.18	1.9	0.54	1	0.7	3.4	0.2
P3 Pond	5.9	1.5	0.49	2	1.1	2.6	< 0.2
H Pond	-	-	-	-	-	-	-
North Pond	3.2	0.8	0.4	3.7	1.6	2.2	0.3
Tot (min)	**1.8**	**0.5**	**0.1**	**0.4**	**0.1**	**1.4**	**< 0.2**
Tot (max)	**15.9**	**11.7**	**13.1**	**18.6**	**5.0**	**9.5**	**0.8**
Tot (mean)	**7.1**	**2.2**	**1.2**	**4.5**	**1.7**	**3.9**	**0.4**

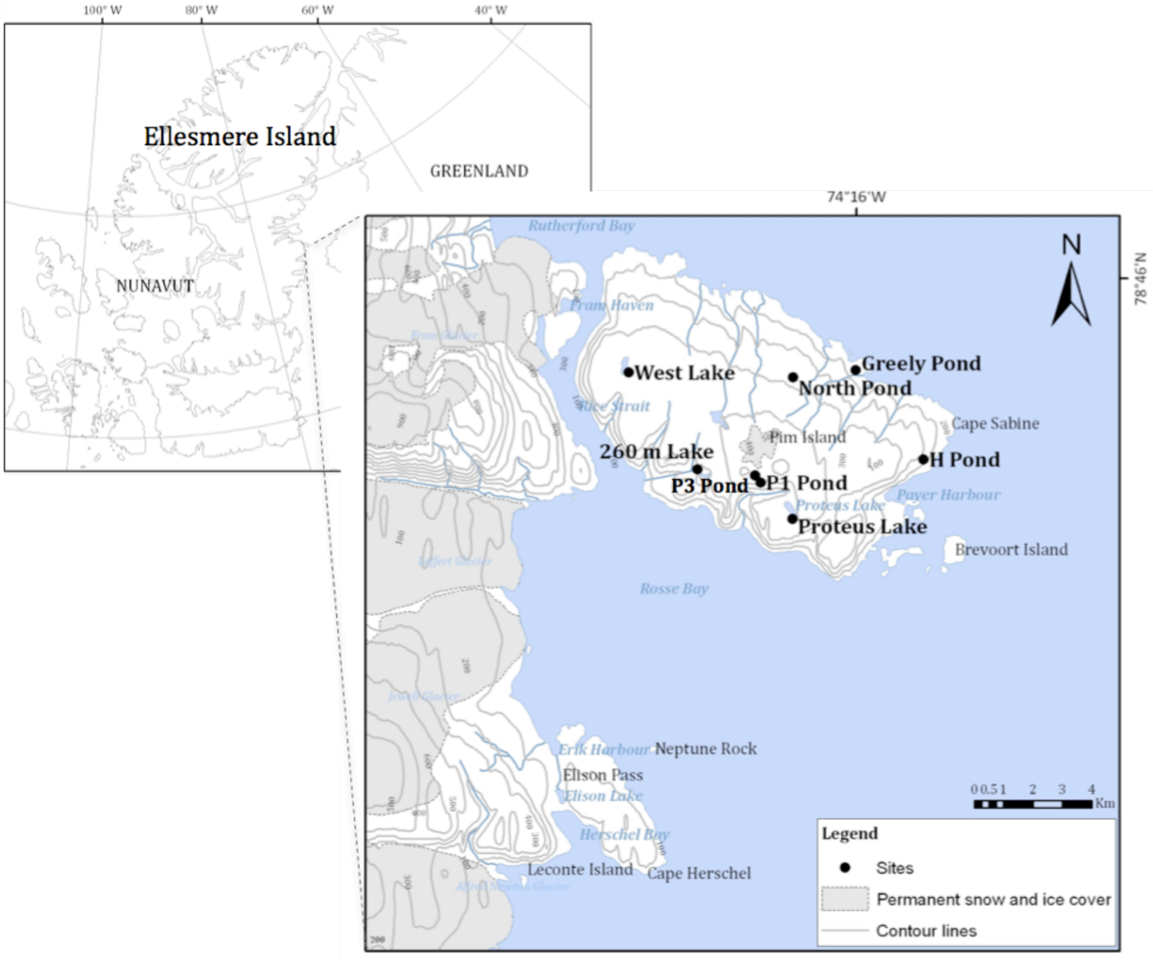


Fig. A.1: Topographic map of Pim Island and the Cape Herschel with 100m elevation contour lines and areas with permanent snow and ice-cover (grey-shaded), located on the east-central coast of Ellesmere Island (Nunavut, Canada). The study sites on Pim Island are marked by a black dot. Original geographic data scale 1: 50 000 (source: National Topographic Data Base). Generated with Arc-GIS Desktop ver. 9.2.

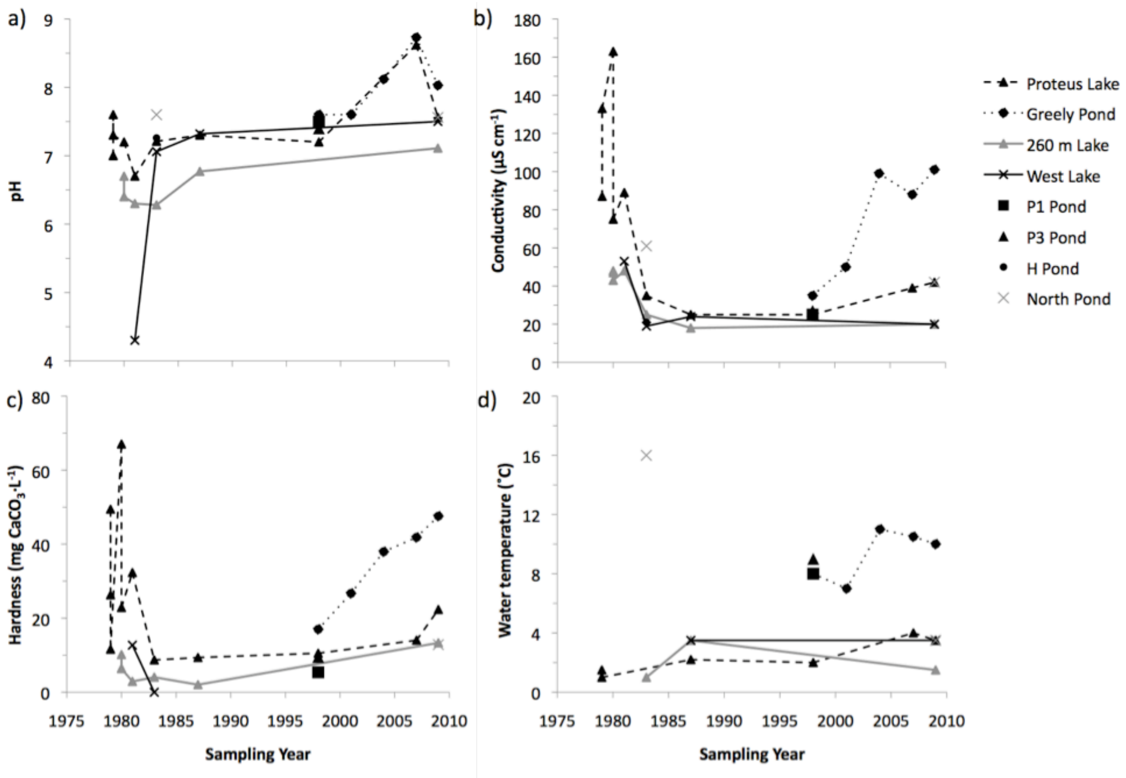
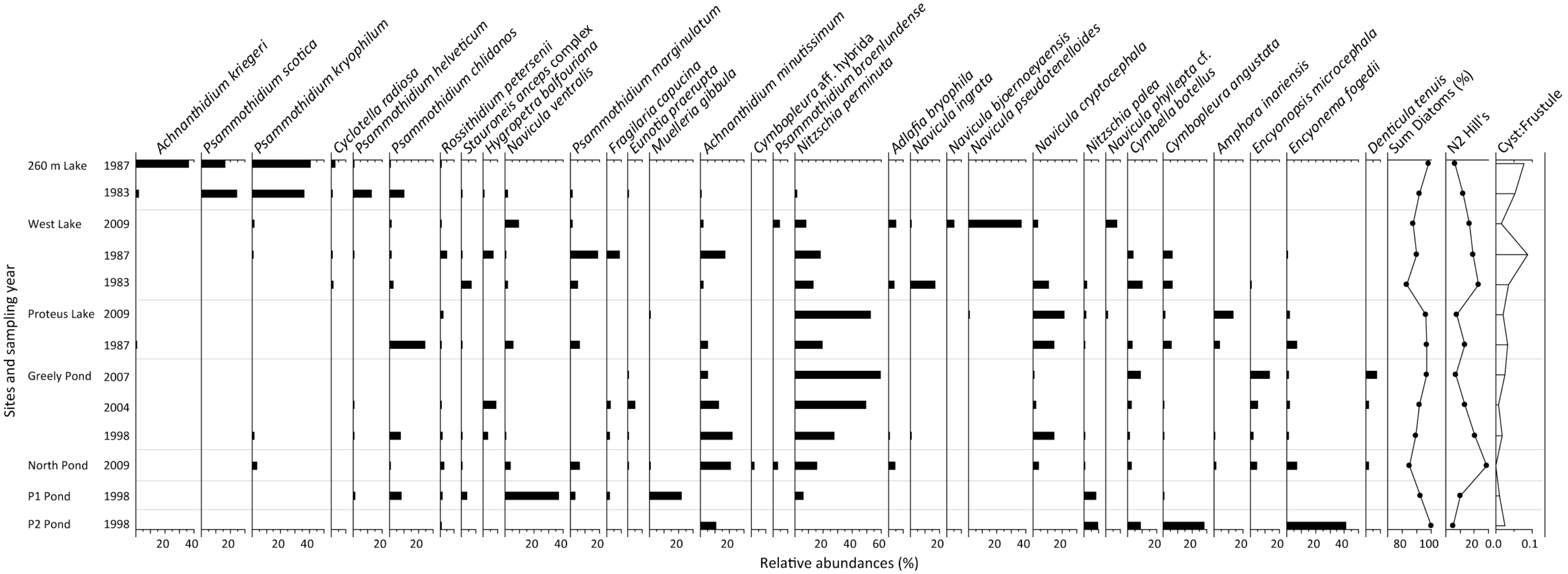


Fig. A.2: (a) Water pH, (b) specific conductivity, (c) hardness (measured in mg·L^{-1} $CaCO_3$) and (d) temperature for Pim Island's lakes (Proteus Lake, West Lake and 260 m Lake) and ponds (Greely, P1, P3, H and North) for sampling seasons 1979, 1980, 1981, 1983, 1987, 1998, 2001, 2007, 2009. Water pH, specific conductivity and temperature measurements were taken on-site and hardness was calculated from Ca^{2+} and Mg^{+} ions measured on water samples analyzed at NLET (Burlington, ON, Canada) and were collected in the summer season between June 4th and August 19th.

(a)


Achnanthidium kriegeri
Psammothidium scotica
Psammothidium kryophilum
Cyclotella radiosa
Psammothidium helveticum
Psammothidium chlidanos
Rossithidium petersenii
Stauroneis anceps complex
Hygropetra balfouriana
Navicula ventralis
Psammothidium marginulatum
Fragilaria capucina
Eunotia praerupta
Muelleria gibbula
Achnanthidium minutissimum
Cymbopleura aff. hybrida
Psammothidium broenlundense
Nitzschia perminuta
Adlafia bryophila
Navicula ingrata
Navicula bjoernoeyaensis
Navicula pseudotenelloides
Navicula cryptocephala
Nitzschia palea
Navicula phyllepta cf.
Cymbella botellus
Cymbopleura angustata
Amphora inariensis
Encyonopsis microcephala
Encyonema fogedii
Denticula tenuis
Sum Diatoms (%)
N2 Hill's
Cyst:Frustule
Sites and sampling year
260 m Lake 1987
1983
West Lake 2009
1987
1983
Proteus Lake 2009
1987
Greely Pond 2007
2004
1998
North Pond 2009
P1 Pond 1998
P2 Pond 1998
20 40
20
20 40
20 20
20 40
20
20
20
20 40 60
20
20 40
20
20 20
20
20
20 40
80 100
20
0.0 0.1
Relative abundances (%)

b)

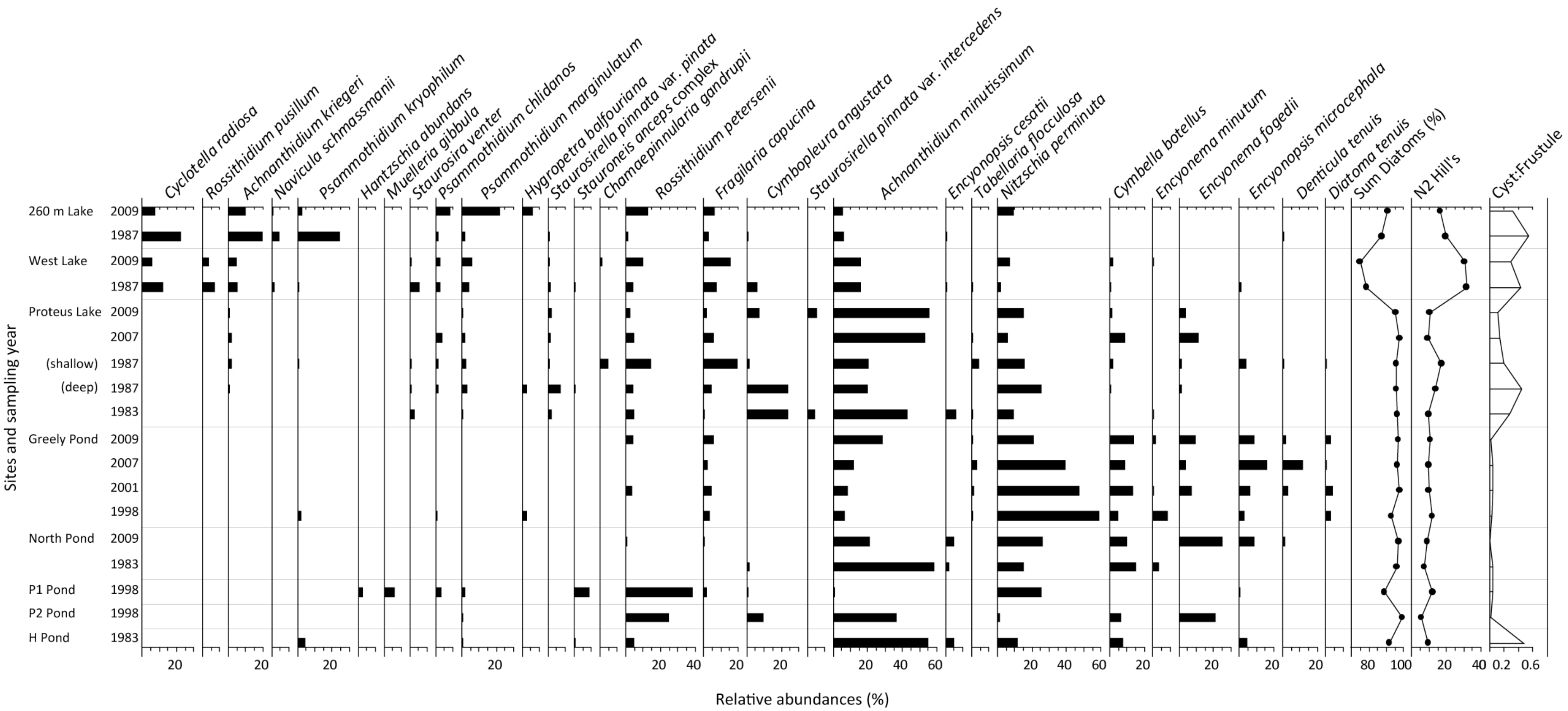


Fig. A.3: Dominant diatom taxa assemblage (>4%) of littoral sediment (a) and rock scrape (b) samples from lakes and ponds on Pim Island, showing relative frequencies of the most abundant taxa ordered by increasing DCA axis 1 species scores (left to right). The Hill's species diversity index (Hill's N2) and the diatom frustule to chrysophyte stomatocyst index (Frustule:Cyst) are plotted for each sample on the diatom stratigraphy. The different lakes and ponds time-series are separated by a dashed line, and the solid line splits the lakes from the ponds.

APPENDIX B: Geographical and physical characteristics and full water chemistry for the Canadian Arctic calibration set, identified by bioclimatic zones (see Chapter 2).

Site	Year	Lat (˚N)	Long (˚W)	Zone	Elev (m a.s.l)	Depth (m)	SA (ha)	Temp (˚C)	pH	Cond (µS·cm-1)	DOC (mg·L^{-1})	POC (mg·L^{-1})	TOC (mg·L^{-1})	POCf (%)	ChlaU (µg·L^{-1})
EPB03	2003	81.85	68.26	3	366	-	48.8	7.5	8.23	232	4.7	0.25	4.9	5.0	<0.1
EPD03	2003	81.78	64.55	2	274	-	49.1	7.5	8.37	172	3.3	0.23	3.5	6.5	0.7
EPF03	2003	82.42	68.21	2	91	-	125	2.5	8.13	110	1.5	0.21	1.7	12.2	0.1
EPG03	2003	82.60	68.20	2	91	-	14.7	7.5	8.2	122	0.8	0.40	1.2	33.5	0.1
EPK03	2003	83.01	75.39	2	30	-	490	6	7.9	69	1.3	0.18	1.5	12.2	0.6
EPN03	2003	82.83	77.94	1	30	-	165.4	4.5	7.73	30	2.4	0.15	2.5	5.7	0.6
EPP03	2003	81.60	73.89	3	686	-	6	14	8.17	102	4.7	0.42	5.1	8.1	1.4
EPR03	2003	81.31	65.58	2	183	-	14.7	2.5	8.3	118	1.1	0.36	1.5	24.5	<0.1
EPS03	2003	81.32	66.42	2	335	-	2.6	7.5	8.33	131	2.2	0.29	2.5	11.5	0.5
EPV03	2003	81.22	72.32	3	305	-	6.7	12.5	8.77	409	5	0.47	5.5	8.6	0.1
EPW03	2003	81.08	74.34	3	518	-	114	7.5	8.3	109	0.6	0.34	0.9	36.4	<0.1
EPX03	2003	80.93	76.54	3	396	-	61.4	8.5	8.3	154	0.9	0.29	1.2	24.2	<0.1
EPAA03	2003	81.40	76.79	3	200	4.0	7.7	15	8.73	500	4.8	0.29	5.1	5.7	0.5
EPAB03	2003	81.97	80.07	2	122	-	0.6	6	7.9	58	1.7	0.22	1.9	11.5	1.6
EPAC03	2003	82.09	81.84	2	76	-	98.2	6	8.2	200	1	0.28	1.3	22.1	0.1
EP103	2003	81.83	71.47	3	296	4.0	1.84	6	8.2	175	5.8	0.53	6.3	8.4	0.6
EP1903	2003	81.82	71.34	3	154	-	54200	5.5	7.73	68	1.1	0.16	1.3	12.4	<0.1
EP2403	2003	81.82	71.78	3	870	-	2.8	5	7.53	45	0.7	0.43	1.1	37.8	0.5
ERB04	2004	78.49	76.74	3	295	15.0	-	5	6.03	5	1.2	0.25	1.4	17.2	-
PPro07	2007	78.70	74.38	2	379	6.9	-	3.50	8.62	39	1.5	0.30	1.8	16.7	2.1
PGre07	2007	78.74	74.27	2	0	-	-	10.5	8.73	88	3.3	0.53	3.8	13.8	2.7
CHEL07	2007	78.61	74.74	3	17	-	-	11.5	8.39	221	3.5	0.23	3.7	6.0	<0.1
AXQ98	1998	78.62	92.45	2	24	-	-	7.5	7.3	40	1.8	0.36	2.2	16.6	2.2
AXY98	1998	79.30	86.40	3	213	-	-	14	8.2	393	18.5	1.01	19.5	5.2	1.9
AXZ98	1998	79.64	87.74	3	238	-	-	12.5	7.9	116	3.9	0.68	4.6	14.8	0.3
AXAI98	1998	80.78	91.67	3	299	-	-	8	7.8	50	2.3	0.40	2.7	14.8	0.05
AXAJ98	1998	79.69	87.38	3	171	-	-	10.5	8.1	382	2.6	0.29	2.9	10.0	<0.1
AXBUC98	1998	79.46	87.71	3	3	80.0	1800	4	7.6	357	1.1	0.27	1.4	19.6	0.3
AXCOL98	1998	79.42	90.75	3	176	-	73	13	3.6	350	1	0.29	1.3	22.3	0.2
LOA05	2005	77.31	104.53	1	15	-	-	7.5	3.53	309	0.9	0.40	1.3	30.8	0.6
MVAE02	2002	75.84	114.69	3	655.3	-	19.635	4.0	8.1	5	0.8	0.18	1.0	18.2	0.3
BC94	1994	75.06	98.00	2	91	-	-	11	8.2	211	3.3	0.35	3.6	9.5	0.2
BG94	1994	75.46	99.44	2	21	-	-	4	8.1	111	1.5	0.36	1.9	19.3	0.4
BH94	1994	75.45	99.54	2	122	-	-	10	8.0	109	1.7	0.29	2.0	14.4	<0.1
BM94	1994	75.14	97.79	2	0	-	-	3.5	8.2	139	2.6	0.45	3.1	14.8	<0.1
BN94	1994	75.14	97.79	2	0	-	-	5	8.1	131	1.9	0.37	2.3	16.2	<0.1
BY94	1994	75.72	98.52	2	0	-	-	7.5	8.3	159	3.2	0.71	3.9	18.1	0.7
BAE94	1994	76.39	98.87	2	61	-	-	4	8.3	140	1.8	0.47	2.3	20.7	1.3
BAJ94	1994	76.66	98.88	2	122	-	-	12	8.6	216	6.9	0.64	7.5	8.5	1.6
BAT05	2005	75.67	102.48	2	122	-	-	1.5	6.79	10	1.9	0.24	2.1	11.4	1.5
DVE01	2001	76.40	95.02	2	-	2.0	-	11	8.5	90	1	0.09	1.1	8.2	0.1
DVF01	2001	74.90	90.60	2	15	2.0	-	11	8.1	140	1	0.13	1.1	11.7	0.5
DVH01	2001	74.65	90.25	2	8	-	-	4.5	8.1	650	0.9	0.15	1.1	14.6	<0.1
DVI01	2001	74.56	89.62	2	12	-	-	4.5	7.8	780	0.8	0.20	1.0	19.9	<0.1
12M93	1993	74.82	95.32	2	6	-	-	5.5	8.6	115	1.8	0.21	2.0	10.6	0.5
Traf93	1993	74.69	94.32	2	60	-	-	5	8.5	75	1.2	0.19	1.4	13.5	1.2
SAP96	1996	73.01	91.87	2	-	-	-	2	7.3	60	0.8	0.26	1.1	24.5	<0.1
SAQ96	1996	73.68	90.61	2	-	-	-	5.5	7.3	75	0.8	0.23	1.0	22.6	0.8
SAS96	1996	74.10	93.47	2	-	-	-	4.5	7.1	89	1	0.32	1.3	24.0	0.4
WE95	1995	73.75	97.31	2	-	-	-	7.5	8.1	82	3.1	0.24	3.3	7.3	0.3
WG95	1995	73.42	97.41	2	-	-	-	7	7.7	40	2	0.21	2.2	9.6	0.4
WL95	1995	72.81	98.33	3	-	-	-	10	8.2	135	3.4	0.24	3.6	6.5	<0.1
WN95	1995	72.76	98.61	3	-	-	-	8.5	8.2	120	1.1	0.20	1.3	15.1	0.3
WQ95	1995	73.52	99.81	2	-	-	-	6.5	8.2	145	4.4	0.36	4.8	7.5	0.9
WW95	1995	72.50	99.39	3	-	-	-	10	8.2	130	2.7	0.39	3.1	12.6	0.9
WAA95	1995	72.23	98.06	3	-	-	-	6	8.2	130	2.3	0.30	2.6	11.5	1.4
WAG95	1995	72.01	97.39	3	-	-	-	8	8.3	95	2.9	0.21	3.1	6.7	<0.1
WAK95	1995	71.67	98.08	3	-	-	-	9.5	8.2	109	2.2	0.20	2.4	8.2	1
BKA00	2000	72.96	118.85	3	85	-	-	4	8.0	96	3.4	0.37	3.8	9.9	1.1
BKF00	2000	73.51	120.33	3	94	-	-	7	7.9	103	3.9	0.50	4.4	11.4	1.9
BKR00	2000	71.99	125.08	3	85	-	-	6.5	7.7	124	2.8	0.71	3.5	20.3	0.9
BKT00	2000	72.00	122.75	3	355	-	-	6	8.1	92	3.7	0.42	4.1	10.2	0.9
BKU00	2000	72.09	122.58	3	271	-	-	5	7.9	106	2.9	0.40	3.3	12.0	0.9
BKY00	2000	74.51	121.68	3	2	-	-	6	7.6	48	6.5	0.69	7.2	9.6	2.5

APPENDIX B: (continued)

Site	Year	Lat (˚N)	Long (˚W)	Zone	Elev (m a.s.l)	Depth (m)	SA (ha)	Temp (˚C)	pH	Cond (µS·cm-1)	DOC (mg·L^{-1})	POC (mg·L^{-1})	TOC (mg·L^{-1})	POCf (%)	ChlaU (µg·L^{-1})
BKAD00	2000	71.73	123.48	3	122	-	-	3	7.8	137	3.3	0.94	4.2	22.2	3.2
BKAH00	2000	73.59	119.58	3	131	-	-	8.5	7.7	41	2.5	0.25	2.8	9.1	1.8
BKAI00	2000	73.35	116.77	3	137	-	-	4	7.9	65	2	0.45	2.4	18.2	0.3
VG97	1997	72.29	110.95	3	140	-	-	1.5	7.4	110	2	0.36	2.4	15.1	1
BI0105	2005	73.08	80.06	3	8	2.8	8.4	10	6.7	86	1.1	-	-	-	2.4
BI0205	2005	73.03	80.08	3	10	2.1	1.8	6.7	6.3	50	2.2	-	-	-	<0.1
BI0405	2005	73.11	79.52	3	10	4.0	3.0	9.2	7.0	87	4.4	-	-	-	<0.1
BI0505	2005	73.12	79.51	3	10	9.5	4.7	7.4	7.0	112	5.3	-	-	-	1.8
BI0705	2005	73.09	80.01	3	10	3.0	4.8	7.4	6.8	57	3.2	-	-	-	<0.1
BI0805	2005	73.09	79.60	3	18	4.4	15.6	6.1	6.7	46	5	-	-	-	<0.1
BI0905	2005	73.09	79.60	3	10	3.0	5.9	7.8	6.9	57	4.5	-	-	-	<0.1
BI1005	2005	73.00	79.51	3	210	12.0	3.0	3.6	6.1	15	3.2	-	-	-	1.2
BI1105	2005	73.09	79.60	3	13	9.8	31.9	9.6	6.5	48	8.2	-	-	-	-
BI1705	2005	73.04	79.25	3	317	7.5	4.8	6.4	6.5	13	2.9	-	-	-	1.9
BI2006	2006	73.02	79.33	3	300	9.3	2.7	12.8	6.4	14	1.1	-	-	-	3.1
BI2106	2006	73.02	79.33	3	300	8.5	4.5	14.6	6.1	-	2.1	-	-	-	0.5
BI2206	2006	72.59	79.45	3	170	3.0	6.4	15.4	6.4	14	3.6	-	-	-	2.8
BI2506	2006	72.53	79.50	3	55	4.4	2.5	13.3	6.8	4	5.8	-	-	-	1
BI2606	2006	73.00	79.51	3	160	8.0	2.4	10.8	6.0	14	4.3	-	-	-	0.9
BI2806	2006	72.51	79.48	3	70	-	14.7	-	-	-	7.2	-	-	-	1.9
JUET208	2008	62.61	69.50	4	-	8.5	-	21	7.0	48	2.9	0.33	3.2	10.3	2.9
U290	1990	60.40	134.59	7	671	10.5	56.9	19	8.8	1500	16.3	0.49	16.8	2.9	0.1
U490	1990	60.37	135.14	7	1113	7	1262.1	14	8.1	87	3.8	0.16	4.0	4.0	1.7
U590	1990	60.42	135.17	7	1021	12	52.5	17	7.8	73	8.6	0.37	9.0	4.1	2.3
U690	1990	61.21	135.39	7	823	49	89	20	8.3	179	10.1	0.35	10.5	3.4	0.3
U790	1990	61.42	135.56	7	634	27	163	20.8	8.3	230	8.4	0.28	8.7	3.2	0.2
U1090	1990	63.01	136.28	7	655	8	88.6	22	8.6	242	14.2	0.83	15.0	5.5	0.9
U1190	1990	63.09	136.30	7	732	5	8.6	23	8.5	49	17.1	0.59	17.7	3.3	0.9
U1290	1990	63.39	135.54	7	579	9.2	23.4	22	8.4	149	13.5	0.41	13.9	3.0	2.8
U1890	1990	64.35	138.18	6*	1173	7.5	18.1	17	8.6	113	6.5	0.31	6.8	4.5	0.8
U1990	1990	64.39	138.23	6*	1128	3.8	20.4	16	8.7	111	10.2	0.40	10.6	3.7	1.1
U2090	1990	64.44	138.22	6*	1097	1.9	13.7	14.3	9.3	39	12.3	0.66	13.0	5.1	0.9
U2190	1990	64.51	138.21	6*	1006	3.8	144	17.5	7.5	32	11.4	0.61	12.0	5.1	1.1
U2290	1990	68.11	133.27	6	76	5.5	8.2	18	7.9	153	17.8	0.30	18.1	1.7	1.8
U2390	1990	68.18	133.16	6	30	2.5	6.8	18.1	7.2	72	10.6	0.47	11.1	4.3	2
U2590	1990	68.24	133.42	6	122	3	1.1	20	7.8	140	13.1	0.46	13.6	3.4	2.6
U2690	1990	69.28	132.49	5	18	2	85.1	17	8.1	100	6.6	0.42	7.0	5.9	1.5
U2790	1990	69.32	132.47	5	15	2	94.6	17	8	343	12.3	0.54	12.8	4.2	1.4
U2890	1990	69.33	132.45	5	15	2	170.3	17	7.8	145	6.7	0.78	7.5	10.4	1.1
U2990	1990	69.33	132.25	5	15	2	547.4	17	8.1	152	5.8	0.44	6.2	7.1	0.8
U3190	1990	69.32	132.04	5	21	3	57.6	16	8.1	165	8	0.36	8.4	4.4	0.8
U3290	1990	69.28	132.12	5	21	9	73.8	12	8	198	4.8	0.20	5.0	4.1	0.2
U3690	1990	69.10	133.16	5	21	4	103.2	17	8.4	105	9.6	0.48	10.1	4.8	1.8
U3490	1990	69.25	132.40	5	24	2.5	116.2	17	7.9	159	10.7	0.49	11.2	4.4	1.8
U3790	1990	69.08	133.17	5	21	6.5	69	17	8.1	98	8.9	0.55	9.4	5.8	1
U3890	1990	69.07	133.11	5	21	3	49.7	18	8.2	139	9.6	0.62	10.2	6.0	1.9
U3990	1990	69.12	133.02	5	24	12	104.9	15.5	8.2	141	6.1	0.32	6.4	5.0	1.4
U4090	1990	69.13	133.00	5	24	3	81.9	17.5	8.2	104	10.1	0.50	10.6	4.7	2.6
U4190	1990	69.20	132.44	5	24	7	85.5	16	8.1	167	7.9	0.30	8.2	3.7	1
U4290	1990	69.03	133.27	5	46	15	84.8	16	7.8	150	4.6	0.23	4.8	4.7	1.1
U4390	1990	68.59	133.28	6	30	14	36	17	7.5	105	5.7	0.35	6.1	5.8	1
U4490	1990	68.50	133.33	6	30	4	61.2	18.5	8.2	129	8.1	0.46	8.6	5.3	1.2
U4590	1990	68.46	133.39	6	76	2	65.4	19	6.9	65	11.8	0.51	12.3	4.1	1.4
U4690	1990	68.29	133.39	6	122	2.5	63.1	19	7.1	81	11.4	0.59	12.0	4.9	1.1
U4790	1990	68.28	133.38	6	122	1.5	21.1	19.5	8.3	220	9.1	0.27	9.4	2.9	0.7
U4890	1990	68.25	133.35	6	114	1.5	96.2	20.5	8.6	71	11.6	3.48	15.1	23.1	20.4
U4990	1990	68.23	133.25	6	84	3.5	5.3	19	6.6	41	21.5	1.18	22.7	5.2	1.8
U5090	1990	68.25	133.22	6	76	2	21.7	20.3	7	71	29.9	0.57	30.5	1.9	0.6
U5190	1990	68.29	133.22	6	128	1.5	87.3	19.5	8.5	72	17.2	2.94	20.1	14.6	4.9
U5290	1990	68.34	133.20	6	145	6	19.5	18	7	116	11.3	0.30	11.6	2.6	0.5
U5490	1990	68.38	133.17	6	91	10	40	18	7.3	85	13	0.36	13.4	2.7	2
U5590	1990	68.42	133.15	6	30	18.5	87.9	18	7.7	70	8.5	0.48	9.0	5.3	1.5
U5690	1990	67.14	135.26	6	366	4	35	18	7.5	35	12.3	1.38	13.7	10.1	10.5
U5890	1990	67.06	136.00	6*	549	5.5	19.3	16.2	5.9	77	3.9	0.62	4.5	13.6	0.8

APPENDIX B: (continued)

Site	Year	Lat (˚N)	Long (˚W)	Zone	Elev (m a.s.l)	Depth (m)	SA (ha)	Temp (˚C)	pH	Cond (µS·cm-1)	DOC ($mg·L^{-1}$)	POC ($mg·L^{-1}$)	TOC ($mg·L^{-1}$)	POCf (%)	ChlaU ($µg·L^{-1}$)
U5990	1990	64.29	138.17	6*	1387	15.5	4.2	13.5	7.9	65	3.1	0.25	3.4	7.5	0.9
IKC809	2009	68.84	133.69	6	-	2	-	-	7.69	-	16	0.38	16.4	2.3	1.6
IKC2309	2009	69.00	133.51	5	76	11	-	12.4	8.07	149.5	6.2	0.22	6.4	3.4	0.2
IKDEM109	2009	68.30	133.28	6	11	1.8	-	19	7.33	-	20.6	0.48	21.1	2.3	2.1
IKDEM209	2009	68.32	133.42	6	95	2.1	-	17.5	7.60	-	21.8	0.52	22.3	2.3	3.2
IKDEM309	2009	67.47	133.77	6	24	1.3	-	17	9.27	-	12.2	0.85	13.1	6.5	2.7
IKDEM409	2009	68.35	133.72	6	-	3.4	-	17	6.75	-	39.6	1.02	40.6	2.5	1.6
IKDEM509	2009	68.35	133.72	6	-	7	-	17	7.29	-	28.5	0.30	28.8	1.1	6.4
IKI309	2009	68.76	133.77	6	58	2.1	-	13	7.66	-	12.7	1.46	14.2	10.3	3.2
IKI809	2009	68.84	133.68	5	46	2.4	-	11	6.74	-	17.8	0.45	18.3	2.5	0.3
IKI1109	2009	68.88	133.71	5	42	2.5	-	10.5	7.71	-	15.7	0.79	16.5	4.8	1.6
IKI12A09	2009	68.88	133.67	5	44	1.8	-	10.5	7.65	-	12.3	0.67	13.0	5.2	0.4
IKI1709	2009	68.95	133.46	5	36	3.2	-	16	7.91	-	26.7	0.38	27.1	1.4	<0.1
IKI2009	2009	68.97	133.53	5	50	4.4	-	-	8.3	-	21.1	1.00	22.1	4.5	1.4
IKI23A09	2009	69.00	133.54	5	49	3.2	-	13.8	8.18	266.5	11.7	0.45	12.2	3.7	0.6
IKI25B09	2009	69.01	133.62	5	44	2.4	-	13.7	7.58	137.0	19.8	0.68	20.5	3.3	2.6
IK5A09	2009	68.54	133.66	6	148	10.9	2.9	13	7.29	-	13.1	0.23	13.3	1.7	0.6
IK7B09	2009	68.61	133.59	6	88	5	3.1	15	7.78	-	15.1	0.31	15.4	2.0	0.6
Y191	1991	62.47	113.40	6	274	13	180.3	14.5	8.5	100	5.6	0.49	6.1	8.0	0.8
Y391	1991	63.18	112.55	6	396	10	223.7	13	8.7	30	4.7	0.39	5.1	7.7	0.4
Y491	1991	63.33	112.22	6	427	2.5	113.8	12	8.2	12	8.7	0.53	9.2	5.8	0.8
Y591	1991	63.43	112.05	6	427	3	79.2	12	7.7	11	4	0.48	4.5	10.8	0.8
Y691	1991	64.37	110.43	5	457	8	254.4	10	8	10	1.7	0.60	2.3	25.9	0.5
Y791	1991	64.51	110.25	5	471	5	488.5	8	8.1	10	2.4	0.48	2.9	16.8	1.2
Y891	1991	64.55	110.12	5	457	6	111.6	9	7.9	10	2	0.55	2.6	21.6	0.8
Y991	1991	65.06	110.13	5	488	8	262.5	8	8.2	8	2.2	0.38	2.6	14.6	1.3
Y1091	1991	65.13	109.11	5	457	20	175.6	7.5	8.6	9	2.7	0.39	3.1	12.5	0.8
Y1191	1991	65.27	108.33	5	427	5	263.1	9	8.4	8	2.6	0.52	3.1	16.7	1
Y1291	1991	65.16	108.29	5	396	15	421.1	8	8	10	2	0.48	2.5	19.5	1.1
Y1391	1991	65.05	108.30	5	442	8.5	244.5	8.5	6.3	10	1.6	0.35	2.0	18.1	0.9
Y1491	1991	64.50	109.11	5	440	3.5	68.3	8	7.4	8	3.2	0.58	3.8	15.3	1
Y1691	1991	64.31	109.38	5	430	7	501.7	9.5	6.2	8	3.2	0.60	3.8	15.7	0.7
Y1791	1991	64.35	110.17	5	457	6	119.8	10.5	6.2	8	2.4	0.55	2.9	18.6	0.6
Y1891	1991	64.18	110.38	5	459	8	317.1	10.5	8	8	3.8	0.58	4.4	13.2	0.7
Y1991	1991	63.35	111.54	6	450	7	130.5	13	8.2	0	4.9	0.58	5.5	10.6	0.7
Y2091	1991	63.39	112.08	6	427	6	288.4	11.5	8.2	0	4.5	0.90	5.4	16.7	0.7
Y2391	1991	63.13	112.29	6	396	5.5	98.2	14	8.8	22	6.4	0.59	7.0	8.5	0.8

APPENDIX B: (continued)

Site	ChlaC (ug·L^{-1})	TPU (ug·L^{-1})	TPF (ug·L^{-1})	SRPF (ug·L^{-1})	TN (mg·L^{-1})	TKN (mg·L^{-1})	NO3NO2 (mg·L^{-1})	NO2 (mg·L^{-1})	NH3 (mg·L^{-1})	PON (mg·L^{-1})	C-N	DIC (mg·L^{-1})	SiO2 (mg·L^{-1})	Ca (mg·L^{-1})
EPB03	<0.1	6.7	2.2	0.2	0.42	0.383	<0.005	<0.002	0.021	0.03	11.9	36.3	0.37	30.1
EPD03	-	19	2.9	0.7	0.32	0.287	<0.005	<0.002	0.036	0.029	11.1	24.4	1.15	31.1
EPF03	<0.1	6.3	1.6	1.7	0.10	0.044	0.029	0.002	0.013	0.024	17.6	7	0.49	18.3
EPG03	<0.1	2.9	2.1	0.6	0.14	0.054	0.047	0.002	0.008	0.039	8.6	14	0.88	20.5
EPK03	-	3.2	2.2	<0.2	0.11	0.078	0.008	<0.002	0.016	0.027	13.1	3.6	0.21	4.89
EPN03	-	7.4	2.2	1	0.07	0.049	<0.005	<0.002	0.008	0.021	35.1	2.8	0.2	3.21
EPP03	-	6.5	3.8	0.6	0.45	0.398	0.011	<0.002	0.023	0.043	11.3	11.9	3.96	19.4
EPR03	<0.1	2.4	1.6	0.5	0.09	0.056	0.012	<0.002	0.007	0.021	16.4	17.9	0.35	24.3
EPS03	-	2.1	1.5	0.5	0.12	0.068	0.038	<0.002	<0.005	0.012	21.1	21.2	0.49	28.3
EPV03	<0.1	5	3.6	0.6	0.52	0.458	0.009	0.002	0.02	0.055	10.5	59.5	1.66	25.9
EPW03	<0.1	2.5	1.3	0.2	0.21	0.084	0.079	0.002	0.03	0.042	4.6	14	0.57	18.7
EPX03	-	2.6	2.2	0.5	0.13	0.091	0.012	<0.002	0.013	0.031	8.9	25.9	1.67	28.4
EPAA03	-	11.7	4.7	0.7	0.45	0.403	0.008	<0.002	0.043	0.042	11.2	23.3	0.18	30
EPAB03	-	3.8	1	0.6	0.11	0.08	<0.005	<0.002	0.005	0.027	17.5	4.8	0.36	6.36
EPAC03	0.2	4.8	1.1	0.4	0.23	0.068	0.124	<0.002	0.005	0.039	5.6	25.4	1.26	33.9
EP103	<0.1	9.5	5.2	1.3	0.40	0.314	0.005	<0.002	0.014	0.084	15.7	20.7	4.61	38.8
EP1903	<0.1	2	2.1	<0.2	0.05	0.04	0.011	0.002	<0.005	0.016	26.7	9	0.6	13.3
EP2403	-	4.8	2	<0.2	0.18	0.087	0.018	<0.002	0.009	0.077	6.2	4.8	1.56	8.87
ERB04	-	5.8	3.6	0.3	0.07	0.057	0.015	0.001	<0.005	0.029	21.0	1	1.13	0.7
PPro07	1.3	3.1	1.8	0.4	0.05	0.078	0.018	0.001	0.006	0.025	40.0	3.2	0.13	3.41
PGre07	<0.1	4.5	3.1	0.6	0.21	0.236	0.018	0.002	0.011	0.052	18.1	8.5	0.63	11.6
CHEL07	<0.1	4.6	2.9	0.7	0.31	0.331	0.007	0.002	0.019	0.023	12.1	16.6	0.76	19.3
AXQ98	1.1	1.1	4.6	-	0.11	-	-	-	-	0.032	20.0	4	0.82	4.2
AXY98	1.2	22.4	6.1	-	1.15	-	-	-	-	0.088	17.0	43.9	1.32	42.8
AXZ98	<0.1	2.3	2.6	-	0.21	-	-	-	-	0.088	22.0	8.7	0.69	10.3
AXAI98	<0.1	3.4	1.2	-	0.12	-	-	-	-	0.042	22.5	4.6	1.66	6.3
AXAJ98	<0.1	1.3	3	-	0.16	-	-	-	-	0.044	18.5	15.5	2.07	71.8
AXBUC98	<0.1	0.1	0.8	-	0.28	-	-	-	-	0.054	4.9	4.7	1.05	23.2
AXCOL98	<0.1	0.6	1.9	-	0.03	-	-	-	-	0.032	47.7	0.3	3.88	48.7
LOA05	<0.1	23.2	21	0.8	0.03	0.039	0.009	0.001	0.01	0.02	41.9	0.6	7.66	13.9
MVAE02	-	12.4	8.9	1.1	0.03	<0.014	0.012	0.001	0.008	0.011	32.6	0.7	0.06	0.1
BC94	<0.1	7.2	5.9	1.1	0.42	0.158	0.01	0.001	<0.005	0.013	8.7	26.2	0.15	36.6
BG94	<0.1	5.5	4.3	1	0.36	0.123	<0.01	0.001	<0.005	0.007	5.2	14.3	0.23	24.7
BH94	<0.1	3.3	3.6	1.4	0.26	0.065	<0.01	0.001	<0.005	0.008	7.6	11.8	0.15	19.4
BM94	<0.1	7.9	2.8	1.2	0.47	0.206	<0.01	0.001	0.005	0.019	6.5	19.2	0.13	29.1
BN94	<0.1	4.8	3.1	0.9	0.42	0.164	<0.01	0.001	<0.005	0.011	5.4	18.9	0.49	28.8
BY94	<0.1	21.8	7.6	2.7	0.51	0.212	<0.01	<0.001	<0.005	0.052	7.6	16.2	0.34	24.2
BAE94	1	4.8	4.3	1.4	0.35	0.107	<0.01	<0.001	0.013	0.023	6.5	18.3	0.21	32
BAJ94	0.9	16	8.8	1.4	0.91	0.752	<0.01	0.003	0.035	0.043	8.3	26.6	1.12	43.7
BAT05	-	11.7	1.6	<0.2	0.07	0.06	0.016	0.002	0.01	0.013	32.0	1.1	0.05	0.42
DVE01	0.3	1.9	2	1.3	0.06	0.037	0.029	0.006	0.009	0.003	18.2	14.4	0.24	16.8
DVF01	<0.1	2.4	2.2	2.1	0.08	0.019	0.034	0.006	0.008	0.001	14.3	19.3	0.53	25.7
DVH01	<0.1	3.2	1.7	4.6	0.08	0.007	0.043	0.007	0.009	0.001	13.7	16.2	0.28	27.6
DVI01	<0.1	4.3	17	11.3	0.19	0.05	0.018	0.001	0.009	0.004	5.3	11.2	0.13	21
12M93	-	4.5	2.7	0.3	-	-	<0.01	<0.001	<0.005	0.019	-	17	0.26	23.3
Traf93	0.95	4.9	2.3	0.3	-	-	<0.01	<0.001	<0.005	0.015	-	12.9	0.26	20
SAP96	<0.1	5.5	2.2	0.1	0.05	0.032	<0.01	0.001	0.007	0.013	21.2	11.2	0.24	15.4
SAQ96	<0.1	6.5	1.8	0.1	0.05	0.032	<0.01	0.001	0.005	0.01	22.0	12.4	0.15	13.8
SAS96	<0.1	8.6	2.6	0.1	0.12	0.102	<0.01	0.001	<0.005	0.015	10.8	16	0.12	20.3
WE95	<0.1	9	2.2	0.7	0.18	0.154	<0.01	0.001	<0.005	0.019	18.8	14	0.09	12.2
WG95	<0.1	2.7	1.6	0.4	0.11	0.081	<0.01	0.001	<0.005	0.022	20.5	5.9	0.37	8
WL95	<0.1	4.6	2.7	0.3	0.21	0.183	<0.01	0.001	<0.005	0.023	17.2	22.1	0.24	32.2
WN95	<0.1	2.4	2.3	0.2	0.14	0.109	<0.01	0.001	<0.005	0.024	9.4	19.1	0.84	26.7
WQ95	<0.1	7.6	3.4	0.5	0.32	0.282	<0.01	0.001	0.005	0.033	14.9	25.5	0.16	25.6
WW95	<0.1	3.7	2.8	0.7	0.21	0.174	<0.01	0.001	<0.005	0.031	14.7	22.3	0.16	31.4
WAA95	<0.1	4.4	3	0.4	0.15	0.105	<0.005	0.001	0.002	0.045	17.0	20.9	0.82	29.9
WAG95	<0.1	2.3	3.6	0.6	0.23	0.197	<0.005	0.001	0.002	0.028	13.7	23.1	0.51	29.4
WAK95	<0.1	2.8	1.4	1	0.19	0.159	<0.005	0.001	0.002	0.028	12.6	19.2	0.59	26.5
BKA00	-	6.9	6.1	0.7	0.24	0.194	<0.001	<0.010	<0.005	0.042	16.0	15.3	1.35	16.4
BKF00	-	14.2	10.3	0.9	0.30	0.254	0.001	<0.010	<0.005	0.049	14.5	14.6	1.37	17.8
BKR00	-	6.8	6.3	0.8	0.32	0.251	<0.001	<0.010	<0.005	0.069	11.0	16.1	1.15	18.2
BKT00	-	12.3	7	0.8	0.24	0.204	<0.001	<0.010	<0.005	0.039	17.0	11.7	0.78	13.9
BKU00	-	18.9	4.8	0.9	0.30	0.25	<0.001	<0.010	<0.005	0.047	11.1	15	1.87	16.7
BKY00	-	34.3	11.4	1.5	0.30	0.233	0.001	<0.010	0.005	0.065	24.1	4.1	0.98	5.6

APPENDIX B: (continued)

Site	ChlaC (μg·L^{-1})	TPU (μg·L^{-1})	TPF (μg·L^{-1})	SRPF (μg·L^{-1})	TN (mg·L^{-1})	TKN (mg·L^{-1})	NO3NO2 (mg·L^{-1})	NO2 (mg·L^{-1})	NH3 (mg·L^{-1})	PON (mg·L^{-1})	C-N	DIC (mg·L^{-1})	SiO2 (mg·L^{-1})	Ca (mg·L^{-1})
BKAD00	-	21.3	6.5	1.4	0.28	0.203	0.001	0.011	<0.005	0.077	15.1	13.5	1.47	20.2
BKAH00	-	11.3	6.2	0.8	0.17	0.141	0.001	<0.010	<0.005	0.033	15.8	7	0.52	6.9
BKAI00	-	10.4	4.7	1.1	0.20	0.149	0.001	<0.010	<0.005	0.046	12.5	12	0.36	13.6
VG97	<0.1	2.9	2	0.4	0.21	0.17	0.005	0.001	0.009	0.027	11.4	23.2	2.83	26.2
BI0105	1.9	8.1	4	1.9	0.12	0.126	0.013	0.001	0.015	-	-	3.5	0.06	5.59
BI0205	<0.1	21.8	8	1.6	0.21	0.249	0.009	0.002	0.012	-	-	2.5	0.07	1.86
BI0405	<0.1	18.5	5.8	1.4	0.27	0.311	0.009	0.002	0.013	-	-	10.2	0.66	8.16
BI0505	<0.1	13	6.4	1.5	0.30	0.319	0.007	0.002	0.009	-	-	10.3	1.44	9.51
BI0705	<0.1	8.7	4.1	1.2	0.21	0.232	0.008	0.002	0.01	-	-	4.2	0.19	2.92
BI0805	<0.1	23.3	5.4	1.5	0.22	0.234	0.008	0.002	0.009	-	-	2.7	0.56	2.38
BI0905	<0.1	16.4	6.8	1.4	0.28	0.319	0.008	0.002	0.009	-	-	3	0.43	2.82
BI1005	-	5.3	3.9	1.4	0.19	0.207	0.009	0.002	0.014	-	-	1.7	1.55	0.99
BI1105	-	9.6	-	-	-	-	-	0.002	-	-	-	4.2	2.32	4.65
BI1705	0.8	9.8	2.9	-	-	0.157	<0.005	-	0.006	-	-	1.9	0.87	1.09
BI2006	2.6	-	2	-	-	0.103	<0.005	0.006	0.008	-	-	2	0.7	1.24
BI2106	<0.1	3.9	2	-	-	0.12	<0.005	0.002	0.008	-	-	1.5	1.39	0.73
BI2206	2.2	8.5	3.5	-	-	0.302	<0.005	0.002	0.017	-	-	2.1	0.08	1.03
BI2506	0.4	29.4	18.1	-	-	0.392	<0.005	0.002	0.008	-	-	5.6	0.73	4.52
BI2606	0.4	12.7	5.8	-	-	0.277	<0.005	0.003	0.005	-	-	1.8	0.63	0.99
BI2806	1.5	19.4	9.5	-	-	0.538	<0.005	0.002	0.015	-	-	19.5	0.71	17
JUET208	-	8.1	3.4	0.6	0.19	0.185	<0.005	0.002	0.02	0.026	17.5	2.2	0.51	2.05
U290	ADL	15.8	14.1	7.5	0.73	0.654	0.015	0.001	0.031	0.064	22.9	134.2	0.78	15.6
U490	ADL	3.7	2.9	1.4	0.16	0.121	ADL	0.0009	ADL	0.026	25.1	14.4	7.84	19
U590	1.3	8.7	4.9	ADL	0.32	0.26	ADL	0.0014	ADL	0.052	27.8	12.4	7.86	16.6
U690	ADL	5.1	4.3	3.3	0.32	0.271	ADL	ADL	ADL	0.04	32.6	33.1	9.26	44.2
U790	ADL	4.9	3.5	0.6	0.26	0.208	ADL	ADL	ADL	0.041	33.5	40.8	9.19	50.3
U1090	0.7	12	8.1	2	0.89	0.743	ADL	ADL	ADL	0.132	17.0	35.1	6.54	30
U1190	0.7	12.3	9	1.6	0.67	0.572	ADL	0.0005	0.005	0.084	26.5	3.8	0.19	7.78
U1290	1	8.7	5.5	1.1	0.42	0.352	ADL	ADL	ADL	0.056	33.3	22.5	3.08	31
U1890	ADL	11.4	6.2	1	0.30	0.239	ADL	0.0008	ADL	0.052	22.5	18.1	2.03	23
U1990	0.8	10	6.9	1.4	0.42	0.348	ADL	0.0008	ADL	0.056	25.5	20.5	1.95	31.6
U2090	0.6	23.1	14.1	2.4	0.61	0.498	ADL	0.002	0.011	0.096	21.4	5.7	0.37	9.66
U2190	ADL	7.8	4.9	1.2	0.42	0.327	ADL	0.0006	ADL	0.084	28.5	3.8	0.3	5.82
U2290	1.3	10.3	7.9	1.6	0.59	0.532	ADL	0.0009	ADL	0.048	30.6	14.4	3.16	39.2
U2390	1.4	17.5	11.3	2.3	0.72	0.637	ADL	0.0016	ADL	0.068	15.4	4.6	0.94	13.9
U2590	2.1	16.1	12.1	2	0.71	0.631	ADL	0.0008	0.022	0.068	19.1	11.5	0.57	20.2
U2690	0.7	15.3	7.1	1.5	0.38	0.305	ADL	0.0011	0.019	0.064	18.5	6.3	0.14	9.14
U2790	0.6	19.8	8	2.2	0.63	0.535	0.015	ADL	0.036	0.08	20.4	27.7	0.32	43.8
U2890	0.5	16.7	8.1	0.7	0.40	0.281	-	0.0004	ADL	0.112	18.6	12.9	0.29	19.3
U2990	0.2	9.2	4.8	ADL	0.31	0.239	-	ADL	ADL	0.06	20.2	17.5	0.1	20.8
U3190	0.3	6.6	3.7	ADL	0.40	0.343	0.01	ADL	0.018	0.048	20.9	19.2	0.17	24.7
U3290	ADL	3	2.9	ADL	0.22	0.172	0.015	0.0009	0.008	0.032	22.7	27.4	1.52	36.2
U3690	1.1	20.8	6.2	0.7	0.54	0.459	ADL	ADL	0.019	0.072	18.6	14.1	0.43	18.3
U3490	0.5	13.7	6.3	ADL	0.47	0.391	ADL	ADL	0.02	0.072	23.7	17.9	0.57	24
U3790	0.3	10.5	5.6	ADL	0.40	0.309	ADL	0.0006	0.017	0.084	23.4	12.7	0.51	16.4
U3890	1	13.3	5.3	ADL	0.51	0.384	ADL	ADL	0.015	0.112	20.2	20.8	0.57	24.2
U3990	0.6	5	3.7	ADL	0.27	0.211	ADL	ADL	ADL	0.052	23.5	21.4	1.37	29.6
U4090	1.4	13.1	10.3	ADL	0.59	0.497	ADL	ADL	0.006	0.08	18.1	13.3	0.64	18.9
U4190	0.6	7.5	4.2	ADL	0.31	0.247	ADL	ADL	0.009	0.048	26.9	24	0.61	32.2
U4290	0.6	3.5	2.7	2.2	0.23	0.139	0.051	0.0072	0.01	0.032	21.1	15.7	1.54	20.8
U4390	0.6	5	3.2	0.5	0.31	0.197	0.023	0.029	0.009	0.056	19.8	10.3	0.81	14
U4490	0.7	12.3	6.6	1.1	0.45	0.336	0.03	0.0037	0.008	0.081	19.0	14.2	0.73	19.8
U4590	0.9	17.8	12.6	ADL	0.50	0.397	0.02	0.0002	0.014	0.08	24.8	3.4	1.92	7.78
U4690	0.6	16.2	10.9	0.6	0.54	0.439	0.014	ADL	0.019	0.088	22.2	4.9	1.18	9.74
U4790	0.4	9.3	6	ADL	0.40	0.334	0.015	ADL	ADL	0.052	23.4	18.9	0.94	33.9
U4890	18.1	48.8	12.7	3.2	1.06	0.518	0.015	0.0014	ADL	0.524	14.3	5.5	0.39	9.23
U4990	0.7	43.9	21.2	2	0.78	0.612	0.016	0.0006	ADL	0.152	29.0	2	3.31	6.73
U5090	0.2	28.6	24.3	0.6	0.92	0.823	0.016	0.0029	0.037	0.08	33.0	3.9	0.75	9.17
U5190	4	55.1	13.6	0.6	1.11	0.688	0.016	0.0019	0.026	0.408	18.1	7.4	1.73	10.2
U5290	0.1	9.7	6.6	0.6	0.39	0.316	0.014	0.0015	0.016	0.056	29.9	1.8	1.54	12.6
U5490	ADL	11.7	7.5	1.4	0.36	0.301	ADL	0.0008	ADL	0.052	36.7	5.1	1.26	11.9
U5590	ADL	9	7.2	0.5	0.32	0.237	ADL	ADL	ADL	0.072	28.2	7.4	0.62	10.4
U5690	8	35.4	14.5	1.6	0.62	0.409	ADL	0.001	0.014	0.2	22.1	2.4	1.02	5.48
U5890	0.6	9.8	4.5	ADL	0.19	0.093	ADL	ADL	ADL	0.088	23.6	0.3	1.92	8.29

APPENDIX B: (continued)

Site	ChlaC (µg·L^{-1})	TPU (µg·L^{-1})	TPF (µg·L^{-1})	SRPF (µg·L^{-1})	TN (mg·L^{-1})	TKN (mg·L^{-1})	NO3NO2 (mg·L^{-1})	NO2 (mg·L^{-1})	NH3 (mg·L^{-1})	PON (mg·L^{-1})	C-N	DIC (mg·L^{-1})	SiO2 (mg·L^{-1})	Ca (mg·L^{-1})
U5990	0.7	4	2.8	0.5	0.12	0.072	ADL	0.0009	ADL	0.04	27.3	5.5	1.74	12.8
IKC809	-	41.9	14.3	2.3	0.57	0.629	<0.005	0.002	0.112	0.045	28.9	2.1	-	13.6
IKC2309	-	6	2.9	1	0.28	0.28	<0.005	<0.001	<0.005	0.017	23.3	17	-	23.5
IKDEM109	2.6	18.5	<0.5	1.6	0.74	0.647	0.03	0.004	0.012	0.059	28.3	4.9	-	14.9
IKDEM209	3.8	29.4	<0.5	1.4	0.75	0.783	0.033	0.006	0.012	0.069	30.0	11.7	-	21.8
IKDEM309	2.7	24.3	10.8	1.2	0.44	0.431	0.031	0.002	<0.005	0.102	29.7	16	-	27.7
IKDEM409	1.3	16	5.7	3.2	0.78	0.8	<0.005	0.007	<0.005	0.103	52.3	2.1	-	9.4
IKDEM509	-	12.6	3.8	2.6	0.75	0.715	0.035	0.005	0.012	0.044	38.2	4.9	-	13.9
IKI309	3.9	52.7	11.6	1	0.56	0.576	<0.005	0.001	0.017	0.174	25.5	9.3	-	15.5
IKI809	-	26.1	9.9	0.9	0.65	0.623	<0.005	0.001	0.019	0.048	27.9	8.5	-	6.7
IKI1109	1.3	50.2	13.7	1.2	0.68	0.649	<0.005	0.001	0.026	0.104	24.3	10.2	-	16.3
IKI12A09	-	37.6	13.4	1.7	0.61	0.605	<0.005	0.001	0.033	0.103	21.4	11	-	16.1
IKI1709	<0.1	20.6	22.2	10.7	0.85	0.867	<0.005	0.001	0.007	0.054	31.7	17.6	-	35.5
IKI2009	-	39.4	48	13.5	0.81	0.874	<0.005	0.001	0.056	0.134	27.5	35.2	-	59.6
IKI23A09	-	15.8	24.3	16	0.51	0.531	<0.005	0.001	0.006	0.06	23.7	27	-	40.2
IKI25B09	2.5	35.8	12.2	2.6	0.67	0.671	0.006	0.002	0.01	0.094	30.7	8.5	-	19.3
IK5A09	-	11.9	6.4	1.2	0.37	0.35	<0.005	0.003	0.005	0.031	35.7	3.2	-	8.3
IK7B09	-	16.2	8	0.8	0.43	0.425	0.031	0.002	0.009	0.049	36.1	12.4	-	29.8
Y191	0.5	9.5	5.2	0.6	0.43	0.352	ADL	0.002	ADL	0.06	14.3	12.1	0.41	13.5
Y391	0.2	3.9	2.3	0.6	0.25	0.176	ADL	0.002	0.006	0.058	20.6	3.5	0.61	5.1
Y491	0.6	9.6	4.7	1	0.39	0.325	ADL	0.003	0.012	0.05	23.7	0.4	0.32	1.2
Y591	0.7	3.6	2.7	0.5	0.24	0.178	ADL	ADL	0.009	0.052	18.5	0.6	0.24	1.1
Y691	0.1	7.7	2.8	0.4	0.14	0.063	ADL	0.001	0.011	0.06	17.0	0.5	0.08	0.7
Y791	0.9	5.5	9	0.4	0.21	0.102	ADL	0.001	0.006	0.098	13.6	0.3	0.1	0.6
Y891	0.2	6.3	3.3	0.5	0.27	0.15	ADL	ADL	0.011	0.104	9.6	0.2	0.26	0.5
Y991	1.1	4.5	8.7	0.5	0.21	0.141	ADL	0.003	0.005	0.056	12.2	0.2	0.19	0.6
Y1091	0.1	3.4	2.2	0.5	0.24	0.126	ADL	0.001	ADL	0.102	12.9	0.2	0.18	0.7
Y1191	0.7	9.7	3	0.5	0.21	0.147	ADL	0.001	0.012	0.052	14.8	0.3	0.27	0.7
Y1291	0.4	3.6	3.1	0.4	0.16	0.105	ADL	0.001	0.008	0.044	15.4	0.1	0.21	0.7
Y1391	0.8	4.6	9.2	0.4	0.15	0.088	ADL	0.002	0.005	0.046	13.3	0.5	0.26	1.2
Y1491	0.8	7.3	2.7	0.6	0.23	0.16	ADL	0.001	0.008	0.061	16.2	0.2	0.19	0.7
Y1691	0.6	7.7	2.9	0.6	0.15	0.032	ADL	0.003	ADL	0.1	26.0	0.2	0.19	0.7
Y1791	0.2	4	2.9	0.5	0.22	0.115	ADL	0.002	ADL	0.094	13.3	0.3	0.33	0.6
Y1891	0.3	6.7	2.3	0.6	0.21	0.157	ADL	0.003	0.006	0.042	20.5	0.1	0.29	0.8
Y1991	0.3	6.1	3.2	1.3	0.26	0.173	ADL	0.003	0.006	0.073	21.1	0.6	0.34	1.3
Y2091	0.4	5.2	4	0.6	0.26	0.183	ADL	0.001	0.012	0.069	20.5	1.1	0.13	1.6
Y2391	0.5	5.9	5.7	0.8	0.38	0.27	ADL	0.002	0.009	0.092	18.6	2.4	0.38	3.4

APPENDIX B: (continued)

Site	Mg (mg·L^{-1})	Na (mg·L^{-1})	K (mg·L^{-1})	Cl (mg·L^{-1})	SO4 (mg·L^{-1})	F (mg·L^{-1})	Ag (µg·L^{-1})	Al (µg·L^{-1})	As (µg·L^{-1})	B (µg·L^{-1})	Ba (µg·L^{-1})	Be (µg·L^{-1})	Bi (µg·L^{-1})	Cd (µg·L^{-1})
EPB03	17.6	5.34	3.53	3.2	6.31	-	<1	1.6	0.53	24.1	32.2	<0.001	<0.001	<0.001
EPD03	3.89	3.18	0.46	7.11	1.58	-	<1	3.7	0.38	0.8	5.26	<0.001	<0.001	0.002
EPF03	3.04	0.69	0.32	1.05	39.7	-	1	177	0.24	1	4.5	0.01	0.003	0.027
EPG03	5.76	0.2	0.26	0.29	20.7	-	<1	30.3	0.04	1.1	27.7	0.006	<0.001	0.003
EPK03	1.99	7.83	0.41	14.7	2.86	-	<1	12.8	0.36	3.9	13.2	0.003	<0.001	0.006
EPN03	0.69	0.72	0.07	1.24	1.51	-	<1	6.9	<0.01	0.9	5.48	<0.001	<0.001	<0.001
EPP03	1.95	0.92	0.69	1.5	3.72	-	2	69.4	0.34	4.4	7.1	0.007	0.001	0.018
EPR03	3.95	1.74	0.2	3.71	2.06	-	<1	20	0.06	2.8	31.7	0.002	0.001	<0.001
EPS03	4.85	0.38	0.17	1.22	5.38	-	<1	13.6	0.15	2.2	4.81	0.003	<0.001	0.007
EPV03	57.3	7.18	5.34	14.2	50.9	-	<1	6	1.31	5.2	8.95	0.002	<0.001	0.003
EPW03	4.99	0.16	0.18	0.3	7.5	-	<1	52.1	0.61	1.1	8.23	0.008	0.001	0.012
EPX03	8.94	0.3	0.36	0.57	3.49	-	<1	8.4	0.33	3.1	25.7	0.003	<0.001	0.008
EPAA03	41.7	25.6	8.48	32.4	166	-	<1	14	1.27	1.5	9.64	0.002	<0.001	0.01
EPAB03	0.94	0.17	0.16	0.17	1.29	-	<1	4	0.15	1.3	8.21	0.002	<0.001	0.093
EPAC03	12	1.54	0.48	2.06	26	-	<1	26.5	0.47	1.7	8.07	0.003	0.001	0.023
EP103	6.53	1.42	1.09	0.61	41.7	-	<1	22.7	0.32	3.6	11.8	0.001	0.001	0.013
EP1903	1.38	0.3	0.25	0.17	6.32	-	2	17.5	0.19	1.7	8.22	0.002	<0.001	0.002
EP2403	0.83	0.52	0.25	0.36	3.25	-	1	37.1	0.07	1.4	4.3	0.003	<0.001	<0.001
ERB04	0.23	0.48	0.12	0.59	0.88	-	<1	45.8	0.02	0.05	1.33	0.001	0.0005	0.003
PPro07	1.34	2.57	0.23	4.48	0.7	-	2	17.2	0.05	2.1	1.43	0.0005	0.006	0.014
PGre07	3.12	6.12	0.83	10.2	5.61	-	2	51.2	0.13	15.3	5.69	0.0005	0.002	0.014
CHEL07	9.68	13.6	0.91	33.3	4.25	-	<1	5.8	0.17	10.8	7.04	0.0005	0.0005	0.004
AXQ98	2	1.6	0.7	1.91	6.5	-	<1	170	-	-	28.4	<0.2	-	<1
AXY98	20.7	17.6	5.8	36.9	4.5	-	<1	<10	-	-	52.7	<0.2	-	<1
AXZ98	3.3	3.6	1.3	5.32	8.1	-	<1	<10	-	-	4.7	<0.2	-	<1
AXAI98	2.2	7.5	0.6	0.87	10.5	-	<1	<10	-	-	0.9	<0.2	-	<1
AXAJ98	11.7	8	4.6	7.46	167	-	<1	10	-	-	13.3	<0.2	-	<1
AXBUC98	13.7	42.8	2.3	63.5	87.4	-	<1	10	-	-	19.8	<0.2	-	<1
AXCOL98	12.8	3.4	3.6	0.46	182	-	<1	1220	-	-	18.6	0.3	-	<1
LOA05	6.61	26.3	2.5	32.1	120	-	4	3110	0.29	41.8	0.83	2.86	0.001	0.74
MVAE02	0.1	0.1	0.1	-	28.3	-	<1	80	-	-	2.7	<0.2	-	<1
BC94	8	4.6	0.6	8.5	4.9	-	-	<10	-	-	66.7	<0.2	-	<1
BG94	1.7	1.1	0.4	1.79	4.6	-	-	20	-	-	15.9	<0.2	-	<1
BH94	2.4	1.4	0.5	1.48	6.7	-	-	<10	-	-	6.8	<0.2	-	<1
BM94	4.5	3.6	0.5	5.41	3.6	-	-	<10	-	-	85.5	<0.2	-	<1
BN94	4.7	3.2	0.5	5.63	4.8	-	-	20	-	-	73.6	<0.2	-	<1
BY94	6.2	6.4	0.5	15.2	3.5	-	-	100	-	-	107	<0.2	-	<1
BAE94	2.9	1.5	0.2	2.87	7	-	-	<10	-	-	39.1	<0.2	-	<1
BAJ94	7.8	3.2	0.9	4.46	18.7	-	-	<10	-	-	161	<0.2	-	<1
BAT05	0.36	0.9	0.21	1.68	0.48	-	1	78.2	0.03	1.1	1.46	0.006	0.001	0.004
DVE01	4.7	0.6	0.1	0.92	2.1	-	<1	10	-	-	2.7	<0.2	-	<1
DVF01	6.2	4.5	0.3	9.23	5.4	-	<1	30	-	-	11	<0.2	-	<1
DVH01	12	55.1	2.1	112	10.8	-	<1	20	-	-	0.8	<0.2	-	<1
DVI01	20.3	153	5.7	278	26.1	-	<1	20	-	-	0.6	<0.2	-	<1
12M93	5.2	2.4	0.2	4.4	3.3	-	-	<10	-	-	12	<0.2	-	<1
Traf93	3.1	1.2	0.2	1.5	1	-	-	62	-	-	5	<0.2	-	<1
SAP96	1.5	1.6	0.2	1.32	0.9	-	<1	30	-	-	1.1	<0.2	-	<1
SAQ96	3.3	1.8	0.2	2.62	1.2	-	<1	20	-	-	997.6	<0.2	-	<1
SAS96	2.7	1.1	0.2	2.05	0.9	-	<1	30	-	-	2.2	<0.2	-	<1
WE95	6.5	1	0.1	2.11	0.4	-	-	<10	-	-	21.8	<0.2	-	<1
WG95	1.1	0.8	0.1	1.16	0.2	-	-	50	-	-	5	<0.2	-	<1
WL95	4	0.9	0.3	1.46	1.2	-	-	30	-	-	5.4	<0.2	-	<1
WN95	3.9	1.3	0.3	2.33	1.5	-	-	20	-	-	1.7	<0.2	-	<1
WQ95	10.7	2.9	0.4	5.01	1.2	-	-	70	-	-	8	<0.2	-	<1
WW95	4	1	0.2	1.81	2	-	-	20	-	-	1.6	<0.2	-	<1
WAA95	3.7	1.9	0.4	3.31	1.6	-	-	10	-	-	2.7	<0.2	-	<1
WAG95	5.4	1.6	0.3	2.72	2.2	-	-	<10	-	-	3.2	<0.2	-	<1
WAK95	3.7	2.2	0.3	4.26	1.3	-	-	<10	-	-	1.7	<0.2	-	<1
BKA00	6.5	0.6	0.4	1.71	7.4	-	<1	10	-	-	14.4	<0.2	-	<1
BKF00	8.2	0.6	0.5	1.63	17	-	<1	200	-	-	15.6	<0.2	-	<1
BKR00	9.9	3.5	0.5	16.1	5.9	-	<1	20	-	-	26.7	<0.2	-	<1
BKT00	7.3	0.9	0.5	1.95	15.1	-	<1	10	-	-	20.2	<0.2	-	<1
BKU00	9.1	1.2	0.5	2.72	15.9	-	<1	10	-	-	14.6	<0.2	-	<1
BKY00	2.9	1.7	1	2.64	9.3	-	<1	990	-	-	34.1	<0.2	-	<1

APPENDIX B: (continued)

Site	Mg (mg·L^{-1})	Na (mg·L^{-1})	K (mg·L^{-1})	Cl (mg·L^{-1})	SO4 (mg·L^{-1})	F (mg·L^{-1})	Ag (µg·L^{-1})	Al (µg·L^{-1})	As (µg·L^{-1})	B (µg·L^{-1})	Ba (µg·L^{-1})	Be (µg·L^{-1})	Bi (µg·L^{-1})	Cd (µg·L^{-1})
BKAD00	11	1.9	0.7	3.91	34.4	-	2	220	-	-	15.9	<0.2	-	<1
BKAH00	3.6	0.4	0.3	0.84	1.6	-	2	10	-	-	7.2	<0.2	-	<1
BKAI00	4.9	0.5	0.4	1.22	4.7	-	3	170	-	-	6.1	<0.2	-	<1
VG97	8.8	0.7	0.3	1.64	1.9	-	<1	10	-	-	8.6	<0.2	-	<1
BI0105	2.3	5.61	1.24	10.1	9.92	-	-	-	-	-	-	-	-	-
BI0205	1.51	4.72	0.58	9.37	0.42	-	-	-	-	-	-	-	-	-
BI0405	3.58	3.78	1.21	0.99	2.76	-	-	-	-	-	-	-	-	-
BI0505	4.75	4.94	1.77	1.57	11.5	-	-	-	-	-	-	-	-	-
BI0705	1.95	4.68	0.87	6.04	3.65	-	-	-	-	-	-	-	-	-
BI0805	1.51	3.63	0.68	5.44	2.24	-	-	-	-	-	-	-	-	-
BI0905	1.81	4.65	0.85	7.22	3.21	-	-	-	-	-	-	-	-	-
BI1005	0.55	0.97	0.27	1	0.6	-	-	-	-	-	-	-	-	-
BI1105	1.59	2.62	0.62	2.34	1.91	-	-	-	-	-	-	-	-	-
BI1705	0.46	0.57	0.51	0.24	0.7	-	-	-	-	-	-	-	-	-
BI2006	0.53	0.76	0.55	0.7	0.77	-	-	-	-	-	-	-	-	-
BI2106	0.27	0.52	0.35	0.16	0.25	-	-	-	-	-	-	-	-	-
BI2206	0.56	1.1	0.58	1.13	0.31	-	-	-	-	-	-	-	-	-
BI2506	2.27	1.9	0.66	2.09	0.51	-	-	-	-	-	-	-	-	-
BI2606	0.55	1.05	0.5	1.32	0.38	-	-	-	-	-	-	-	-	-
BI2806	7.24	2.78	0.56	2.34	1.07	-	-	-	-	-	-	-	-	-
JUET208	1.39	7.08	0.46	9.78	3.08	-	-	34.8	-	8.8	0.82	0.001	0.0005	0.013
U290	-	187	29.9	24.5	1242	-	-	-	-	-	-	-	-	-
U490	-	2.8	0.77	0.3	8.8	-	-	-	-	-	-	-	-	-
U590	-	1.95	0.56	0.6	3.9	-	-	-	-	-	-	-	-	-
U690	-	4.6	1.21	0.9	24.5	-	-	-	-	-	-	-	-	-
U790	-	7.56	1.85	0.9	29	-	-	-	-	-	-	-	-	-
U1090	-	4.36	2.94	1.5	28.9	-	-	-	-	-	-	-	-	-
U1190	-	0.73	1.57	4.2	2	-	-	-	-	-	-	-	-	-
U1290	-	1.32	1.45	1	0.5	-	-	-	-	-	-	-	-	-
U1890	-	3.71	0.39	0.3	11.5	-	-	-	-	-	-	-	-	-
U1990	-	3.4	0.58	0.4	9	-	-	-	-	-	-	-	-	-
U2090	-	0.34	0.1	0.4	1.9	-	-	-	-	-	-	-	-	-
U2190	-	0.34	0.39	0.6	4.1	-	-	-	-	-	-	-	-	-
U2290	-	2.26	1.04	6.1	38.9	-	-	-	-	-	-	-	-	-
U2390	-	1.6	0.65	3.7	13.2	-	-	-	-	-	-	-	-	-
U2590	-	8.28	2.07	3.2	32.6	-	-	-	-	-	-	-	-	-
U2690	-	8.16	1.11	15.5	1.9	-	-	-	-	-	-	-	-	-
U2790	-	33.4	3.23	75.2	17.9	-	-	-	-	-	-	-	-	-
U2890	-	9.42	1.79	18.8	6	-	-	-	-	-	-	-	-	-
U2990	-	10.3	0.9	18.7	1.1	-	-	-	-	-	-	-	-	-
U3190	-	8.97	1.43	16.3	10.5	-	-	-	-	-	-	-	-	-
U3290	-	7.63	1.36	13.2	9.2	-	-	-	-	-	-	-	-	-
U3690	-	4.71	1.15	7.2	1.4	-	-	-	-	-	-	-	-	-
U3490	-	9.72	1.43	17.3	3	-	-	-	-	-	-	-	-	-
U3790	-	4.58	1.02	6.8	1.4	-	-	-	-	-	-	-	-	-
U3890	-	7.27	1.31	8.9	2.1	-	-	-	-	-	-	-	-	-
U3990	-	5.04	1.16	7.4	4.7	-	-	-	-	-	-	-	-	-
U4090	-	4.86	1.15	8.2	0.8	-	-	-	-	-	-	-	-	-
U4190	-	7.83	1.96	12.2	9.2	-	-	-	-	-	-	-	-	-
U4290	-	3.36	0.89	5.2	1.9	-	-	-	-	-	-	-	-	-
U4390	-	3.08	0.98	5.6	1.6	-	-	-	-	-	-	-	-	-
U4490	-	3.08	1.1	3.7	2.1	-	-	-	-	-	-	-	-	-
U4590	-	2.22	0.9	1.9	12.9	-	-	-	-	-	-	-	-	-
U4690	-	2.39	1.39	1.9	14.6	-	-	-	-	-	-	-	-	-
U4790	-	5.02	1.64	2.7	42.3	-	-	-	-	-	-	-	-	-
U4890	-	1.6	1.38	1.6	8.1	-	-	-	-	-	-	-	-	-
U4990	-	1.38	0.45	1.4	9.1	-	-	-	-	-	-	-	-	-
U5090	-	4.93	1.1	5.2	9.3	-	-	-	-	-	-	-	-	-
U5190	-	4.21	1.22	2	3.8	-	-	-	-	-	-	-	-	-
U5290	-	7.23	1.14	1.7	49.4	-	-	-	-	-	-	-	-	-
U5490	-	4.01	1.01	1.9	19	-	-	-	-	-	-	-	-	-
U5590	-	2.07	0.98	2.5	3.2	-	-	-	-	-	-	-	-	-
U5690	-	0.77	0.84	0.7	7.6	-	-	-	-	-	-	-	-	-
U5890	-	0.7	0.45	0.3	39	-	-	-	-	-	-	-	-	-

APPENDIX B: (continued)

Site	Mg (mg·L^{-1})	Na (mg·L^{-1})	K (mg·L^{-1})	Cl (mg·L^{-1})	SO4 (mg·L^{-1})	F (mg·L^{-1})	Ag (ug·L^{-1})	Al (ug·L^{-1})	As (ug·L^{-1})	B (ug·L^{-1})	Ba (ug·L^{-1})	Be (ug·L^{-1})	Bi (ug·L^{-1})	Cd (ug·L^{-1})
U5990	-	0.24	0.14	0.2	15.2	-	-	-	-	-	-	-	-	-
IKC809	4.2	3.4	1.2	4.6	1	0.1	6	75.9	0.58	11.4	24.6	0.026	0.001	0.018
IKC2309	6.2	5	1.6	7.8	<1	0.1	<1	6.4	0.29	12	123	0.002	<0.001	0.007
IKDEM109	3.0	1.7	0.7	4.8	10	0.1	<1	65.7	0.56	13.5	23.6	0.021	0.002	0.012
IKDEM209	4.3	3.3	1.2	6.1	2	0.1	<1	22.7	0.43	7.6	28.5	0.008	<0.001	0.007
IKDEM309	11.0	5.3	1.0	5.3	22	0.2	<1	11.6	1.71	13.7	93.5	0.004	0.002	0.018
IKDEM409	3.0	1.8	0.3	<0.7	5	<0.01	<1	255	0.79	8.5	26.6	0.042	0.002	0.012
IKDEM509	3.7	1.0	0.4	0.8	11	<0.01	<1	132	0.41	6.4	16.6	0.038	0.001	0.023
IKI309	4.9	3	1.1	3	9	0.1	1	20.2	0.7	12.1	45.5	0.007	0.001	0.007
IKI809	2.2	2.3	0.8	3.1	6	<0.1	<1	46.2	0.7	11.5	47	0.007	0.001	0.008
IKI1109	4.7	3.3	1.3	5.5	2	0.1	<1	9.3	0.82	11.3	47	0.006	<0.001	0.004
IKI12A09	4.5	5.4	1.8	7	4	0.2	<1	85.9	0.77	23.7	110	0.014	0.001	0.009
IKI1709	13.4	12.8	6.7	43.6	16	0.2	<1	15.1	0.74	7.2	104	0.006	<0.001	0.018
IKI2009	16.7	7	1.7	6.9	51	0.1	<1	46.3	0.83	14.8	155	0.006	0.001	0.019
IKI23A09	10.6	9.1	3.1	20.8	6	0.2	3	28.5	0.51	8.3	45.1	0.01	<0.001	0.014
IKI25B09	6.4	4.8	1.2	8	21	0.1	<1	599	1.28	15.5	93.3	0.024	0.009	0.01
IK5A09	2.2	1.9	1.1	1.5	7	0.1	<1	63.7	0.59	9.9	30.7	0.018	0.003	0.02
IK7B09	10.9	13	2	3.4	72	0.2	<1	164	0.64	27.3	49.3	0.031	0.004	0.017
Y191	-	4.66	1.95	4.8	2.1	-	-	-	-	-	-	-	-	-
Y391	-	0.81	0.58	0.7	0.6	-	-	-	-	-	-	-	-	-
Y491	-	0.79	0.51	0.7	1.4	-	-	-	-	-	-	-	-	-
Y591	-	0.67	0.4	0.6	0.3	-	-	-	-	-	-	-	-	-
Y691	-	0.44	0.46	0.6	0.5	-	-	-	-	-	-	-	-	-
Y791	-	0.46	0.37	0.7	0.4	-	-	-	-	-	-	-	-	-
Y891	-	0.42	0.34	0.5	1	-	-	-	-	-	-	-	-	-
Y991	-	0.38	0.33	0.6	0.4	-	-	-	-	-	-	-	-	-
Y1091	-	0.42	0.34	0.8	0.9	-	-	-	-	-	-	-	-	-
Y1191	-	0.46	0.3	0.6	0.3	-	-	-	-	-	-	-	-	-
Y1291	-	0.44	0.35	0.6	1.5	-	-	-	-	-	-	-	-	-
Y1391	-	0.36	0.27	0.5	1.4	-	-	-	-	-	-	-	-	-
Y1491	-	0.38	0.4	0.5	1	-	-	-	-	-	-	-	-	-
Y1691	-	0.46	0.47	0.7	1	-	-	-	-	-	-	-	-	-
Y1791	-	0.46	0.44	0.5	0.9	-	-	-	-	-	-	-	-	-
Y1891	-	0.4	0.34	0.8	1.2	-	-	-	-	-	-	-	-	-
Y1991	-	0.67	0.42	0.8	1.2	-	-	-	-	-	-	-	-	-
Y2091	-	0.77	0.6	0.7	0.9	-	-	-	-	-	-	-	-	-
Y2391	-	0.83	0.83	0.6	1	-	-	-	-	-	-	-	-	-

APPENDIX B: (continued)

Site	Ce (µg·L^{-1})	Co (µg·L^{-1})	Cr (µg·L^{-1})	Cs (µg·L^{-1})	Cu (µg·L^{-1})	Fe (µg·L^{-1})	Ga (µg·L^{-1})	La (µg·L^{-1})	Li (µg·L^{-1})	Mn (µg·L^{-1})	Mo (µg·L^{-1})	Nb (µg·L^{-1})	Ni (µg·L^{-1})	Pb (µg·L^{-1})
EPB03	-	0.03	0.026	-	0.37	12.4	0.003	0.005	11.2	9.52	0.086	-	0.42	0.026
EPD03	-	0.023	0.016	-	0.54	25.9	0.002	0.007	1.1	1.49	0.162	-	0.36	0.045
EPF03	-	0.656	0.203	-	0.66	374	0.044	0.152	2.3	30.6	0.178	-	1.92	0.558
EPG03	-	0.058	0.1	-	0.46	48.2	0.008	0.017	0.8	3.55	0.138	-	0.27	0.071
EPK03	-	0.02	0.053	-	0.42	23.2	0.005	0.013	0.2	4.51	0.045	-	0.15	0.023
EPN03	-	0.011	0.025	-	0.25	12.1	0.002	0.008	<0.2	0.86	0.045	-	0.16	0.065
EPP03	-	0.136	0.106	-	1.07	528	0.022	0.334	1.6	28.2	0.06	-	0.73	0.512
EPR03	-	0.02	0.058	-	0.22	25.6	0.008	0.027	0.7	1.35	0.046	-	0.21	0.105
EPS03	-	0.01	0.066	-	0.27	12.7	0.008	0.019	0.4	0.35	0.195	-	0.21	0.071
EPV03	-	0.038	0.027	-	1	16.8	0.004	0.006	9.2	0.73	0.302	-	0.46	0.075
EPW03	-	0.055	0.12	-	0.45	90	0.016	0.048	0.8	1.19	0.066	-	0.33	0.227
EPX03	-	0.014	0.056	-	0.33	12.9	0.003	0.01	1.6	0.58	0.04	-	0.28	0.048
EPAA03	-	0.061	0.038	-	0.68	45.8	0.008	0.012	9.4	5.23	0.512	-	0.53	0.086
EPAB03	-	0.012	0.023	-	0.85	12.9	0.003	0.004	0.3	0.76	0.231	-	0.39	0.059
EPAC03	-	0.062	0.098	-	0.55	47.9	0.01	0.013	1.6	1.34	0.25	-	0.57	0.07
EP103	-	0.055	0.063	-	0.7	29.4	0.008	0.01	3.8	5.45	0.161	-	0.53	0.14
EP1903	-	0.022	0.061	-	0.16	37.5	0.01	0.038	1	1.3	0.136	-	0.44	0.06
EP2403	-	0.04	0.079	-	0.26	53.4	0.01	0.169	0.2	2.92	0.035	-	0.27	0.173
ERB04	-	0.031	0.122	-	0.45	51.9	0.011	0.048	0.1	1.7	0.067	-	0.18	0.035
PPro07	0.036	0.008	0.101	<0.005	15.8	27.4	0.009	0.02	0.2	1.43	0.02	0.008	0.1	0.218
PGre07	0.116	0.03	0.254	0.008	2.11	78.1	0.018	0.062	0.5	2.13	0.418	0.007	0.2	0.156
CHEL07	0.024	0.014	0.079	<0.005	0.77	65.3	0.004	0.012	1.8	1.05	0.142	0.003	0.26	0.042
AXQ98	-	<1	<1	-	<1	32	-	-	1	<0.5	<1	-	<2	<5
AXY98	-	<1	<1	-	1	15	-	-	16	<0.5	<1	-	<2	<5
AXZ98	-	<1	<1	-	1	2	-	-	2	<0.5	<1	-	<2	<5
AXAI98	-	<1	<1	-	<1	2	-	-	1	<0.5	<1	-	<2	<5
AXAJ98	-	<1	<1	-	<1	<1	-	-	7	<0.5	<1	-	<2	<5
AXBUC98	-	<1	<1	-	<1	1	-	-	7	<0.5	<1	-	2	<5
AXCOL98	-	14	<1	-	3	31	-	-	14	1630	<1	-	20	<5
LOA05	-	23.4	1.72	-	7.26	3270	0.018	7.78	21.3	2750	0.036	-	43.6	0.084
MVAE02	-	<1	<1	-	<1	128	-	-	<1	5.3	<1	-	<2	<5
BC94	-	<1	<1	-	<1	12	-	-	1	1.3	1	-	<2	<5
BG94	-	<1	<1	-	<1	48	-	-	2	3.1	2	-	2	<5
BH94	-	<1	<1	-	<1	18	-	-	2	1.9	1	-	<2	<5
BM94	-	<1	<1	-	<1	53	-	-	2	3.8	<1	-	4	<5
BN94	-	<1	<1	-	<1	64	-	-	2	3.5	1	-	<2	<5
BY94	-	<1	<1	-	<1	382	-	-	2	6.4	2	-	2	<5
BAE94	-	<1	<1	-	<1	29	-	-	1	1.7	1	-	<2	<5
BAJ94	-	<1	<1	-	<1	139	-	-	3	4.3	3	-	3	<5
BAT05	0.052	0.052	0.126	-	0.21	98.5	0.023	0.083	0.2	1.93	-	-	0.31	0.08
DVE01	-	<1	<1	-	7	6	-	-	<1	0.25	<1	-	33	<5
DVF01	-	<1	<1	-	<1	34	-	-	1	0.9	<1	-	<2	<5
DVH01	-	<1	<1	-	2	12	-	-	2	0.8	<1	-	<2	<5
DVI01	-	<1	<1	-	4	16	-	-	3	1.4	1	-	21	<5
12M93	-	<1	<1	-	1	3	-	-	1	1.1	1	-	<2	<5
Traf93	-	<1	<1	-	<1	77	-	-	1	1.8	<1	-	<2	<5
SAP96	-	<1	<1	-	<1	27	-	-	1	1.4	<1	-	<2	<5
SAQ96	-	<1	<1	-	<1	23	-	-	1	1.3	<1	-	<2	<5
SAS96	-	<1	<1	-	1	29	-	-	1	0.8	<1	-	<2	<5
WE95	-	<1	<1	-	<1	23	-	-	<1	1.4	<1	-	<2	<5
WG95	-	<1	<1	-	<1	39	-	-	<1	5	<1	-	<2	<5
WL95	-	<1	<1	-	<1	41	-	-	<1	0.8	<1	-	<2	<5
WN95	-	<1	<1	-	<1	37	-	-	<1	1.6	<1	-	<2	<5
WQ95	-	<1	<1	-	<1	132	-	-	<1	2.3	<1	-	<2	<5
WW95	-	<1	<1	-	<1	33	-	-	1	1.3	<1	-	2	<5
WAA95	-	<1	<1	-	<1	28	-	-	<1	1.2	<1	-	<2	<5
WAG95	-	<1	<1	-	<1	17	-	-	1	0.8	<1	-	<2	<5
WAK95	-	<1	<1	-	<1	13	-	-	<1	1	<1	-	<2	<5
BKA00	-	<1	<1	-	2	33	-	-	<1	7.8	<1	-	<2	<5
BKF00	-	<1	1	-	2	425	-	-	1	15.6	<1	-	<2	<5
BKR00	-	<1	<1	-	2	98	-	-	<1	55.4	<1	-	<2	<5
BKT00	-	<1	<1	-	2	81	-	-	1	39.6	<1	-	<2	<5
BKU00	-	<1	1	-	1	73	-	-	3	44	1	-	<2	<5
BKY00	-	<1	2	-	3	1130	-	-	3	26.7	<1	-	4	<5

APPENDIX B: (continued)

Site	Ce (µg·L^{-1})	Co (µg·L^{-1})	Cr (µg·L^{-1})	Cs (µg·L^{-1})	Cu (µg·L^{-1})	Fe (µg·L^{-1})	Ga (µg·L^{-1})	La (µg·L^{-1})	Li (µg·L^{-1})	Mn (µg·L^{-1})	Mo (µg·L^{-1})	Nb (µg·L^{-1})	Ni (µg·L^{-1})	Pb (µg·L^{-1})
BKAD00	-	1	<1	-	2	508	-	-	2	17.7	1	-	3	<5
BKAH00	-	<1	<1	-	1	54	-	-	<1	21.4	<1	-	<2	<5
BKAI00	-	1	<1	-	2	304	-	-	1	23.4	<1	-	<2	<5
VG97	-	<1	<1	-	<1	43	-	-	<1	5.3	<1	-	<2	<5
BI0105	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI0205	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI0405	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI0505	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI0705	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI0805	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI0905	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI1005	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI1105	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI1705	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI2006	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI2106	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI2206	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI2506	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI2606	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BI2806	-	-	-	-	-	-	-	-	-	-	-	-	-	-
JUET208	0.247	0.068	0.148	<0.005	1.85	74.3	0.008	0.152	0.2	6.52	0.055	0.001	1.58	0.093
U290	-	-	-	-	-	11.4	-	-	-	12	-	-	-	-
U490	-	-	-	-	-	8.6	-	-	-	5	-	-	-	-
U590	-	-	-	-	-	76	-	-	-	4	-	-	-	-
U690	-	-	-	-	-	15.8	-	-	-	12	-	-	-	-
U790	-	-	-	-	-	5.9	-	-	-	7	-	-	-	-
U1090	-	-	-	-	-	6.3	-	-	-	17	-	-	-	-
U1190	-	-	-	-	-	50.2	-	-	-	ADL	-	-	-	-
U1290	-	-	-	-	-	26.5	-	-	-	11	-	-	-	-
U1890	-	-	-	-	-	56.9	-	-	-	35	-	-	-	-
U1990	-	-	-	-	-	35.2	-	-	-	11	-	-	-	-
U2090	-	-	-	-	-	664	-	-	-	22	-	-	-	-
U2190	-	-	-	-	-	127	-	-	-	17	-	-	-	-
U2290	-	-	-	-	-	52.7	-	-	-	11	-	-	-	-
U2390	-	-	-	-	-	287	-	-	-	11	-	-	-	-
U2590	-	-	-	-	-	136	-	-	-	20	-	-	-	-
U2690	-	-	-	-	-	170	-	-	-	14	-	-	-	-
U2790	-	-	-	-	-	754	-	-	-	16	-	-	-	-
U2890	-	-	-	-	-	376	-	-	-	13	-	-	-	-
U2990	-	-	-	-	-	65.5	-	-	-	11	-	-	-	-
U3190	-	-	-	-	-	44.6	-	-	-	7	-	-	-	-
U3290	-	-	-	-	-	15.6	-	-	-	6	-	-	-	-
U3690	-	-	-	-	-	92.5	-	-	-	18	-	-	-	-
U3490	-	-	-	-	-	153	-	-	-	46	-	-	-	-
U3790	-	-	-	-	-	58	-	-	-	13	-	-	-	-
U3890	-	-	-	-	-	38.9	-	-	-	16	-	-	-	-
U3990	-	-	-	-	-	24.2	-	-	-	7	-	-	-	-
U4090	-	-	-	-	-	165	-	-	-	18	-	-	-	-
U4190	-	-	-	-	-	51.7	-	-	-	9	-	-	-	-
U4290	-	-	-	-	-	21.1	-	-	-	160	-	-	-	-
U4390	-	-	-	-	-	19.1	-	-	-	14	-	-	-	-
U4490	-	-	-	-	-	72	-	-	-	19	-	-	-	-
U4590	-	-	-	-	-	348	-	-	-	23	-	-	-	-
U4690	-	-	-	-	-	235	-	-	-	33	-	-	-	-
U4790	-	-	-	-	-	26.7	-	-	-	8	-	-	-	-
U4890	-	-	-	-	-	272	-	-	-	39	-	-	-	-
U4990	-	-	-	-	-	1660	-	-	-	61	-	-	-	-
U5090	-	-	-	-	-	774	-	-	-	50	-	-	-	-
U5190	-	-	-	-	-	771	-	-	-	43	-	-	-	-
U5290	-	-	-	-	-	348	-	-	-	72	-	-	-	-
U5490	-	-	-	-	-	265	-	-	-	14	-	-	-	-
U5590	-	-	-	-	-	160	-	-	-	20	-	-	-	-
U5690	-	-	-	-	-	612	-	-	-	23	-	-	-	-
U5890	-	-	-	-	-	196	-	-	-	160	-	-	-	-

APPENDIX B: (continued)

Site	Ce (µg·L^{-1})	Co (µg·L^{-1})	Cr (µg·L^{-1})	Cs (µg·L^{-1})	Cu (µg·L^{-1})	Fe (µg·L^{-1})	Ga (µg·L^{-1})	La (µg·L^{-1})	Li (µg·L^{-1})	Mn (µg·L^{-1})	Mo (µg·L^{-1})	Nb (µg·L^{-1})	Ni (µg·L^{-1})	Pb (µg·L^{-1})
U5990	-	-	-	-	-	37.4	-	-	-	11	-	-	-	-
IKC809	0.138	0.158	0.25	<0.005	1.66	994	0.01	0.056	2.2	47	0.269	0.003	1.63	0.413
IKC2309	0.013	0.027	0.027	<0.005	2.69	30.6	0.002	0.009	1.9	19.6	0.395	<0.001	0.39	0.207
IKDEM109	0.159	0.188	0.238	0.007	1.87	460	0.015	0.065	2.5	20	0.084	0.002	2.2	0.305
IKDEM209	0.032	0.046	0.076	0.005	1.01	182	0.007	0.016	1.7	22	0.055	<0.001	0.53	0.337
IKDEM309	0.034	0.106	0.07	<0.005	2.07	365	0.008	0.019	3.7	21.3	1.08	<0.001	1.61	0.168
IKDEM409	0.116	0.91	0.36	0.007	1.33	850	0.021	0.044	1.8	187	0.064	0.002	2.86	0.343
IKDEM509	0.165	0.663	0.198	0.006	2.86	307	0.011	0.084	2	22.8	0.064	0.001	6.15	0.345
IKI309	0.05	0.118	0.057	<0.005	0.86	731	0.011	0.025	3.4	105	0.323	0.001	1.2	0.201
IKI809	0.063	0.092	0.196	<0.005	1.57	810	0.019	0.028	2.8	56.4	0.342	0.005	0.92	0.273
IKI1109	0.045	0.092	0.043	<0.005	0.98	740	0.007	0.021	1.9	48.3	0.38	<0.001	0.91	0.135
IKI12A09	0.1	0.126	0.129	0.011	1.03	451	0.036	0.047	7.7	66.4	0.88	0.003	1.63	1.63
IKI1709	0.042	0.072	0.175	<0.005	11.4	143	0.012	0.025	4.3	77.9	0.269	<0.001	0.65	0.503
IKI2009	0.087	0.131	0.078	0.006	1.17	392	0.026	0.043	5.2	81.4	0.813	0.004	1.11	0.256
IKI23A09	0.075	0.093	0.157	<0.005	1.05	519	0.01	0.036	1.4	26.2	0.245	<0.001	0.91	0.312
IKI25B09	0.33	0.362	1	0.033	2.01	1820	0.216	0.152	3.1	73.6	0.749	0.067	2.18	0.33
IK5A09	0.26	0.192	0.197	0.007	2.22	488	0.016	0.098	2.7	97.4	0.292	0.001	1.86	0.613
IK7B09	0.223	0.22	0.294	0.028	1.85	417	0.064	0.082	11.7	36.9	0.64	0.004	3.69	0.353
Y191	-	-	-	-	-	36.6	-	-	-	4	-	-	-	-
Y391	-	-	-	-	-	17.5	-	-	-	3	-	-	-	-
Y491	-	-	-	-	-	178	-	-	-	8	-	-	-	-
Y591	-	-	-	-	-	43.6	-	-	-	4	-	-	-	-
Y691	-	-	-	-	-	49.3	-	-	-	ADL	-	-	-	-
Y791	-	-	-	-	-	16.1	-	-	-	ADL	-	-	-	-
Y891	-	-	-	-	-	27.2	-	-	-	ADL	-	-	-	-
Y991	-	-	-	-	-	10.2	-	-	-	ADL	-	-	-	-
Y1091	-	-	-	-	-	10.3	-	-	-	ADL	-	-	-	-
Y1191	-	-	-	-	-	34.3	-	-	-	ADL	-	-	-	-
Y1291	-	-	-	-	-	17.1	-	-	-	ADL	-	-	-	-
Y1391	-	-	-	-	-	7.5	-	-	-	ADL	-	-	-	-
Y1491	-	-	-	-	-	134	-	-	-	ADL	-	-	-	-
Y1691	-	-	-	-	-	53.1	-	-	-	26	-	-	-	-
Y1791	-	-	-	-	-	51.3	-	-	-	4	-	-	-	-
Y1891	-	-	-	-	-	33.5	-	-	-	2	-	-	-	-
Y1991	-	-	-	-	-	30.1	-	-	-	ADL	-	-	-	-
Y2091	-	-	-	-	-	44.3	-	-	-	3	-	-	-	-
Y2391	-	-	-	-	-	17	-	-	-	10	-	-	-	-

APPENDIX B: (continued)

Site	Pt (µg·L^{-1})	Rb (µg·L^{-1})	Sb (µg·L^{-1})	Se (µg·L^{-1})	Sn (µg·L^{-1})	Sr (µg·L^{-1})	Tl (µg·L^{-1})	U (µg·L^{-1})	V (µg·L^{-1})	W (µg·L^{-1})	Y (µg·L^{-1})	Zn (µg·L^{-1})
EPB03	-	0.43	0.023	<0.05	-	348	0.001	0.114	0.061	-	-	0.19
EPD03	-	0.08	0.044	<0.05	-	63.3	<0.001	0.0793	0.021	-	-	0.86
EPF03	-	0.5	0.055	<0.05	-	137	0.003	0.0969	0.096	-	-	1.55
EPG03	-	0.11	0.015	<0.05	-	58.4	0.001	0.362	0.031	-	-	0.71
EPK03	-	0.07	0.004	1.35	-	14	<0.001	0.0282	0.075	-	-	0.42
EPN03	-	0.02	0.012	<0.05	-	8.5	<0.001	0.0213	0.024	-	-	0.4
EPP03	-	0.24	0.048	<0.05	-	111	0.001	0.0659	0.167	-	-	3.6
EPR03	-	0.11	0.016	<0.05	-	139	0.001	0.0831	0.042	-	-	0.86
EPS03	-	0.12	0.034	0.95	-	40.5	0.001	0.132	0.038	-	-	1.16
EPV03	-	0.4	0.192	2.68	-	107	0.001	1.09	0.032	-	-	3.15
EPW03	-	0.11	0.049	5.24	-	47.1	0.001	0.272	0.061	-	-	1.4
EPX03	-	0.06	0.065	2.2	-	52.3	0.001	0.198	0.036	-	-	0.11
EPAA03	-	0.99	0.127	1.33	-	224	0.002	0.235	0.106	-	-	0.91
EPAB03	-	0.05	0.017	0.33	-	12.3	0.001	0.0168	0.017	-	-	0.75
EPAC03	-	0.13	0.099	2.68	-	85.5	0.001	0.786	0.065	-	-	0.86
EP103	-	0.22	0.007	<0.05	-	178	<0.001	0.297	0.09	-	-	2.3
EP1903	-	0.17	0.026	0.86	-	70.5	0.001	0.112	0.045	-	-	0.49
EP2403	-	0.12	0.017	0.31	-	40.4	0.001	0.0309	0.055	-	-	0.81
ERB04	-	0.35	0.0005	0.025	-	3.07	0.002	0.0224	0.116	-	-	0.34
PPro07	0.0005	0.11	0.009	0.06	0.06	5.13	0.001	0.0036	0.04	-	0.009	1.39
PGre07	0.0005	0.5	0.028	0.12	0.066	27.1	0.0005	0.137	0.406	-	0.032	0.83
CHEL07	0.002	0.39	0.009	0.06	<0.005	57.9	0.001	0.0922	0.102	-	0.012	0.17
AXQ98	-	-	-	-	-	11.9	-	-	<1	-	-	1
AXY98	-	-	-	-	-	146	-	-	<1	-	-	10
AXZ98	-	-	-	-	-	32.8	-	-	<1	-	-	<1
AXAI98	-	-	-	-	-	27.8	-	-	<1	-	-	<1
AXAJ98	-	-	-	-	-	126	-	-	<1	-	-	<1
AXBUC98	-	-	-	-	-	105	-	-	<1	-	-	2
AXCOL98	-	-	-	-	-	82.7	-	-	<1	-	-	30
LOA05	-	3.74	0.014	0.12	-	47.7	0.025	2.84	0.2	-	-	136
MVAE02	-	-	-	-	-	<0.5	-	-	<1	-	-	1
BC94	-	-	-	-	-	76.9	-	-	<1	-	-	5
BG94	-	-	-	-	-	96.7	-	-	<1	-	-	2
BH94	-	-	-	-	-	81.6	-	-	<1	-	-	1
BM94	-	-	-	-	-	62.8	-	-	<1	-	-	15
BN94	-	-	-	-	-	55.8	-	-	<1	-	-	6
BY94	-	-	-	-	-	60.7	-	-	<1	-	-	8
BAE94	-	-	-	-	-	251	-	-	<1	-	-	<1
BAJ94	-	-	-	-	-	153	-	-	1	-	-	17
BAT05	-	0.2	0.003	0.05	-	1.98	0.001	0.0055	0.147	-	-	0.52
DVE01	-	-	-	-	-	9.9	-	-	<1	-	-	5
DVF01	-	-	-	-	-	560	-	-	<1	-	-	<1
DVH01	-	-	-	-	-	58.1	-	-	<1	-	-	<1
DVI01	-	-	-	-	-	124	-	-	<1	-	-	3
12M93	-	-	-	-	-	31.7	-	-	<1	-	-	1
Traf93	-	-	-	-	-	18.8	-	-	<1	-	-	1
SAP96	-	-	-	-	-	23.8	-	-	<1	-	-	1
SAQ96	-	-	-	-	-	142	-	-	<1	-	-	1
SAS96	-	-	-	-	-	39.9	-	-	<1	-	-	1
WE95	-	-	-	-	-	6.7	-	-	<1	-	-	1
WG95	-	-	-	-	-	3.4	-	-	<1	-	-	1
WL95	-	-	-	-	-	45.6	-	-	<1	-	-	1
WN95	-	-	-	-	-	41.2	-	-	<1	-	-	1
WQ95	-	-	-	-	-	30.9	-	-	<1	-	-	1
WW95	-	-	-	-	-	37.2	-	-	1	-	-	1
WAA95	-	-	-	-	-	37.4	-	-	<1	-	-	4
WAG95	-	-	-	-	-	56.9	-	-	<1	-	-	1
WAK95	-	-	-	-	-	43.6	-	-	<1	-	-	1
BKA00	-	-	-	-	-	21	-	-	<1	-	-	1
BKF00	-	-	-	-	-	26.6	-	-	1	-	-	2
BKR00	-	-	-	-	-	20.5	-	-	<1	-	-	1
BKT00	-	-	-	-	-	25.4	-	-	<1	-	-	<1
BKU00	-	-	-	-	-	21.2	-	-	<1	-	-	1
BKY00	-	-	-	-	-	25.6	-	-	4	-	-	5

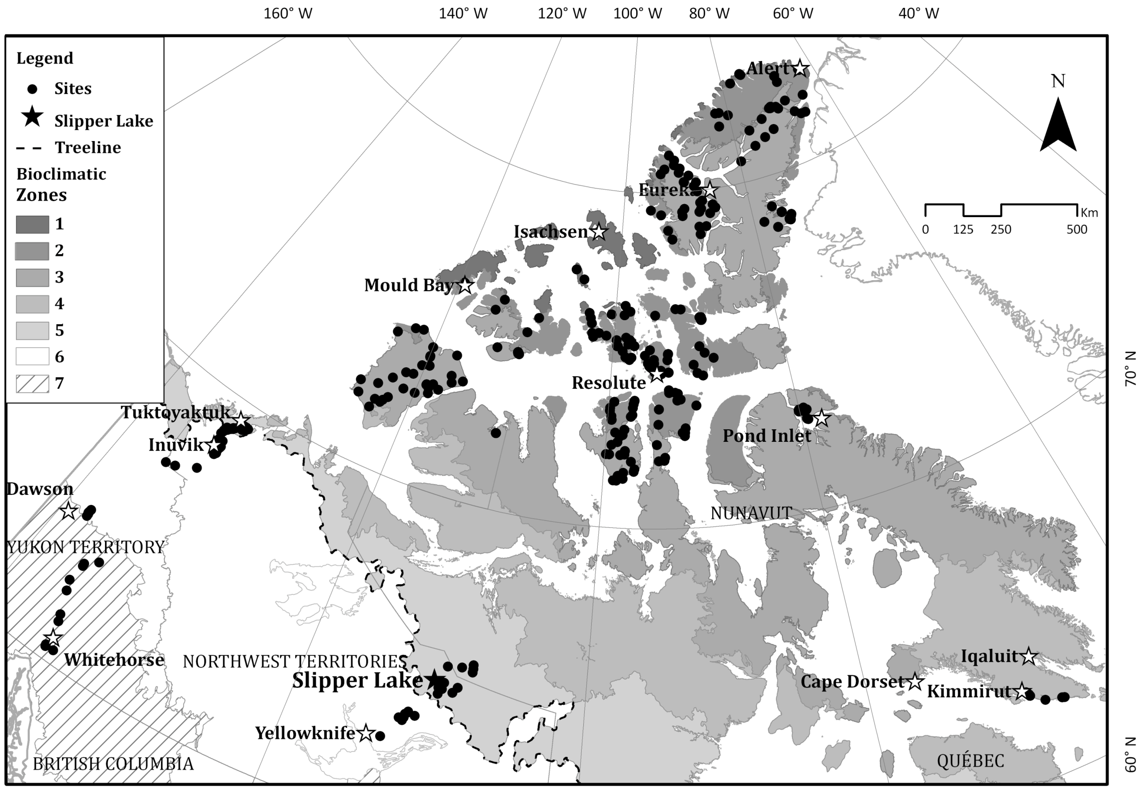
APPENDIX B: (continued)

Site	Pt (µg·L^{-1})	Rb (µg·L^{-1})	Sb (µg·L^{-1})	Se (µg·L^{-1})	Sn (µg·L^{-1})	Sr (µg·L^{-1})	Tl (µg·L^{-1})	U (µg·L^{-1})	V (µg·L^{-1})	W (µg·L^{-1})	Y (µg·L^{-1})	Zn (µg·L^{-1})
BKAD00	-	-	-	-	-	29.1	-	-	1	-	-	5
BKAH00	-	-	-	-	-	7.7	-	-	<1	-	-	<1
BKAI00	-	-	-	-	-	17.7	-	-	<1	-	-	1
VG97	-	-	-	-	-	18.2	-	-	<1	-	-	2
BI0105	-	-	-	-	-	-	-	-	-	-	-	-
BI0205	-	-	-	-	-	-	-	-	-	-	-	-
BI0405	-	-	-	-	-	-	-	-	-	-	-	-
BI0505	-	-	-	-	-	-	-	-	-	-	-	-
BI0705	-	-	-	-	-	-	-	-	-	-	-	-
BI0805	-	-	-	-	-	-	-	-	-	-	-	-
BI0905	-	-	-	-	-	-	-	-	-	-	-	-
BI1005	-	-	-	-	-	-	-	-	-	-	-	-
BI1105	-	-	-	-	-	-	-	-	-	-	-	-
BI1705	-	-	-	-	-	-	-	-	-	-	-	-
BI2006	-	-	-	-	-	-	-	-	-	-	-	-
BI2106	-	-	-	-	-	-	-	-	-	-	-	-
BI2206	-	-	-	-	-	-	-	-	-	-	-	-
BI2506	-	-	-	-	-	-	-	-	-	-	-	-
BI2606	-	-	-	-	-	-	-	-	-	-	-	-
BI2806	-	-	-	-	-	-	-	-	-	-	-	-
JUET208	0.0005	0.42	0.011	0.025	0.021	9.03	0.015	0.006	0.083	0.007	0.069	0.62
U290	-	-	-	-	-	-	-	-	-	-	-	-
U490	-	-	-	-	-	-	-	-	-	-	-	-
U590	-	-	-	-	-	-	-	-	-	-	-	-
U690	-	-	-	-	-	-	-	-	-	-	-	-
U790	-	-	-	-	-	-	-	-	-	-	-	-
U1090	-	-	-	-	-	-	-	-	-	-	-	-
U1190	-	-	-	-	-	-	-	-	-	-	-	-
U1290	-	-	-	-	-	-	-	-	-	-	-	-
U1890	-	-	-	-	-	-	-	-	-	-	-	-
U1990	-	-	-	-	-	-	-	-	-	-	-	-
U2090	-	-	-	-	-	-	-	-	-	-	-	-
U2190	-	-	-	-	-	-	-	-	-	-	-	-
U2290	-	-	-	-	-	-	-	-	-	-	-	-
U2390	-	-	-	-	-	-	-	-	-	-	-	-
U2590	-	-	-	-	-	-	-	-	-	-	-	-
U2690	-	-	-	-	-	-	-	-	-	-	-	-
U2790	-	-	-	-	-	-	-	-	-	-	-	-
U2890	-	-	-	-	-	-	-	-	-	-	-	-
U2990	-	-	-	-	-	-	-	-	-	-	-	-
U3190	-	-	-	-	-	-	-	-	-	-	-	-
U3290	-	-	-	-	-	-	-	-	-	-	-	-
U3690	-	-	-	-	-	-	-	-	-	-	-	-
U3490	-	-	-	-	-	-	-	-	-	-	-	-
U3790	-	-	-	-	-	-	-	-	-	-	-	-
U3890	-	-	-	-	-	-	-	-	-	-	-	-
U3990	-	-	-	-	-	-	-	-	-	-	-	-
U4090	-	-	-	-	-	-	-	-	-	-	-	-
U4190	-	-	-	-	-	-	-	-	-	-	-	-
U4290	-	-	-	-	-	-	-	-	-	-	-	-
U4390	-	-	-	-	-	-	-	-	-	-	-	-
U4490	-	-	-	-	-	-	-	-	-	-	-	-
U4590	-	-	-	-	-	-	-	-	-	-	-	-
U4690	-	-	-	-	-	-	-	-	-	-	-	-
U4790	-	-	-	-	-	-	-	-	-	-	-	-
U4890	-	-	-	-	-	-	-	-	-	-	-	-
U4990	-	-	-	-	-	-	-	-	-	-	-	-
U5090	-	-	-	-	-	-	-	-	-	-	-	-
U5190	-	-	-	-	-	-	-	-	-	-	-	-
U5290	-	-	-	-	-	-	-	-	-	-	-	-
U5490	-	-	-	-	-	-	-	-	-	-	-	-
U5590	-	-	-	-	-	-	-	-	-	-	-	-
U5690	-	-	-	-	-	-	-	-	-	-	-	-
U5890	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX B: (continued)

Site	Pt (µg·L^{-1})	Rb (µg·L^{-1})	Sb (µg·L^{-1})	Se (µg·L^{-1})	Sn (µg·L^{-1})	Sr (µg·L^{-1})	Tl (µg·L^{-1})	U (µg·L^{-1})	V (µg·L^{-1})	W (µg·L^{-1})	Y (µg·L^{-1})	Zn (µg·L^{-1})
U5990	-	-	-	-	-	-	-	-	-	-	-	-
IKC809	0.001	0.26	0.073	0.1	0.013	16.8	0.002	0.0228	0.337	0.01	0.156	5.15
IKC2309	<0.001	0.68	0.033	<0.05	0.028	56.1	<0.001	0.0236	0.031	0.001	0.022	1.42
IKDEM109	0.001	0.26	0.049	0.11	0.041	31.9	0.002	0.0209	0.37	0.003	0.168	2.6
IKDEM209	<0.001	0.83	0.03	<0.05	0.038	40.1	0.002	0.0059	0.18	0.005	0.037	1.82
IKDEM309	<0.001	0.42	0.107	0.16	0.048	117	0.003	0.222	0.234	0.016	0.042	1.43
IKDEM409	0.001	0.41	0.053	0.09	0.089	24.2	0.002	0.0113	0.371	0.003	0.208	6.24
IKDEM509	<0.001	0.34	0.048	0.19	0.063	22.3	0.004	0.0213	0.193	0.004	0.403	12.4
IKI309	0.001	0.35	0.034	0.08	0.03	34.3	0.001	0.0292	0.143	0.008	0.058	1.51
IKI809	<0.001	0.39	0.043	0.07	0.023	30.7	0.001	0.0219	0.199	0.012	0.045	1.98
IKI1109	<0.001	0.42	0.031	0.06	0.02	29.4	0.001	0.0242	0.168	0.003	0.04	1.09
IKI12A09	0.001	0.62	0.049	0.09	0.024	98.1	0.001	0.0658	0.354	0.037	0.073	2.53
IKI1709	0.001	0.8	0.04	0.07	0.108	106	0.001	0.0701	0.222	0.003	0.041	2.66
IKI2009	0.003	0.46	0.055	0.07	0.063	110	0.001	0.262	0.265	0.005	0.069	2.4
IKI23A09	0.003	0.57	0.043	0.08	0.039	41	0.001	0.032	0.242	0.007	0.077	1.88
IKI25B09	0.002	0.96	0.058	0.1	0.056	52.4	0.005	0.117	1.27	0.045	0.111	5.04
IK5A09	<0.001	0.39	0.053	0.13	0.024	21	0.003	0.0774	0.219	0.006	0.249	2.44
IK7B09	0.001	0.76	0.068	0.17	0.035	99.3	0.01	0.118	0.409	0.001	0.164	4.83
Y191	-	-	-	-	-	-	-	-	-	-	-	-
Y391	-	-	-	-	-	-	-	-	-	-	-	-
Y491	-	-	-	-	-	-	-	-	-	-	-	-
Y591	-	-	-	-	-	-	-	-	-	-	-	-
Y691	-	-	-	-	-	-	-	-	-	-	-	-
Y791	-	-	-	-	-	-	-	-	-	-	-	-
Y891	-	-	-	-	-	-	-	-	-	-	-	-
Y991	-	-	-	-	-	-	-	-	-	-	-	-
Y1091	-	-	-	-	-	-	-	-	-	-	-	-
Y1191	-	-	-	-	-	-	-	-	-	-	-	-
Y1291	-	-	-	-	-	-	-	-	-	-	-	-
Y1391	-	-	-	-	-	-	-	-	-	-	-	-
Y1491	-	-	-	-	-	-	-	-	-	-	-	-
Y1691	-	-	-	-	-	-	-	-	-	-	-	-
Y1791	-	-	-	-	-	-	-	-	-	-	-	-
Y1891	-	-	-	-	-	-	-	-	-	-	-	-
Y1991	-	-	-	-	-	-	-	-	-	-	-	-
Y2091	-	-	-	-	-	-	-	-	-	-	-	-
Y2391	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX C: Geographical distribution of the original Canadian Arctic calibration set including lakes (>2 m depth) and ponds (<2 m depth).



APPENDIX D: Full summer water chemistry and approximate ice cover of lakes and ponds on Pim Island, Ellesmere Island, Nunavut (1979-2009)

Site	Year	Sampling Date	Ice-cover (%)	pH	Conductivity (µS·cm^{-1})	Temperature (˚C)	Chl a (µg·L^{-1})	TPF (mg·L^{-1})	TPU (mg·L^{-1})	TNU (mg·L^{-1})
Proteus Lake	1979	June 13	100	7	87	1.5	-	-	0.008	0.12
	1979	June 17	100	7.6	133	1.0	-	-	-	-
	1979	July 20	80	7.3	-	-	-	-	-	-
	1980	June 5	-	7.2	163	-	-	-	-	-
	1980	June 12	-	7.2	75	-	-	-	-	-
	1981	June 4	-	6.7	89	-	-	-	-	-
	1983	July 19	80	7.21	35	-	-	-	0.0056	-
	1987	August 19	75	7.3	25	2.2	-	-	-	-
	1998	July 15	95	7.2	25	2	0.05	0.0012	0.0001	0.083
	2007	July 24	30	8.62	39	4	2.1	0.0018	0.0031	-
	2009	July 10	90	7.56	42	3.5	-	0.0029	0.0037	0.15
West Lake	1981	June 7	-	4.3	53	-	-		0.017	-
	1983	June 23	100	7.06	19	-	-	-	-	-
	1987	August 19	-	7.32	24	3.5	-	-	-	-
	2009	July 10	90	7.5	20	3.5	-	0.0027	0.0115	0.133
260 m Lake	1980	June 9	-	6.4	47	-	-		-	-
	1980	June 9	-	6.7	48	-	-		-	-
	1980	June 16	-	6.4	43	-	-		-	-
	1981	June 6	-	6.3	48	-	-		0.013	0.13
	1983	July 19	-	6.28	25	1	-	-	0.0113	-
	1987	August 19	100	6.77	18	3.5	-	-	-	-
	2009	July 10	90	7.11	20	1.5		0.0025	0.004	0.221
Greely Pond	1998	July 12	-	7.6	35	8	-	0.0012	0.0031	0.111
	2001	July 7	-	7.6	50	7	0.5	-	0.0037	0.287
	2004	July 19	-	8.12	99	11	2	-	0.0094	0.0028
	2007	July 24	-	8.73	88	10.5	2.7	0.0031	0.0045	-
	2009	July 10	0	8.03	101	10	-	0.0032	0.0054	0.174
P1 Pond	1998	July 12	25	7.5	25	8	3.7	0.0027	< 0.0002	0.11
P3 Pond	1998	July 12	-	7.4	27	9	0.3	0.0014	< 0.0002	0.104
H Pond	1983	June 22	0	7.26	21	-	-	-	-	-
North Pond	1983	June 22	0	7.6	61	16	-	-	-	-
	2009	July 10	0	7.56	42	3.5	-	0.0039	0.0087	0.271
Lakes	**mean**			7.0	51	2	1.1	0.0022	0.0077	0.140
Ponds	**mean**			7.5	35	9	2.0	0.0027	0.0030	0.162
Proteus Lake	**mean**			7.4	71	2	1.1	0.0020	0.0041	0.118
West Lake	**mean**			6.5	29	4	-	0.0027	0.0143	0.133
260 m Lake	**mean**			6.6	36	2	-	0.0025	0.0094	0.176
Greely Pond	**mean**			8.0	75	9	1.7	0.0025	0.0052	0.144
North Pond	**mean**			7.6	52	10	-	0.0039	0.0087	0.271
Total	**min**			**4.3**	**18**	**1**	**0.1**	**0.0012**	**0.0001**	**0.003**
	max			**8.7**	**163**	**16**	**3.7**	**0.0039**	**0.0170**	**0.287**
	mean			**7.2**	**52**	**6**	**1.6**	**0.0024**	**0.0062**	**0.146**

APPENDIX D: (continued)

Site	Year	DOC (mg·L^{-1})	DIC (mg·L^{-1})	Alk $CaCO_3$ (mg·L^{-1})	POC (mg·L^{-1})	POC/DOC (%)	PON (mg·L^{-1})	Hardness $CaCO_3$ (mg·L^{-1})	TNF (mg·L^{-1})	Cl (mg·L^{-1})
Proteus Lake	1979	L1	5.00	23	-	-	-	26.3	0.07	10.0
	1979	-	-	42	-	-	-	49.4	-	10.0
	1979	-	-	13.8	-	-	-	11.6	-	6.7
	1980	1.6	-	65	-	-	-	67.0	-	10.2
	1980	1.3	-	23	-	-	-	22.9	-	10.0
	1981	-	-	23	-	-	-	32.3	-	10.0
	1983	-	-	5.2	-	-	-	8.7	-	4.9
	1987	-	-	8	-	-	-	9.4	-	3
	1998	1.2	2.7	-	0.383	31.9	0.028	10.5	-	4.12
	2007	1.5	3.2	-	0.301	20.1	0.025	14.0	0.045	4.48
	2009	0.8	4.4	-	-	-	-	22.3	0.15	8.59
West Lake	1981	-	-	11.4	-	-	-	12.7	-	8.0
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	6.9	-	-	-	7.7	-	2.3
	2009	0.5	2.2	-	-	-	-	9.3	0.133	2.26
260 m Lake	1980	0.9	-	7	-	-	-	6.5	-	10.2
	1980	1.3	-	7	-	-	-	10.2	-	9.2
	1980	0.6	-	-	-	-	-	6.4	-	9.8
	1981	-	-	3	-	-	-	2.9	-	7.8
	1983	-	-	1.9	-	-	-	4.1	-	3.4
	1987	-	-	1.7	-	-	-	2.0	-	1.8
	2009	0.4	1	-		-	-	13.3	0.221	4.65
Greely Pond	1998	1.6	4.3	-	-	-	-	17.0	-	3.52
	2001	1.3	5.9	-	0.224	17.2	0.012	26.7	-	6.23
	2004	1.8	7.5	-	0.275	15.3	0.033	37.9	-	12.3
	2007	3.3	8.5	-	0.528	16	0.052	41.8	0.211	10.2
	2009	1.4	7.4	-	-	-	-	47.6	0.174	15.9
P1 Pond	1998	1.2	1.2	-	0.353	29.4	0.018	5.4	-	6.18
P3 Pond	1998	1.5	1.7	-	0.288	19.2	0.014	9.5	-	5.9
H Pond	1983	-	-	-	-	-	-	-	-	-
North Pond	1983	-	-	-	-	-	-	-	-	-
	2009	0.9	4.6	-	-	-	-	12.8	0.271	3.2
Lakes	**mean**	1.0	3.1	16.1	0.342	26	0.027	16.6	0.12	6.7
Ponds	**mean**	1.2	2.5	-	0.321	16	0.016	9.3	0.27	5.1
Proteus Lake	**mean**	1.3	3.8	25.4	0.342	26	0.027	24.9	0.09	7.5
West Lake	**mean**	0.5	2.2	9.2	-	-	-	9.9	0.13	4.2
260 m Lake	**mean**	0.8	1.0	4.1	-	-	-	6.5	0.22	6.7
Greely Pond	**mean**	1.9	6.7	-	0.342	16	0.032	34.2	0.19	9.6
North Pond	**mean**	0.9	4.6	-	-	-	-	12.8	0.27	3.2
Total	**min**	**0.4**	**1.0**	**1.7**	**0.224**	**-**	**0.012**	**2.0**	**0.05**	**1.8**
	max	**3.3**	**8.5**	**65.0**	**0.528**	**32**	**0.052**	**67.0**	**0.27**	**15.9**
	mean	**1.3**	**4.3**	**16.1**	**0.336**	**19**	**0.026**	**18.9**	**0.16**	**7.1**

APPENDIX D: (continued)

Site	Year	SO_4 (mg·L^{-1})	SiO_2 (mg·L^{-1})	Ca (mg·L^{-1})	Mg (mg·L^{-1})	Na (mg·L^{-1})	K (mg·L^{-1})	NO_3NO_2 (mg·L^{-1})	NH_3 (mg·L^{-1})	NO_2 (mg·L^{-1})
Proteus Lake	1979	1.4	0.8	5.9	2.8	5.2	0.6	0.01	-	-
	1979	2.0	6.8	13.2	4.0	6.7	0.8	-	-	-
	1979	0.9	0.28	2.5	1.3	3.7	0.2	-	-	-
	1980	4	13.1	18.6	5.0	5.9	0.7	1.56	-	-
	1980	2	0.6	5.2	2.4	5.1	0.8	0.02	-	-
	1981	2	-	7.00	3.6	5.9	0.6	-	-	-
	1983	2.8	0.25	2	0.9	2.7	L.2	-	-	-
	1987	0.6	0.33	2.1	1	1.94	0.14	-	-	-
	1998	1	0.21	2.4	1.1	2.3	< 0.2	-	-	-
	2007	0.7	0.13	3.41	1.34	2.57	0.23	0.018	0.006	0.001
	2009	1.3	0.23	4.72	2.21	4.08	0.36	0.011	< 0.005	0.001
West Lake	1981	3	-	2.45	1.6	4.0	0.4	0.02	0.032	-
	1983	-	-	-	-	-	-	-	-	-
	1987	0.5	0.34	1.59	0.91	1.67	0.15	-	-	-
	2009	0.62	0.67	1.56	0.88	1.73	0.33	0.006	0.011	0.001
260 m Lake	1980	2	0.3	1.1	0.9	5.0	0.8	0.01	-	-
	1980	3	1.6	1.1	1.8	4.2	0.5	0.17	-	-
	1980	2	0.3	0.9	1.0	4.6	0.6	0.01	-	-
	1981	2	-	1.00	0.1	4.4	0.6	-	-	-
	1983	2.4	0.22	0.8	0.5	2	L.2	-	-	-
	1987	0.5	0.47	0.37	0.27	1.4	0.11	-	-	-
	2009	1.28	0.51	0.7	0.54	2.91	0.3	0.024	0.042	0.001
Greely Pond	1998	1.8	0.34	4.5	1.4	2.4	0.4	-	-	-
	2001	2.5	0.35	6.9	2.3	3.6	0.4	0.012	0.032	0.002
	2004	2.82	0.32	10.3	2.97	6.04	0.54	0.008	< 0.005	0.001
	2007	5.61	0.63	11.6	3.12	6.12	0.83	0.018	0.011	0.002
	2009	11.7	0.52	11.6	3.38	9.5	0.83	0.005	0.007	0.001
P1 Pond	1998	1.9	0.54	1	0.7	3.4	0.2	-	-	-
P3 Pond	1998	1.5	0.49	2	1.1	2.6	< 0.2	-	-	-
H Pond	1983	-	-	-	-	-	-	-	-	-
North Pond	1983	-	-	-	-	-	-	-	-	-
	2009	0.8	0.41	3.66	1.6	2.15	0.33	0.047	0.006	0.001
Lakes	**mean**	1.7	1.5	3.7	1.6	3.7	0.4	0.17	0.019	0.001
Ponds	**mean**	1.4	0.5	2.2	1.1	2.7	0.2	0.05	0.006	0.001
Proteus Lake	**mean**	1.7	2.3	6.1	2.3	4.2	0.5	0.32	0.004	0.001
West Lake	**mean**	1.4	0.5	1.9	1.1	2.5	0.3	0.01	0.022	0.001
260 m Lake	**mean**	1.9	0.6	0.9	0.7	3.5	0.5	0.05	0.042	0.001
Greely Pond	**mean**	4.9	0.4	9.0	2.6	5.5	0.6	0.01	0.013	0.002
North Pond	**mean**	0.8	0.4	3.7	1.6	2.2	0.3	0.05	0.006	0.001
Total	**min**	**0.5**	**0.1**	**0.4**	**0.1**	**1.4**	**0.1**	**0.01**	**0.003**	**0.001**
	max	**11.7**	**13.1**	**18.6**	**5.0**	**9.5**	**0.8**	**1.56**	**0.042**	**0.002**
	mean	**2.2**	**1.2**	**4.5**	**1.7**	**3.9**	**0.4**	**0.12**	**0.015**	**0.001**

APPENDIX D: (continued)

Site	Year	TNU (mg·L^{-1})	TKN (mg·L^{-1})	Ag (mg·L^{-1})	Al (mg·L^{-1})	As (mg·L^{-1})	B (mg·L^{-1})	Ba (mg·L^{-1})	Be (mg·L^{-1})	Bi (mg·L^{-1})
Proteus Lake	1979	0.12	-	-	0.067	0.0005	L.02	L.1	-	-
	1979	-	-	-	-	0.0005	0.18	-	-	-
	1979	-	-	-	-	-	-	-	-	-
	1980	-	0.384	-	-	-	-	-	-	-
	1980	-	0.485	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	1998	0.083	-	< 0.001	< 0.01	-	-	0.0009	< 0.0002	-
	2007	-	0.078	0.002	0.0172	0.0005	0.0021	0.00143	< 0.00001	0.00006
	2009		0.102	< 0.001	0.041	0.0005	0.0025	0.00211	0.00002	< 0.00001
West Lake	1981	-	0.704	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009		0.104	0.003	0.34	0.0006	0.0015	0.00498	0.00009	0.00001
260 m Lake	1980	-	0.664	-	-	-	-	-	-	-
	1980	-	0.371	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	0.13	0.348	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009		0.073	< 0.001	0.0977	0.0002	0.0017	0.00188	0.00003	0.00001
Greely Pond	1998	0.111	-	< 0.001	< 0.01	-	-	0.002	< 0.0002	-
	2001	0.287	0.163	< 0.001	0.01	-	-	0.0032	< 0.0002	-
	2004	-	0.097	< 0.001	0.02	0.0008	0.0056	0.00412	0.00001	< 0.00001
	2007	-	0.236	0.002	0.0512	0.0013	0.00153	0.00569	< 0.00001	0.00002
	2009	-	0.14	< 0.001	0.0424	0.0011	0.134	0.00729	0.00001	0.00001
P1 Pond	1998	0.11	-	< 0.001	< 0.01	-	-	0.0005	< 0.0002	-
P3 Pond	1998	0.104	-	< 0.001	0.01	-	-	0.0009	< 0.0002	-
H Pond	1983	-	-	-	-	-	-	-	-	-
North Pond	1983	-	-	-	-	-	-	-	-	-
	2009	-	0.00218	< 0.00001	0.106	0.0007	0.002	0.00321	0.00004	0.00001
Lakes	**mean**	0.111	0.331	0.001	0.09	0.0005	0.537	0.002	0.00005	0.00002
Ponds	**mean**	0.107	0.218	0.000	0.04	0.0007	0.002	0.002	0.00008	0.00001
Proteus Lake	**mean**	0.102	0.262	0.001	0.03	0.0005	0.894	0.001	0.00004	0.00003
West Lake	**mean**	-	0.404	0.003	0.34	0.0006	0.002	0.005	0.00009	0.00001
260 m Lake	**mean**	0.130	0.364	0.001	0.10	0.0002	0.002	0.002	0.00003	0.00001
Greely Pond	**mean**	0.199	0.159	0.001	0.03	0.0011	0.004	0.004	0.00005	0.00001
North Pond	**mean**	-	0.218	0.000	0.11	0.0007	0.002	0.003	0.00004	0.00001
Total	**min**	**0.083**	**0.073**	**0.000**	**0.01**	**0.0002**	**0.002**	**0.001**	**0.00001**	**0.00001**
	max	**0.287**	**0.704**	**0.003**	**0.34**	**0.0013**	**0.134**	**0.007**	**0.00010**	**0.00006**
	mean	**0.135**	**0.278**	**0.001**	**0.06**	**0.0007**	**0.024**	**0.003**	**0.00005**	**0.00002**

APPENDIX D: (continued)

Site	Year	Cd (mg·L^{-1})	Ce (mg·L^{-1})	Co (mg·L^{-1})	Cr (mg·L^{-1})	Cs (mg·L^{-1})	Cu (mg·L^{-1})	Fe (mg·L^{-1})	Ga (mg·L^{-1})	La (mg·L^{-1})
Proteus Lake	1979	0.011	-	L.002	-	-	0.01	0.09	-	-
	1979	-	-	-	-	-	-	-	-	-
	1979	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	1998	< 0.001	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	-
	2007	0.00014	0.00036	0.00008	0.00101	< 0.00005	0.0158	0.0274	0.00009	0.02
	2009	0.00011	0.00078	0.00025	0.00072	< 0.00005	0.0032	0.0526	0.00016	0.046
West Lake	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009	0.00011	0.00436	0.00211	0.00537	0.00018	0.0074	0.379	0.00119	0.00239
260 m Lake	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009	0.00003	0.00248	0.00072	0.00129	0.00005	0.0031	0.122	0.0004	0.00116
Greely Pond	1998	< 0.001	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	-
	2001	< 0.001	-	< 0.001	< 0.001	-	0.001	0.025	-	-
	2004	0.00005	-	0.0001	0.00099	-	0.0043	0.0318	0.0001	0.033
	2007	0.00014	0.00116	0.0003	0.00254	0.00008	0.00211	0.0781	0.00018	0.062
	2009	0.00006	0.00076	0.00026	0.00104	0.00006	0.0049	0.0625	0.00019	0.047
P1 Pond	1998	< 0.001	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	-
P3 Pond	1998	< 0.001	-	< 0.001	< 0.001	-	< 0.001	0.003	-	-
H Pond	1983	-	-	-	-	-	-	-	-	-
North Pond	1983	-	-	-	-	-	-	-	-	-
	2009	0.00006	0.00185	0.00049	0.00161	0.00006	0.0047	0.112	0.00035	0.0011
Lakes	**mean**	0.00198	0.002	0.0007	0.0018	0.00006	0.007	0.112	0.00046	0.017
Ponds	**mean**	0.00035	0.002	0.0005	0.0009	0.00006	0.002	0.039	0.00035	0.001
Proteus Lake	**mean**	0.00294	0.001	0.0003	0.0007	0.00000	0.007	0.043	0.00013	0.033
West Lake	**mean**	0.00011	0.004	0.0021	0.0054	0.00018	0.007	0.379	0.00119	0.002
260 m Lake	**mean**	0.00003	0.002	0.0007	0.0013	0.00005	0.003	0.122	0.00040	0.001
Greely Pond	**mean**	0.00025	0.001	0.0003	0.0011	0.00007	0.003	0.040	0.00016	0.047
North Pond	**mean**	0.00006	0.002	0.0005	0.0016	0.00006	0.005	0.112	0.00035	0.001
Total	**min**	**0.00003**	**0.000**	**0.0001**	**0.0005**	**0.00000**	**0.001**	**0.001**	**0.00009**	**0.001**
	max	**0.01100**	**0.004**	**0.0021**	**0.0054**	**0.00018**	**0.016**	**0.379**	**0.00119**	**0.062**
	mean	**0.00101**	**0.002**	**0.0005**	**0.0013**	**0.00006**	**0.004**	**0.070**	**0.00033**	**0.027**

APPENDIX D: (continued)

Site	Year	Li (mg·L^{-1})	Mn (mg·L^{-1})	Mo (mg·L^{-1})	Nb (mg·L^{-1})	Ni (mg·L^{-1})	Pb (mg·L^{-1})	Pt (mg·L^{-1})	Rb (mg·L^{-1})	Sb (mg·L^{-1})
Proteus Lake	1979	-	L.01	-	-	0.007	0.01	-	-	-
	1979	-	-	-	-	-	-	-	-	-
	1979	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	1998	< 0.001	< 0.0005	< 0.001	-	< 0.002	< 0.005	-	-	-
	2007	0.002	0.00143	0.0002	0.00008	0.001	0.00218	< 0.00001	0.0011	0.00009
	2009	< 0.002	0.00215	0.0001	0.00005	0.0013	0.00084	0.00001	0.0021	0.00025
West Lake	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009	0.003	0.00762	0.00013	0.00043	0.005	0.002	< 0.00001	0.0096	0.00073
260 m Lake	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009	< 0.002	0.00368	0.0001	0.00011	0.0015	0.00075	< 0.00001	0.0038	0.00012
Greely Pond	1998	< 0.001	< 0.0005	< 0.001	-	< 0.002	< 0.005	-	-	-
	2001	0.001	0.0012	< 0.001	-	< 0.002	< 0.005	-	-	-
	2004	0.004	0.0082	0.00236	-	0.001	0.00102	-	0.003	< 0.00001
	2007	0.005	0.00213	0.00418	0.00007	0.002	0.00156	< 0.00001	0.005	0.00028
	2009	0.005	0.00154	0.00251	0.00003	0.0014	0.00115	0.00002	0.004	0.00023
P1 Pond	1998	< 0.001	< 0.0005	< 0.001	-	< 0.002	< 0.005	-	-	-
P3 Pond	1998	< 0.001	< 0.0005	< 0.001	-	< 0.002	< 0.005	-	-	-
H Pond	1983	-	-	-	-	-	-	-	-	-
North Pond	1983	-	-	-	-	-	-	-	-	-
	2009	0.002	0.00286	0.00018	0.00007	0.0018	0.00059	< 0.00001	0.0034	0.00019
Lakes	**mean**	0.002	0.0030	0.0002	0.00017	0.0028	0.0030	0.00001	0.0042	0.0003
Ponds	**mean**	0.001	0.0011	0.0004	0.00007	0.0013	0.0019	0.00000	0.0034	0.0002
Proteus Lake	**mean**	0.001	0.0013	0.0003	0.00007	0.0026	0.0039	0.00001	0.0016	0.0002
West Lake	**mean**	0.003	0.0076	0.0001	0.00043	0.0050	0.0020	0.00001	0.0096	0.0007
260 m Lake	**mean**	0.001	0.0037	0.0001	0.00011	0.0015	0.0008	0.00001	0.0038	0.0001
Greely Pond	**mean**	0.003	0.0027	0.0020	0.00005	0.0013	0.0017	0.00001	0.0040	0.0002
North Pond	**mean**	0.002	0.0029	0.0002	0.00007	0.0018	0.0006	0.00000	0.0034	0.0002
Total	**min**	**0.001**	**0.0003**	**0.0001**	**0.00003**	**0.0010**	**0.0006**	**0.00000**	**0.0011**	**0.0000**
	max	**0.005**	**0.0082**	**0.0042**	**0.00043**	**0.0070**	**0.0100**	**0.00002**	**0.0096**	**0.0007**
	mean	**0.002**	**0.0024**	**0.0009**	**0.00012**	**0.0019**	**0.0023**	**0.00001**	**0.0040**	**0.0002**

APPENDIX D: (continued)

Site	Year	Se (mg·L^{-1})	Sn (mg·L^{-1})	Sr (mg·L^{-1})	Ti (mg·L^{-1})	U (mg·L^{-1})	V (mg·L^{-1})	W (mg·L^{-1})	Y (mg·L^{-1})	Zn (mg·L^{-1})
Proteus Lake	1979	L.0005	-	-	-	-	L.001	-	-	0.04
	1979	L.0005	-	-	-	-	-	-	-	-
	1979	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	1998	-	-	-	-	-	< 0.001	-	-	0.001
	2007	0.0006	0.0006	0.0513	0.00001	0.000036	0.0004	0.00009	0.00009	0.00139
	2009	0.0005	0.00008	0.0805	0.00002	0.00006	0.00096	0.00004	0.0002	0.0066
West Lake	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009	< 0.0005	0.0002	0.00354	0.00007	0.000179	0.00682	0.00019	0.00123	0.00162
260 m Lake	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1980	-	-	-	-	-	-	-	-	-
	1981	-	-	-	-	-	-	-	-	-
	1983	-	-	-	-	-	-	-	-	-
	1987	-	-	-	-	-	-	-	-	-
	2009	0.0005	0.00015	0.00334	0.00003	0.000081	0.00203	0.00012	0.00049	0.00109
Greely Pond	1998	-	-	-	-	-	< 0.001	-	-	0.002
	2001	-	-	-	-	-	< 0.001	-	-	< 0.001
	2004	< 0.0005	-	0.0222	0.00004	0.00068	0.00139			0.0044
	2007	0.0012	0.00066	0.0271	< 0.00001	0.00137	0.00406	0.00094	0.00032	0.0083
	2009	0.0006	0.00014	0.0287	0.00002	0.00156	0.00204	0.00127	0.00028	0.0086
P1 Pond	1998	-	-	-	-	-	< 0.001	-	-	0.001
P3 Pond	1998	-	-	-	-	-	< 0.001	-	-	< 0.001
H Pond	1983	-	-	-	-	-	-	-	-	-
North Pond	1983	-	-	-	-	-	-	-	-	-
	2009	< 0.0005	0.00006	0.0057	0.00003	0.000134	0.00232	0.00003	0.00045	0.0068
Lakes	**mean**	0.0005	0.0003	0.0347	0.00003	0.00009	0.0021	0.00011	0.0005	0.0086
Ponds	**mean**	0.0003	0.0001	0.0057	0.00003	0.00013	0.0011	0.00003	0.0005	0.0028
Proteus Lake	**mean**	0.0006	0.0003	0.0659	0.00002	0.00005	0.0006	0.00007	0.0001	0.0122
West Lake	**mean**	0.0003	0.0002	0.0035	0.00007	0.00018	0.0068	0.00019	0.0012	0.0016
260 m Lake	**mean**	0.0005	0.0002	0.0033	0.00003	0.00008	0.0020	0.00012	0.0005	0.0011
Greely Pond	**mean**	0.0007	0.0004	0.0260	0.00002	0.00120	0.0017	0.00111	0.0003	0.0048
North Pond	**mean**	0.0003	0.0001	0.0057	0.00003	0.00013	0.0023	0.00003	0.0005	0.0068
Total	**min**	**0.0003**	**0.0001**	**0.0033**	**0.00001**	**0.00004**	**0.0004**	**0.00003**	**0.0001**	**0.0005**
	max	**0.0012**	**0.0007**	**0.0805**	**0.00007**	**0.00156**	**0.0068**	**0.00127**	**0.0012**	**0.0400**
	mean	**0.0005**	**0.0003**	**0.0278**	**0.00003**	**0.00051**	**0.0017**	**0.00038**	**0.0004**	**0.0060**

APPENDIX E: Taxonomy used for the dominant diatom species (>5% relative abundance) in the modern Pim Island lakes and ponds epipelic and epiphytic samples and in the West and 260m Lakes sediment records, with corresponding synonyms and taxonomic authorities.

Taxon	**Synonym**	**Authority**
Achnanthes acares		Hohn & Hellerman
Achnanthes curtissima		Carter
A. suchlandtii		Hustedt
Achnanthidium kriegeri	*Achnanthes kriegeri*	Krasske
Achnanthidium minutissimum	*Achnanthes minutissima*	(Kützing) Czarnecki
Aulacoseira alpigena		(Grunow) Krammer
Aulacoseira distans		(Ehrenberg) Simonsen
Aulacoseira tethera		Howart
Brachysira brebissonii		Ross in Hartley
Cavinula pseudoscutiformis	*Navicula pseudoscutiformes*	(Hustedt) Mann & Stickle in Round
Cymbopleura naviculiformis	*Cymbella naviculiformis*	(Auerswald) Krammer
C. descripta (Hustedt)		Krammer & Lange-Bertalot
Encyonema gaeumannii	*Cymbella gaeumannii*	(Meister) Krammer
Encyonema silesiacum	*C. silesiaca*	(Bleisch) Mann in Round *et al.*
Encyonopsis cesatii	*C. cesatii*	Krammer
Encyonopsis microcephala	*C. microcephala*	Grunow in Van Heurck
Eunotia bilunaris		(Ehrenberg) Mills
Eunotia praerupta		Ehrenberg
Fragilaria pinnata		
var. pinnata	*Staurosirella pinnata var. pinnata*	(Ehrenberg) Grunow in Van Heurck
var. intercedens	*Staurosirella pinnata var. intercedens*	
Fragilaria construens v.*venter*		
Fragilaria		
Fragilariforma virescens	*Fragilaria virescens* v. *exigua*	(Grunow) Krammer & Lange-Bertalot
Navicula vulpina		Kützing
Naviculadicta digitulus	*Navicula digitulus*	Hustedt
Neidium affine		(Ehrenberg) Pfitzer
Neidium ampliatum		(Ehrenberg) Krammer
Nitzschia perminuta		(Grunow) Peragallo
Pinnularia biceps		Gregory
Psammothidium helveticum	*Achnanthes helvetica* (Hustedt)	Bukhtiyarova & Round
Psammothidium lacus-vulcani	*Achnanthes lacus-vulcani*	Lange-Bertalot & Krammer
Psammothidium marginulatum	*Achnanthes marginulata* (Grunow)	Bukhtiyarova & Round
Psammothidium scoticum	*A. scotica*	
Pseudostaurosira brevistriata	*Fragilaria brevistriata*	(Grunow in Van Heurck) Williams & Round
Pseudostaurosira brevistriata var. papillosa	*F. brevistriata* var. *papillosa*	(Cleve-Euler)
Pseudostaurosira pseudoconstruens	*Fragilaria pseudoconstruens*	Marciniak
Sellaphora seminulum	*N. seminulum*	(Grunow) Mann
Stauroneis anceps		Ehrenberg
Staurosirella pinnata	*F. pinnata*	Ehrenberg

APPENDIX F: Diatom counts for West Lake Holocene sedimentary profile (BS-81-39, Core 1)

Interval (cm)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**13**	**15**	**17**	**19**	**21**
Achnanthes chlidanos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes curtissima	2	0	1	1	0	0	0	0	0	8	2	3	0	0	0	18	0
Achnanthidium kriegeri	1	3	1	1	0	0	0	0	0	0	0	0	2	2	1	0	1
Psammothidium lacus-vulcani/levanderii	12	4	0	0	0	0	0	0	0	2	8	5	3	0	2	9	0
Psammothidium marginulatum	0	2	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Achnanthidium minutissima	23	13	16	2	1	1	0	4	3	14	17	14	14	2	1	8	7
Rossithidium petersenii	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Achnanthes pusilla	22	23	33	26	7	14	12	132	187	133	92	149	116	19	14	25	13
Achnanthes suchlandti	89	48	16	50	38	43	31	23	0	2	6	1	13	28	4	0	8
Amphora inariensis	0	3	1	2	6	5	0	0	0	1	0	0	1	0	15	3	0
Aulacoseira distans	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Caloneis fasciata	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0
Caloneis fusus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	1	0	0	1	0	0	0	3	0	0	1	1	0	0	0	0	0
Caloneis sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Cyclotella antiqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	65	117	81	24	17	14	27	22	4	15	8	13	15	28	12	4	1
Cyclotella stelligera/pseudostelligera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella botellus	0	0	1	1	4	0	0	0	0	0	0	0	0	0	0	1	0
Cymbella cleve-eulerae aff. arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura amphicephala cf	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Cymbopleura angustata	0	0	0	0	0	0	4	0	0	0	0	0	0	10	0	0	3
Cymbopleura anglica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura cuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema elginense	0	0	0	2	0	9	3	15	0	0	0	0	6	0	6	1	1
Encyonema fogedii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema gaeumanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Encyonema lange-bertalotii/ventricosum	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema minutum	0	5	0	0	2	3	0	0	0	1	5	11	3	1	0	0	0
Encyonema naviculiformis	0	2	13	80	66	62	125	12	0	10	3	7	5	74	119	16	18
Encyonema reichardtii	1	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Encyonema silesciacum cf	3	2	8	15	2	15	5	3	0	2	0	1	1	10	0	0	0
Encyonopsis cesatii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis descripta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	0	0	0	1	4	0	2	1	1	0	0	0	0	0	0	0	0
Reimeria sinuata	1	0	1	1	0	0	7	2	0	0	1	0	0	8	15	5	3
Denticula tenuis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia arcubus/praerupta	0	0	1	1	0	0	4	0	0	0	0	0	0	1	0	0	0
Fragilaria capucina sensu lato	2	2	1	0	0	0	2	3	14	14	11	3	1	1	0	0	0
Fragilaria delicatissima	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Fragilaria robusta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Staurosira construens	0	1	0	0	0	0	0	0	0	1	0	0	0	4	0	0	1
Staurosira elliptica	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Staurosira construens var venter	0	7	6	2	8	7	6	11	16	2	1	1	2	292	19	178	89
Pseudostaurosira brevistriata	0	0	0	0	0	0	1	0	2	0	0	0	0	1	0	0	0

APPENDIX F: (continued)

Interval (cm)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**13**	**15**	**17**	**19**	**21**
Pseudostaurosira brevistriata var elliptica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Pseudostaurosira brevistriata var papillosa	24	0	2	0	0	0	2	0	0	5	3	7	3	0	0	0	0
Pseudostaurosira elliptica-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens	17	0	4	0	0	1	0	0	19	17	14	18	9	14	1	2	22
Pseudostaurosira trainorii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var pinata	10	1	3	4	3	6	12	4	11	5	10	5	21	58	168	392	327
Staurosirella pinnata var intercedens	33	1	32	274	279	207	154	104	35	80	141	110	233	6	0	3	0
Staurosirella lapponica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria sp 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema acuminatum cf	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Gomphonema distans cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema interpositum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Gomphonema parvulum	6	2	3	3	12	1	55	137	50	19	13	4	1	0	8	7	2
Adlafia bryophila	0	1	0	0	0	0	0	0	2	0	0	0	2	0	5	1	0
Brachysira vitrea	32	175	141	107	30	45	7	0	0	0	0	1	0	5	1	0	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Navicula angusta cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula digitulus	4	4	12	10	2	4	2	0	2	4	2	8	12	5	11	1	15
Navicula mediocris	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Navicula radiosa	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Sellaphora seminulum	218	55	111	53	29	9	7	129	228	366	408	381	325	23	3	9	16
Navicula schmassmanii	10	168	161	62	17	30	0	4	5	13	19	29	19	10	0	4	2
Navicula salsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Navicula vulpina	1	0	0	3	12	8	15	4	0	1	1	0	1	10	57	7	0
Cavinula pseudocutiformis	0	0	0	1	2	3	0	1	1	1	3	0	1	1	9	24	21
Sellaphora pupula	7	15	18	9	5	6	6	10	0	1	1	0	3	7	12	1	0
Stauroneis anceps	6	17	6	10	14	9	18	4	0	2	1	1	4	18	37	14	12
Neidium decoratum	0	5	2	12	13	35	27	2	0	1	0	0	0	33	60	6	5
Nitzschia fonticola	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Nitzschia inconspicua	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Nitzschia perminuta	0	1	0	2	0	0	0	0	3	2	0	1	1	0	0	0	0
Pinnularia grunowii	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Hygropetra balfouriana	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0
Tabellaria flocculosa	0	0	0	0	1	0	7	0	0	0	1	0	0	0	0	0	1
Chrysophycean cysts	27	56	34	49	32	42	123	41	8	11	10	14	17	44	161	32	16
Total number of valves	598	691	694	770	590	550	564	651	601	728	783	778	819	706	597	757	594
Total number of taxa	31	31	33	32	25	26	29	29	23	32	32	26	31	34	29	29	26
Frustule:Cyst	0.92	0.86	0.91	0.89	0.90	0.87	0.70	0.89	0.97	0.97	0.98	0.97	0.96	0.89	0.65	0.92	0.95
Poorly preserved valves (%)	1.00	1.74	2.02	1.30	2.37	2.36	3.72	2.46	1.33	0.69	0.89	0.39	0.24	4.11	2.01	1.98	3.54

APPENDIX F: (continued)

Interval (cm)	**23**	**24**	**25**	**26**	**27**	**29**	**31**	**33**	**35**	**37**	**39**	**41**	**43**	**45**	**46**	**47**
Achnanthes chlidanos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes curtissima	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2	5
Achnanthidium kriegeri	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Psammothidium lacus-vulcani/levanderii	0	4	7	0	0	0	0	0	0	0	0	0	0	0	0	0
Psammothidium marginulatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthidium minutissima	2	23	49	17	8	16	17	9	57	51	14	9	42	154	164	128
Rossithidium petersenii	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0
Achnanthes pusilla	90	120	133	63	7	5	1	5	4	21	7	2	7	25	45	116
Achnanthes suchlandti	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Amphora inariensis	5	2	0	1	0	2	0	0	0	0	0	0	0	0	1	0
Aulacoseira distans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis fasciata	2	2	7	0	0	2	0	0	0	1	0	0	1	0	2	0
Caloneis fusus	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Caloneis sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella antiqua	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	2	1	0	1	0	0	0	1	1	2	0	1	2	4	1	0
Cyclotella stelligera/pseudostelligera	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0
Cymbella botellus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella cleve-eulerae aff. arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura amphicephala cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura angustata	0	0	0	0	0	0	0	0	1	11	0	0	0	0	0	0
Cymbopleura anglica	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura cuspidata	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Cymbopleura incerta	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Encyonema elginense	2	3	6	2	3	0	0	0	2	5	1	1	2	0	2	0
Encyonema fogedii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema gaeumanii	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Encyonema lange-bertalotii/ventricosum	0	0	2	0	0	0	0	0	8	16	0	0	2	4	2	0
Encyonema minutum	2	0	1	0	11	11	16	15	68	72	0	1	0	1	0	0
Encyonema naviculiformis	8	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema reichardtii	13	20	23	12	4	2	2	0	89	34	0	1	4	1	6	5
Encyonema silesciacum cf	0	0	0	0	2	4	0	0	4	9	0	0	2	0	0	0
Encyonopsis cesatii	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Encyonopsis descripta	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	0	2	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Reimeria sinuata	4	4	0	2	1	0	0	0	0	0	0	0	1	0	1	0
Denticula tenuis	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0
Eunotia arcubus/praerupta	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria capucina sensu lato	2	0	6	0	0	1	1	0	0	1	0	0	0	0	0	1
Fragilaria delicatissima	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	0	0	0	0	0	2	3	0	2	3	0	0	0	0
Staurosira construens	2	6	4	6	28	3	35	35	88	4	33	21	9	7	12	12
Staurosira elliptica	0	0	3	5	10	11	5	7	20	1	5	0	2	3	2	2
Staurosira construens var venter	88	51	131	110	106	134	193	179	551	114	253	332	313	345	345	250
Pseudostaurosira brevistriata	0	0	11	1	5	6	9	2	7	1	3	0	0	8	0	3

APPENDIX F: (continued)

Interval (cm)	**23**	**24**	**25**	**26**	**27**	**29**	**31**	**33**	**35**	**37**	**39**	**41**	**43**	**45**	**46**	**47**
Pseudostaurosira brevistriata var elliptica	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Pseudostaurosira brevistriata var papillosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira elliptica-like	0	0	0	0	0	4	0	0	0	0	5	0	0	0	0	0
Pseudostaurosira pseudoconstruens	25	55	60	58	131	226	85	291	314	211	190	217	211	137	225	176
Pseudostaurosira trainorii cf	0	2	0	1	0	0	0	0	3	0	0	2	0	0	0	0
Staurosirella pinnata var pinata	370	338	499	360	475	324	482	553	590	223	0	92	49	36	43	25
Staurosirella pinnata var intercedens	1	1	3	0	0	0	0	1	4	0	0	0	0	3	3	1
Staurosirella lapponica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria sp 1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Gomphonema acuminatum cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema distans cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema interpositum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum	15	22	0	13	0	0	3	0	29	0	0	0	0	0	0	0
Adlafia bryophila	1	0	2	0	0	0	0	0	10	11	0	0	2	0	1	1
Brachysira vitrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diadesmis gallica	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula angusta cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	0	7	12	3	0	1	0	2	38	22	9	14	18	4	2	4
Navicula digitulus	11	10	12	2	0	0	0	0	6	4	0	2	0	0	0	1
Navicula mediocris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula radiosa	0	0	0	0	0	0	0	0	0	2	1	0	0	0	2	0
Sellaphora seminulum	30	20	21	7	0	2	0	0	0	0	0	1	0	0	0	0
Navicula schmassmanii	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0
Navicula salsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vulpina	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	2
Cavinula pseudocutiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sellaphora pupula	12	9	13	10	0	7	8	10	9	0	1	0	0	0	0	0
Stauroneis anceps	9	1	4	1	1	0	0	0	0	0	0	0	0	0	0	0
Neidium decoratum	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	0	4	6	5	12	18	12	12	57	76	13	30	20	27	10	13
Nitzschia inconspicua	1	1	3	0	4	0	0	3	6	13	0	2	2	0	4	3
Nitzschia perminuta	1	5	5	4	3	7	2	1	15	5	0	2	5	11	1	17
Pinnularia grunowii	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Hygropetra balfouriana	0	0	3	2	0	0	0	0	0	1	0	0	0	5	2	1
Tabellaria flocculosa	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysophycean cysts	20	16	18	5	8	2	10	17	14	6	6	3	6	13	21	10
Total number of valves	701	723	1049	692	815	789	880	1134	2020	918	537	737	697	796	881	767
Total number of taxa	31	31	38	31	20	24	18	20	39	28	17	22	21	24	28	22
Frustule:Cyst	0.95	0.96	0.97	0.99	0.98	0.99	0.98	0.97	0.99	0.99	0.98	0.99	0.98	0.97	0.95	0.97
Poorly preserved valves (%)	0.00	0.69	1.14	0.29	0.25	0.00	0.80	0.09	1.24	0.33	0.00	0.14	0.29	2.01	0.00	0.13

APPENDIX F: (continued)

Interval (cm)	**49**	**50**	**51**	**53**	**55**	**57**	**59**	**61**	**63**	**65**	**67**	**69**	**71**	**73**
Achnanthes chlidanos	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Achnanthes curtissima	2	0	1	1	0	0	2	0	0	0	0	0	0	0
Achnanthidium kriegeri	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psammothidium lacus-vulcani/levanderii	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psammothidium marginulatum	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Achnanthidium minutissima	56	54	46	17	70	50	33	12	20	3	5	1	2	1
Rossithidium petersenii	0	0	0	2	0	0	0	0	0	0	1	1	0	1
Achnanthes pusilla	19	6	2	5	1	3	4	1	2	3	24	12	1	8
Achnanthes suchlandti	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphora inariensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira distans	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis fasciata	0	0	0	1	2	3	1	2	17	0	0	0	0	0
Caloneis fusus	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Caloneis silicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella antiqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella stelligera/pseudostelligera	1	0	0	1	0	0	2	1	0	0	1	0	0	0
Cymbella botellus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella cleve-eulerae aff. arctica	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Cymbopleura amphicephala cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura angustata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura anglica	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura cuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema elginense	5	5	6	15	24	14	5	0	10	1	2	1	1	0
Encyonema fogedii	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Encyonema gaeumanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema lange-bertalotii/ventricosum	10	4	6	4	14	12	5	11	7	2	0	0	0	0
Encyonema minutum	2	6	0	2	2	3	4	3	2	0	0	0	0	0
Encyonema naviculiformis	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Encyonema reichardtii	194	196	71	108	140	36	0	0	4	0	10	0	0	0
Encyonema silesciacum cf	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Encyonopsis cesatii	0	2	0	0	0	2	2	0	0	0	0	0	0	0
Encyonopsis descripta	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	5	6	0	4	23	14	8	5	3	1	2	0	0	1
Reimeria sinuata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denticula tenuis	1	0	0	0	0	0	0	1	0	0	5	0	0	2
Eunotia arcubus/praerupta	2	0	0	0	0	0	0	0	0	0	0	1	0	0
Fragilaria capucina sensu lato	0	1	0	1	0	0	2	0	2	0	0	0	0	0
Fragilaria delicatissima	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Staurosira construens	1	3	7	18	10	35	26	1	11	1	14	16	41	35
Staurosira elliptica	0	0	0	2	0	0	4	1	0	3	1	0	0	7
Staurosira construens var venter	237	302	328	289	478	444	261	238	132	235	330	326	509	416
Pseudostaurosira brevistriata	1	2	2	0	7	4	2	0	0	1	1	0	4	1

APPENDIX F: (continued)

Interval (cm)	**49**	**50**	**51**	**53**	**55**	**57**	**59**	**61**	**63**	**65**	**67**	**69**	**71**	**73**
Pseudostaurosira brevistriata var elliptica	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Pseudostaurosira brevistriata var papillosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira elliptica-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens	110	199	230	132	144	178	289	141	112	283	294	299	177	161
Pseudostaurosira trainorii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var pinata	35	49	81	128	158	315	302	593	367	218	245	51	72	181
Staurosirella pinnata var intercedens	3	0	0	2	11	0	4	4	1	5	6	1	0	2
Staurosirella lapponica	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Fragilaria sp 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema acuminatum cf	0	2	2	2	3	0	0	0	0	0	0	0	0	0
Gomphonema distans cf	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Gomphonema interpositum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum	0	0	0	0	0	2	1	0	0	0	0	0	0	0
Adlafia bryophila	12	35	16	23	19	32	22	21	9	0	2	2	0	2
Brachysira vitrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula angusta cf	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	3	16	3	23	24	23	41	38	14	4	26	7	8	5
Navicula digitulus	3	4	0	0	7	0	0	0	10	0	0	0	0	0
Navicula mediocris	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula radiosa	3	13	4	9	10	14	1	2	18	2	1	2	0	1
Sellaphora seminulum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula schmassmanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula salsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vulpina	1	4	1	1	6	2	0	1	1	0	1	0	0	0
Cavinula pseudocutiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sellaphora pupula	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Stauroneis anceps	0	1	0	1	0	1	0	2	0	1	0	0	0	0
Neidium decoratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	31	27	29	32	47	47	64	50	42	13	53	16	16	18
Nitzschia inconspicua	3	9	1	7	35	31	5	0	2	4	2	0	0	2
Nitzschia perminuta	7	11	19	21	30	21	19	30	40	6	20	8	0	10
Pinnularia grunowii	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hygropetra balfouriana	2	0	1	0	1	1	0	0	0	2	3	0	0	2
Tabellaria flocculosa	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Chrysophycean cysts	9	5	10	11	4	5	5	8	23	3	13	8	2	3
Total number of valves	754	963	859	861	1288	1288	1119	1163	836	799	1049	745	831	860
Total number of taxa	27	27	21	32	29	26	30	23	25	22	24	16	12	23
Frustule:Cyst	0.98	0.99	0.98	0.98	0.99	0.99	0.99	0.99	0.95	0.99	0.98	0.98	1.00	0.99
Poorly preserved valves (%)	0.53	0.62	0.35	0.46	1.63	0.00	0.45	0.26	0.72	1.25	0.00	0.13	0.00	0.12

APPENDIX G: Diatom counts for 260 m Lake Holocene sedimentary profile (BS-81-36, Core 2)

Interval (cm)	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22
Psammothidium acares	14	7	9	12	0	12	12	9	11	16	13	4	19	31	4	3	9
Achnanthes chlidanos	0	1	2	1	1	0	2	1	0	1	0	2	2	1	2	4	0
Achnanthes curtissima	12	16	33	28	38	48	45	23	34	28	40	19	31	25	26	20	12
Achnanthes daonensis	9	7	15	33	36	2	9	16	21	9	17	14	45	14	11	18	17
Eucocconeis flexella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthidium kriegeri	1	1	5	8	2	0	0	1	7	6	7	8	16	8	1	8	5
Psammothidium lacus-vulcani/levanderii	44	74	120	132	140	246	175	90	83	120	97	204	133	70	100	82	71
Psammothidium marginulatum	96	49	72	100	69	38	110	107	54	60	63	60	35	52	70	20	25
Achnanthidium minutissimum	10	2	0	8	3	2	2	4	12	8	5	20	21	29	12	10	63
Rossithidium petersenii	0	3	1	13	0	1	1	7	2	4	2	6	0	4	1	2	4
Achnanthes pusilla	26	35	36	30	38	28	56	46	31	39	35	39	35	44	68	103	82
Psammothidium saccula	1	1	0	0	0	1	0	0	5	0	2	0	6	1	10	5	0
Achnanthes suchlandti	2	0	4	0	1	1	3	2	1	3	3	2	3	4	1	6	1
Amphora inariensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira distans var humilis	0	0	0	1	1	0	0	0	0	4	1	1	3	0	0	0	0
Aulacoseira distans var nivaloides	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Aulacoseira tethera	2	5	0	0	0	0	0	0	0	0	0	5	1	1	0	0	0
Caloneis fasciata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Cyclotella antiqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella ocellata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cymbella cleve-eulerae (arctica)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella designata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella neocistula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura angustata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura venetaeformis cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema elginense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema gaeumanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema lange-bertalotii/ventricosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema minutum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema naviculiformis	4	1	0	1	1	0	1	0	0	0	1	0	0	0	0	0	0
Encyonema reichardtii	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Encyonema silesiacum cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis cesatii	0	1	0	0	2	1	0	0	0	0	0	1	0	0	0	0	0
Encyonopsis cesatiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denticula tenuis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia arcubus/praerupta	11	1	2	7	3	0	0	3	3	7	3	22	9	0	6	1	3
Eunotia bilunaris cf	2	4	0	4	1	0	1	0	1	1	0	2	5	3	0	3	0
Eunotia monodon var monodon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia musicola var tridentula	1	1	8	10	8	0	5	1	1	1	0	8	2	3	0	0	0
Eunotia unk sp1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Fragilaria capucina sensu lato	2	7	4	1	8	3	5	0	1	6	4	2	8	2	6	0	4
Fragilaria delicatissima	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria virescence var exigua	14	2	5	7	1	0	0	0	0	0	1	3	3	10	7	23	3
Fragilaria tenera cf	0	0	1	2	1	0	0	1	1	3	3	2	1	2	1	1	0

APPENDIX G: (continued)

Interval (cm)	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22
Staurosira construens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosira construens var venter	0	0	0	0	0	0	0	1	0	4	0	1	0	1	0	5	0
Pseudostaurosira brevistriata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira elliptica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens KLB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira trainorii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var pinata	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	4
Staurosirella pinnata var intercedens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum	0	0	7	2	0	0	1	2	2	0	1	9	1	0	1	4	3
Gomphonema truncatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Adlafia bryophila	14	1	1	1	0	0	0	0	0	2	0	0	0	0	2	4	2
Diadesmis gallica	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Navicula cuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula digitulus	65	5	3	4	0	1	0	2	2	2	0	1	4	1	1	5	5
Navicula expecta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Navicula ingrata	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Navicula minusculoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula radiosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula schmassmanii	58	36	55	47	45	39	53	65	119	73	65	120	119	74	81	83	91
Navicula seminulum	222	246	152	105	125	107	171	123	172	126	197	135	271	164	134	210	211
Navicula ventralis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Navicula vincentii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vulpina	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Cavinula pseudocutiformis	3	1	0	4	1	0	0	1	3	1	0	2	3	0	0	2	1
Sellaphora pupula var mutata	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stauroneis anceps	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stauroneis neohyalina	0	0	1	2	0	0	0	1	0	3	1	2	1	1	0	0	0
Neidium decoratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neidium distincte-punctatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	1	0	2	0	0	0	1	0	0	0	2	3	0	0	0	2	1
Nitzschia inconspicua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Nitzschia perminuta	23	1	3	0	2	0	7	3	0	0	2	2	0	5	2	0	2
Pinnularia intermedia	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia interrupta complex	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hygropetra balfouriana	4	3	2	0	0	0	0	0	1	1	0	0	10	6	1	2	0
Tabellaria flocculosa	0	0	1	1	0	0	0	0	0	0	1	1	2	0	0	0	1
Chrysophycean cysts	32	9	8	11	15	11	19	11	10	13	9	26	18	20	15	15	6
Total number of valves	652	516	547	566	528	531	662	510	569	530	568	701	793	557	550	631	624
Number of taxa in interval	33	31	33	31	28	19	25	28	25	32	29	34	34	30	30	31	31
Frustule:Cyst	0.91	0.97	0.97	0.96	0.95	0.96	0.95	0.96	0.97	0.95	0.97	0.93	0.96	0.93	0.95	0.95	0.98
Poorly preserved valves (%)	0.77	0.19	0.00	0.18	0.00	0.00	0.15	0.00	0.00	0.00	0.18	0.14	0.25	0.00	0.00	0.16	0.00

APPENDIX G: (continued)

Interval (cm)	24	26	28	30	32	33	34	35	36	37	38	40	42	44	46	48	49
Psammothidium acares	16	9	19	22	7	15	17	14	19	37	51	41	34	37	44	52	9
Achnanthes chlidanos	1	1	1	0	1	1	0	0	0	4	0	0	0	0	2	0	0
Achnanthes curtissima	22	24	27	12	4	12	12	4	19	7	5	7	5	15	10	2	2
Achnanthes daonensis	2	23	6	1	5	2	14	9	0	1	2	0	0	0	4	0	4
Eucocconeis flexella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthidium kriegeri	6	9	9	7	27	20	19	23	18	23	30	10	16	21	11	8	14
Psammothidium lacus-vulcani/levanderii	117	91	45	42	65	55	56	58	39	41	25	19	4	11	25	14	7
Psammothidium marginulatum	38	9	32	14	38	32	32	71	48	11	12	8	0	10	7	5	0
Achnanthidium minutissimum	27	16	45	33	17	29	47	19	92	102	169	68	59	86	54	31	40
Rossithidium petersenii	5	4	2	8	7	10	5	8	9	5	1	1	0	1	0	0	0
Achnanthes pusilla	56	50	30	43	40	48	23	10	29	23	40	5	15	35	7	3	27
Psammothidium saccula	2	0	0	0	0	0	4	0	0	0	0	0	0	3	0	0	0
Achnanthes suchlandti	0	6	4	7	6	6	8	9	6	9	19	9	8	11	8	16	31
Amphora inariensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira distans var humilis	1	0	2	0	0	1	3	8	0	1	0	0	1	0	0	0	0
Aulacoseira distans var nivaloides	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira tethera	2	13	2	3	3	7	19	10	65	45	35	14	8	3	4	0	0
Caloneis fasciata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Cyclotella antiqua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella ocellata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	2	3	2	7	4	6	10	7	8	9	3	3	7	11	7	10	8
Cymbella cleve-eulerae (arctica)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella designata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cymbella neocistula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura angustata	0	2	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura venetaeformis cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema elginense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema gaeumanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema lange-bertalotii/ventricosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema minutum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema naviculiformis	0	3	0	1	0	1	2	3	1	6	2	3	2	0	4	7	23
Encyonema reichardtii	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Encyonema silesciacum cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis cesatii	0	0	1	3	0	0	0	0	0	2	0	0	1	0	0	0	0
Encyonopsis cesatiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denticula tenuis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia arcubus/praerupta	6	5	11	4	1	0	7	2	4	0	7	0	13	4	8	2	18
Eunotia bilunaris cf	4	2	1	2	10	10	9	13	6	3	8	2	2	3	2	0	6
Eunotia monodon var monodon	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Eunotia musicola var tridentula	0	1	0	0	4	3	4	11	0	0	0	0	0	0	0	0	0
Eunotia unk sp1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria capucina sensu lato	6	5	6	6	14	14	13	8	9	7	11	7	2	9	4	2	0
Fragilaria delicatissima	0	0	0	0	0	0	0	0	1	0	5	0	0	0	0	2	0
Fragilaria virescence var exigua	0	11	1	4	5	4	25	25	26	33	115	90	167	101	68	14	188
Fragilaria tenera cf	0	1	2	1	6	0	4	2	2	1	0	3	0	4	2	0	1

APPENDIX G: (continued)

Interval (cm)	24	26	28	30	32	33	34	35	36	37	38	40	42	44	46	48	49
Staurosira construens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosira construens var venter	5	0	1	0	2	9	3	8	6	11	46	32	9	10	0	3	22
Pseudostaurosira brevistriata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira elliptica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens KLB	0	0	0	2	0	0	1	2	0	2	3	4	2	2	2	0	6
Pseudostaurosira trainorii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var pinata	0	0	0	8	1	3	2	0	0	10	15	9	32	14	15	20	14
Staurosirella pinnata var intercedens	0	0	1	0	2	0	5	0	9	0	5	1	5	2	4	0	5
Gomphonema parvulum	4	14	1	10	15	2	1	0	2	3	4	0	0	7	0	0	1
Gomphonema truncatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Adlafia bryophila	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	0	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0
Navicula cuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula digitulus	0	1	4	2	3	6	10	6	7	5	11	4	15	12	15	11	12
Navicula expecta	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Navicula ingrata	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Navicula minusculoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula radiosa	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
Navicula schmassmanii	96	91	46	57	95	104	135	87	73	47	45	56	64	51	95	167	21
Navicula seminulum	108	137	244	197	132	120	208	76	57	101	102	91	19	114	104	115	6
Navicula ventralis	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1
Navicula vincentii cf	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Navicula vulpina	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	3
Cavinula pseudocutiformis	2	0	0	0	1	1	3	3	0	2	2	2	2	1	3	2	2
Sellaphora pupula var mutata	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stauroneis anceps	0	0	0	0	0	0	0	0	0	1	1	0	0	2	1	1	4
Stauroneis neohyalina	0	1	0	3	2	2	10	5	3	3	2	1	1	0	0	3	10
Neidium decoratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Neidium distincte-punctatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Nitzschia fonticola	0	1	3	4	1	1	2	1	0	3	7	6	1	0	0	2	0
Nitzschia inconspicua	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia perminuta	5	1	2	0	1	0	3	2	11	2	3	2	1	0	2	2	0
Pinnularia intermedia	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Pinnularia interrupta complex	0	0	0	1	2	2	0	1	0	2	4	0	0	5	3	1	4
Hygropetra balfouriana	1	2	0	0	2	0	4	4	0	2	2	0	0	4	1	4	3
Tabellaria flocculosa	0	1	0	3	0	1	0	4	2	1	1	0	0	2	0	0	0
Chrysophycean cysts	15	18	18	12	17	13	16	26	24	18	19	8	20	19	16	19	51
Total number of valves	535	545	554	510	529	533	724	517	574	565	799	500	501	595	517	500	506
Number of taxa in interval	31	37	36	36	43	39	39	40	35	40	42	33	32	35	35	32	35
Frustule:Cyst	0.95	0.94	0.94	0.96	0.94	0.95	0.96	0.91	0.92	0.94	0.95	0.97	0.93	0.94	0.94	0.93	0.83
Poorly preserved valves (%)	0.00	0.18	0.18	0.00	0.00	0.19	0.55	0.00	0.17	0.00	0.00	0.00	1.00	0.34	0.00	0.00	1.78

APPENDIX G: (continued)

Interval (cm)	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
Psammothidium acares	95	104	103	49	11	11	0	0	0	0	0	0	0	2	0	0
Achnanthes chlidanos	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Achnanthes curtissima	2	4	2	4	4	0	1	0	0	14	0	0	0	3	0	2
Achnanthes daonensis	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Eucocconeis flexella	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0
Achnanthidium kriegeri	13	3	3	3	7	1	1	0	3	0	0	0	0	0	0	0
Psammothidium lacus-vulcani/levanderii	18	32	34	51	15	35	31	40	10	7	13	4	4	0	0	0
Psammothidium marginulatum	6	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0
Achnanthidium minutissimum	62	16	7	17	15	1	17	4	23	30	78	26	28	89	101	77
Rossithidium petersenii	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5
Achnanthes pusilla	41	3	7	10	36	2	63	11	77	233	194	61	16	25	29	8
Psammothidium saccula	0	0	0	2	2	0	3	0	4	4	0	0	0	0	0	0
Achnanthes suchlandti	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphora inariensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
Aulacoseira distans var humilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira distans var nivaloides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira tethera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis fasciata	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Caloneis silicula	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0
Cyclotella antiqua	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Cyclotella ocellata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cyclotella radiosa	6	4	0	0	2	5	0	0	0	0	0	0	0	0	0	0
Cymbella cleve-eulerae (arctica)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella designata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella neocistula	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Cymbopleura angustata	1	1	4	0	2	0	3	0	6	8	5	11	2	11	7	8
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0
Cymbopleura venetaeformis cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema elginense	0	0	0	0	0	0	1	0	0	2	0	2	1	1	2	1
Encyonema gaeumanii	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema lange-bertalotii/ventricosum	0	0	0	0	0	0	0	0	0	1	5	0	0	4	5	3
Encyonema minutum	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	2
Encyonema naviculiformis	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema reichardtii	0	0	0	0	0	0	0	0	1	7	40	77	87	87	1	8
Encyonema silesiacum cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Encyonopsis cesatii	0	0	0	0	0	0	2	0	0	2	2	0	0	0	1	0
Encyonopsis cesatiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0	0
Denticula tenuis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia arcubus/praerupta	11	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Eunotia bilunaris cf	10	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia monodon var monodon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia musicola var tridentula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia unk sp1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria capucina sensu lato	12	0	0	3	5	3	1	0	2	8	0	2	0	0	0	0
Fragilaria delicatissima	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Fragilaria virescence var exigua	42	92	18	8	45	20	9	0	0	0	0	0	0	0	0	0
Fragilaria tenera cf	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0

APPENDIX G: (continued)

Interval (cm)	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
Staurosira construens	1	1	0	0	5	0	0	0	9	0	0	0	1	0	1	0
Staurosira construens var venter	25	7	7	29	127	259	252	171	254	255	276	298	245	22	45	51
Pseudostaurosira brevistriata	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0
Pseudostaurosira elliptica	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Pseudostaurosira pseudoconstruens KLB	18	25	20	209	237	9	28	12	25,2	58	43	55	244	35	183	246
Pseudostaurosira trainorii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Staurosirella pinnata var pinata	1	10	8	16	137	260	251	502	221	88	82	71	32	146	143	188
Staurosirella pinnata var intercedens	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0
Gomphonema truncatum	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Adlafia bryophila	0	0	0	0	0	0	0	0	0	20	17	2	12	39	21	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	0	0	0	0	0	0	0	0	0	2	4	0	13	29	9	0
Navicula cuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula digitulus	13	5	1	2	1	0	4	0	0	0	0	0	0	0	2	1
Navicula expecta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula ingrata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Navicula minusculoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula radiosa	0	0	0	0	0	0	0	0	0	1	0	4	3	17	6	4
Navicula schmassmanii	93	211	253	78	6	0	4	2	0	0	0	0	0	0	0	0
Navicula seminulum	22	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0
Navicula ventralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vincentii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vulpina	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cavinula pseudocutiformis	8	4	12	9	2	1	0	0	0	0	0	0	0	0	0	0
Sellaphora pupula var mutata	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	0
Stauroneis anceps	2	2	1	4	0	0	0	0	2	0	2	0	1	1	0	1
Stauroneis neohyalina	3	3	3	5	0	0	0	0	0	0	0	0	0	0	0	0
Neidium decoratum	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neidium distincte-punctatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	0	1	2	0	1	0	11	0	4	25	40	30	21	49	52	21
Nitzschia inconspicua	0	0	0	2	1	0	0	0	0	0	2	5	1	0	12	5
Nitzschia perminuta	3	2	6	0	3	0	2	0	2	22	13	2	10	13	5	7
Pinnularia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Pinnularia interrupta complex	1	0	1	11	8	3	3	1	5	5	13	7	10	0	0	0
Hygropetra balfouriana	4	2	1	2	0	2	5	0	0	0	2	1	3	0	2	3
Tabellaria flocculosa	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysophycean cysts	29	16	19	20	15	5	10	8	10	7	11	8	22	2	6	10
Total number of valves	530	540	497	518	687	613	695	744	653	802	840	665	744	588	642	648
Number of taxa in interval	38	27	26	22	30	17	23	9	20	24	22	25	24	23	26	23
Frustule:Cyst	0.90	0.94	0.93	0.93	0.96	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.94	0.99	0.98	0.97
Poorly preserved valves (%)	0.00	0.00	0.00	0.39	0.29	0.00	0.00	0.00	0.31	0.37	0.24	0.15	0.54	0.68	0.16	0.31

APPENDIX G: (continued)

Interval (cm)	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Psammothidium acares	0	0	0	0	0	0	0	0	0	0	0	0	7	6
Achnanthes chlidanos	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Achnanthes curtissima	0	0	0	0	6	0	0	0	0	6	6	0	4	0
Achnanthes daonensis	0	0	0	0	0	0	0	0	0	7	1	0	12	1
Eucocconeis flexella	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Achnanthidium kriegeri	0	0	0	0	0	1	0	0	0	1	0	0	10	2
Psammothidium lacus-vulcani/levanderii	0	0	0	0	0	0	0	0	0	35	43	4	90	8
Psammothidium marginulatum	0	0	0	0	0	0	0	0	0	23	16	2	52	5
Achnanthidium minutissimum	105	11	21	29	35	67	48	15	1	2	6	1	16	2
Rossithidium petersenii	0	0	0	0	0	0	0	0	0	3	0	0	3	2
Achnanthes pusilla	17	0	0	0	0	2	0	0	0	12	20	5	49	25
Psammothidium saccula	0	0	0	0	0	0	0	8	0	0	0	0	0	0
Achnanthes suchlandti	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Amphora inariensis	0	0	0	0	0	0	0	0	3	7	0	0	0	0
Aulacoseira distans var humilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira distans var nivaloides	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira tethera	0	0	0	0	0	0	0	0	0	1	1	0	2	0
Caloneis fasciata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	0	0	0	0	0	0	0	0	2	2	0	0	0	0
Cyclotella antiqua	0	0	0	0	0	0	0	2	0	0	0	0	1	0
Cyclotella ocellata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella cleve-eulerae (arctica)	0	0	0	3	1	1	0	0	1	0	0	0	0	0
Cymbella designata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella neocistula	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura angustata	16	2	0	0	1	0	0	2	0	0	0	0	0	0
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura venetaeformis cf	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Encyonema elginense	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema gaeumanii	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema lange-bertalotii/ventricosum	2	0	0	0	1	0	0	0	0	0	0	0	0	0
Encyonema minutum	0	0	0	1	0	0	2	0	0	0	0	0	0	0
Encyonema naviculiformis	0	2	1	0	0	0	1	0	0	1	1	0	0	0
Encyonema reichardtii	2	0	0	0	0	0	0	0	0	1	0	2	0	0
Encyonema silesiacum cf	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis cesatii	1	0	0	0	0	0	0	0	0	0	0	0	2	0
Encyonopsis cesatiformis	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	5	0	2	1	0	0	0	0	0	0	0	0	0	0
Denticula tenuis	2	1	5	0	1	8	3	39	14	0	0	0	2	0
Eunotia arcubus/praerupta	0	0	0	0	0	0	0	0	0	2	1	1	6	1
Eunotia bilunaris cf	0	0	0	0	0	0	0	0	0	2	1	0	4	0
Eunotia monodon var monodon	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia musicola var tridentula	0	0	0	0	0	0	0	0	0	3	1	0	5	2
Eunotia unk sp1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria capucina sensu lato	4	0	0	0	0	0	0	0	0	4	0	0	4	0
Fragilaria delicatissima	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria virescence var exigua	0	0	0	0	0	0	0	0	0	0	2	0	9	2
Fragilaria tenera cf	0	0	0	0	0	0	0	0	0	1	4	0	1	0

APPENDIX G: (continued)

Interval (cm)	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Staurosira construens	0	0	0	0	0	0	0	6	3	0	0	0	0	0
Staurosira construens var venter	88	106	184	352	305	198	25	0	0	6	4	8	19	3
Pseudostaurosira brevistriata	0	0	0	0	0	0	0	7	0	0	0	0	0	0
Pseudostaurosira elliptica	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens KLB	62	101	46	122	160	166	167	318	594	214	7	0	14	0
Pseudostaurosira trainorii cf	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Staurosirella pinnata var pinata	208	346	256	143	65	159	249	45	16	2	4	5	28	3
Staurosirella pinnata var intercedens	0	0	0	1	4	2	0	0	0	0	0	2	4	1
Gomphonema parvulum	0	0	0	0	0	0	0	0	0	1	3	0	1	0
Gomphonema truncatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Adlafia bryophila	9	0	0	13	2	8	9	1	0	2	1	0	4	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula circumborealis	30	12	16	16	29	12	4	0	4	4	0	0	0	0
Navicula cuspidata	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula digitulus	1	1	0	2	0	0	0	7	0	2	1	0	0	2
Navicula expecta	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula ingrata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula minusculoides	0	4	0	0	0	3	0	0	0	0	0	0	0	0
Navicula radiosa	5	0	2	3	2	3	1	0	0	0	0	0	0	0
Navicula schmassmanii	0	0	0	0	0	0	0	0	0	52	24	3	60	13
Navicula seminulum	0	2	0	0	0	0	0	0	0	122	83	35	182	70
Navicula ventralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vincentii cf	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula vulpina	1	1	0	5	2	2	2	4	2	1	0	0	2	1
Cavinula pseudocutiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sellaphora pupula var mutata	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Stauroneis anceps	2	0	0	2	1	2	0	0	0	1	2	0	0	0
Stauroneis neohyalina	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Neidium decoratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neidium distincte-punctatum	0	0	0	0	0	0	0	0	1	5	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	87	80	96	156	88	110	83	203	5	5	2	0	17	0
Nitzschia inconspicua	7	0	4	10	0	2	0	0	0	0	0	0	0	0
Nitzschia perminuta	8	7	9	20	10	14	13	12	0	1	0	0	0	1
Pinnularia intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia interrupta complex	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hygropetra balfouriana	3	1	4	6	6	0	4	7	0	0	1	0	0	0
Tabellaria flocculosa	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Chrysophycean cysts	4	1	2	4	2	2	1	7	7	5	10	4	17	12
Total number of valves	666	681	647	888	719	760	611	678	649	533	237	68	614	154
Number of taxa in interval	24	19	14	22	18	19	15	17	14	36	25	13	35	22
Frustule:Cyst	0.99	1.00	0.99	0.99	0.99	0.99	1.00	0.98	0.98	0.98	0.92	0.89	0.95	0.87
Poorly preserved valves (%)	0.00	0.00	0.15	0.11	0.00	0.00	0.00	0.15	0.31	0.19	0.84	0.00	0.16	1.30

APPENDIX H: Diatom counts for the modern near-shore sediment samples and rock scrapes.

Type of sample	Rock	Rock	Rock	RockS	RockD	Sed	Sed	CSed	Rock	Rock	Sed
Site	Proteus	Proteus	Proteus	Proteus	Proteus	Proteus	Proteus	Proteus	West	West	West
	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake
Year	2009	2007	1983	1987	1987	2009	2007	1998	2009	1987	2009
Psammothidium broenlundense	0	0	0	0	0	0	0	0	0	3	15
Achnanthes chlidanos	2	13	0	8	6	1	109	7	10	9	4
Achnanthes curtissima	0	0	0	0	0	0	0	0	0	0	0
Achnanthes daonensis	0	0	0	0	0	0	0	0	0	6	0
Achnanthes flexella	3	0	0	4	0	0	3	0	5	0	0
Psammothidium helveticum	0	0	0	0	0	0	0	0	0	0	0
Achnanthidium holstii	0	0	0	0	0	0	0	0	0	1	0
Achnanthidium kriegeri	2	7	0	9	4	0	1	7	19	21	0
Psammothidium kryophilum	0	0	0	4	0	0	0	0	2	4	5
Psammothidium lacus-vulcani	0	0	0	0	0	0	0	0	0	2	0
Psammothidium marginulatum	4	6	2	12	15	0	28	0	25	17	5
Achnanthidium minutissimum	278	206	188	103	104	0	22	40	69	62	6
Achnanthes petersenii	12	18	21	73	21	9	3	1	42	15	2
Achnanthes pusilla	0	0	0	0	0	0	0	0	14	28	0
Psammothidium saccula	0	0	0	0	0	0	0	0	0	0	0
Achnanthes scotica	1	0	0	0	2	0	0	0	0	1	0
Psammothidium submuralis	0	0	0	0	0	0	0	0	0	0	0
Achnanthes suchlandti	0	0	0	0	0	0	0	0	10	0	0
Eucocconeis laevis	0	0	0	0	0	0	0	0	0	0	0
Eucocconeis leptostriata	0	0	0	0	0	0	0	0	0	0	0
Amphora copulata	0	0	0	0	0	0	0	0	0	0	0
Amphora inariensis	3	3	2	0	9	53	17	0	4	0	0
Amphora dusenii	0	0	0	0	0	0	0	0	0	0	9
Aulacoseira distans sensu lato	0	0	0	0	3	0	0	0	0	0	0
Caloneis bacillum	0	0	0	0	0	0	0	0	0	0	0
Caloneis fasciata	0	0	0	0	0	0	0	0	6	1	6
Caloneis fusus	0	0	0	0	0	0	0	0	0	7	2
Caloneis lepidula cf	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	0	0	0	0	0	0	0	1	0	0	0
Cyclotella antiqua	0	0	0	0	0	0	0	0	0	0	0
Cyclotella ocellata	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	0	0	0	0	0	0	0	0	24	46	0
Cymbella affinis	0	0	0	0	0	0	0	0	0	0	0
Cymbella botellus	5	34	0	9	3	0	16	0	9	3	0
Cymbella clece-eulerae	0	0	0	0	0	0	0	0	0	0	0
Cymbella latens	0	0	0	1	0	0	0	0	0	0	0
Cymbopleura amphicephala	0	0	0	0	0	0	0	0	0	2	0
Cymbopleura angustata	35	0	106	6	124	4	25	0	0	23	0
Cymbopleura cuspidata	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura fluminea cf	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura aff. *hybrida*	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura stauroneiformis	0	0	0	0	0	0	0	0	0	0	0
Encyonema designata	0	0	0	0	0	0	0	0	0	4	0
Encyonema fogedii	19	44	0	8	8	9	32	0	2	0	0
Encyonema lange-bertalotii/ventricosum	6	2	2	0	0	0	2	0	0	0	0
Encyonema minutum	0	0	1	0	0	3	0	0	2	0	0

APPENDIX H: (continued)

Type of sample	Rock	Rock	Rock	RockS	RockD	Sed	Sed	CSed	Rock	Rock	Sed
Site	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	West Lake	West Lake	West Lake
Year	2009	2007	1983	1987	1987	2009	2007	1998	2009	1987	2009
Encyonema naviculiformis	0	0	0	0	0	0	0	0	3	4	0
Encyonema paucistratum cf	0	0	0	0	0	0	0	0	0	1	0
Encyonema reichardtii	0	0	0	0	0	0	0	0	0	6	0
Encyonema silesciacum cf	0	0	0	0	0	1	0	0	2	0	0
Encyonopsis cesatii	0	0	25	1	0	0	0	0	0	2	0
Encyonopsis descripta	0	0	0	0	0	0	0	0	2	0	0
Encyonopsis microcephala	0	0	0	20	0	0	0	0	0	3	0
Reimeria sinuata	0	0	0	0	0	0	0	0	0	1	0
Denticula tenuis	0	0	0	2	0	0	0	0	0	0	0
Eunotia arcubus	0	0	0	0	0	0	0	0	0	0	0
Eunotia praerupta	0	0	0	0	0	0	0	0	2	0	0
Eunotia musicola var. *tridentula*	0	0	0	0	0	0	0	0	2	0	1
Fragilaria capucina	9	21	1	99	23	0	1	0	68	29	0
Fragilaria exigua var virescence	0	1	0	0	0	0	0	0	0	2	0
Fragilaria perminuta cf	0	0	0	0	0	0	0	0	0	0	0
Fragilaria tenera cf	5	0	0	0	0	0	1	0	0	0	0
Staurosira venter	0	0	10	3	4	0	0	47	4	21	0
Pseudostaurosira brevistriata var. *papillosa*	0	0	0	0	0	0	0	0	3	11	0
Pseudostaurosira pseudoconstruens	0	0	0	0	0	0	0	0	9	0	0
Staurosirella pinnata var pinata	10	4	9	5	38	0	0	95	2	6	0
Staurosirella pinnata var intercedens	26	0	19	2	2	0	0	172	0	0	0
Staurosirella lapponica	0	1	0	0	0	0	0	0	0	0	0
Hannaea arcus	0	0	0	0	0	0	0	0	2	0	1
Frustulia rhomboides var. *saxonica*	0	0	0	0	1	0	0	0	0	0	0
Gomphonema acuminatum	0	0	1	0	0	0	0	0	0	2	0
Gomphonema clavatum cf	0	0	0	0	0	0	0	0	0	0	0
Gomphonema kaweckanum	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum	0	0	2	0	0	0	0	0	1	4	0
Adlafia bryophila	0	0	0	0	0	0	0	0	0	0	15
Brachysira vitrea	0	0	0	0	0	0	0	0	0	0	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0	2	0
Geisseleria boreosiberica cf	0	0	0	0	0	0	0	0	0	1	0
Geisseleria schoenfeldii	0	0	0	0	0	0	0	0	0	0	0
Navicula bjoernoeyaensis	0	0	0	0	0	0	0	0	0	0	15
Navicula cincta	0	0	0	1	0	0	0	0	1	0	6
Navicula cryptocephala	2	0	0	5	0	85	62	0	12	0	9
Navicula digitulus	0	0	0	0	0	0	2	0	0	8	0
Navicula jonssonii	0	0	0	0	0	0	0	0	2	0	2
Navicula ingrata	0	0	0	0	0	0	0	0	0	0	3
Navicula minusculoides	0	0	0	0	0	0	0	0	0	0	0
Navicula phyllepta cf	0	0	0	0	0	5	0	0	0	0	23
Navicula pseudotenelloides	0	0	0	0	0	4	0	0	9	0	112
Navicula schmassmanii	1	0	0	0	2	0	0	0	0	6	0
Sellaphora seminulum	0	0	0	0	0	0	0	0	0	4	1
Navicula variostriata	0	0	0	0	0	0	0	0	2	0	0
Navicula ventralis	0	2	2	4	2	0	24	0	14	0	28
Navicula vulpina	0	0	0	0	0	0	0	0	0	0	0

APPENDIX H: (continued)

Type of sample	Rock	Rock	Rock	RockS	RockD	Sed	Sed	CSed	Rock	Rock	Sed
Site	Proteus	Proteus	Proteus	Proteus	Proteus	Proteus	Proteus	Proteus	West	West	West
	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake
Year	2009	2007	1983	1987	1987	2009	2007	1998	2009	1987	2009
Navicula sp.1	0	0	0	2	0	0	0	0	0	0	0
Cavinula pseudocutiformis	0	0	0	0	0	0	1	0	0	0	0
Cavinula cocconeiformis	0	0	0	1	0	0	0	0	0	0	0
Sellaphora pupula sensu lato	0	0	0	0	0	0	0	0	0	1	0
Stauroneis anceps complex	0	1	0	0	2	0	1	12	1	3	0
Aneumastus tusculus	0	0	0	0	0	0	0	0	0	0	0
Luticola mutica	0	0	0	0	0	0	0	0	4	0	0
Luticola palaearctica	0	0	0	0	0	0	0	0	1	0	0
Luticola ventricosa	0	0	0	0	0	0	0	0	0	0	3
Microcostratus egregius	0	0	0	0	0	0	0	0	1	0	0
Microstatus krasskei	0	0	0	0	0	0	0	0	0	0	0
Neidium affine	0	0	0	0	0	0	0	0	0	0	0
Neidium bergii	0	0	0	0	0	0	0	0	0	0	0
Neidium decoratum	0	0	3	0	0	0	0	0	0	0	0
Neidium distincte-punctatum	0	0	0	0	1	3	0	0	0	0	0
Neidium septentrionale	0	0	0	0	0	0	0	0	0	0	0
Neidium sp.1	0	0	0	0	0	0	0	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	0	0	0
Nitzschia denticula	0	0	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	0	0	0	0	0	0	0	0	0	0	0
Nitzschia frustulum	2	0	0	1	2	5	2	0	1	5	0
Nitzschia homburgiensis	0	0	0	0	0	0	0	0	0	0	0
Nitzschia inconspicua	0	0	0	0	0	0	0	0	0	0	0
Nitzschia palea	0	0	0	2	2	5	3	1	2	2	0
Nitzschia perminuta	74	23	42	78	134	209	85	13	31	6	24
Nitzschia pusilla	0	0	0	0	0	0	0	0	0	0	0
Hantzschia abundans	0	0	0	0	0	0	0	0	1	0	0
Pinnularia brebissonii	0	0	0	0	0	0	0	0	3	0	0
Pinnularia gibba var. mesogongyla cf	0	0	0	0	0	0	0	0	0	0	0
Pinnularia humilis	0	0	0	0	0	0	0	0	0	0	0
Pinnularia intermedia	0	0	0	0	0	0	0	0	0	0	0
Pinnularia interrupta	0	0	0	0	0	2	0	0	3	2	0
Pinnularia microstauron cf	0	0	0	0	0	0	0	0	2	0	0
Pinnularia obscura	0	0	0	0	0	0	0	0	0	0	0
Pinnularia perrinterrupta	0	0	0	0	0	0	0	0	0	0	3
Pinnularia sp.1	0	0	3	0	0	0	0	0	0	0	0
Chamaepinnularia gandrupii	0	0	0	25	0	0	0	1	5	0	5
Muelleria gibbula	0	0	0	0	0	2	0	0	0	0	0
Muelleria latima	0	0	0	0	0	0	0	0	0	0	0
Muelleria linearis	0	0	0	0	0	0	0	0	0	0	0
Hygropetra balfouriana	0	0	0	1	14	0	0	2	0	1	0
Tryblionella debilis	1	0	0	0	0	0	0	0	0	0	0
Tabellaria flocculosa	1	2	3	20	2	0	2	0	0	2	0
Diploneis oculata	0	0	0	0	0	0	0	0	3	0	0
Diatoma tenuis	0	0	0	1	0	0	0	0	0	0	0
Amphipleura kriegeriana	0	0	0	0	0	0	0	0	0	0	0
Total number of valves	501	388	443	510	528	400	442	399	441	391	305
Number of taxa	24	18	21	32	27	16	22	17	48	49	26

APPENDIX H: (continued)

Type of sample	Rock	Rock	Rock	RockS	RockD	Sed	Sed	CSed	Rock	Rock	Sed
Site	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	Proteus Lake	West Lake	West Lake	West Lake
Year	2009	2007	1983	1987	1987	2009	2007	1998	2009	1987	2009
Total number of cysts	34	34	88	62	208	4	7	184	95	153	2

APPENDIX H: (continued)

Type of sample	Sed	Sed	Rock	Rock	Sed	Sed	Rock	Rock	Rock	Rock	Sed	Sed
Site	West Lake	West Lake	260 m Lake	260 m Lake	260 m Lake	260 m Lake	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond
Year	1987	1983	2009	1987	1987	1983	2009	2007	2001	1998	2007	2004
Psammothidium broenlundense	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes chlidanos	7	14	26	6	5	51	0	0	0	4	0	0
Achnanthes curtissima	0	0	0	0	0	1	0	0	0	0	0	0
Achnanthes daonensis	0	0	0	0	2	11	0	0	0	0	0	0
Achnanthes flexella	0	0	2	0	0	0	0	1	1	5	0	1
Psammothidium helveticum	2	0	2	7	4	63	0	0	0	0	0	2
Achnanthidium holstii	0	2	2	3	0	0	0	0	0	0	0	0
Achnanthidium kriegeri	0	0	32	88	192	9	0	0	0	0	0	0
Psammothidium kryophilum	6	0	8	110	214	184	0	0	0	12	0	0
Psammothidium lacus-vulcani	0	0	0	0	0	0	0	0	0	0	0	0
Psammothidium marginulatum	107	28	72	9	0	7	0	0	1	0	0	0
Achnanthidium minutissimum	97	8	18	28	1	2	163	68	52	49	25	65
Achnanthes petersenii	25	2	42	5	4	3	24	0	21	0	0	4
Achnanthes pusilla	2	0	0	1	0	0	0	0	0	0	0	0
Psammothidium saccula	0	0	0	0	0	1	0	0	0	0	0	0
Achnanthes scotica	0	0	1	0	87	126	0	0	0	0	0	0
Psammothidium submuralis	0	5	0	0	0	0	0	0	0	0	0	0
Achnanthes suchlandti	0	0	0	1	0	0	0	0	0	0	0	0
Eucocconeis laevis	0	8	2	0	0	0	0	0	0	0	0	0
Eucocconeis leptostriata	0	0	0	0	0	0	0	0	0	0	0	1
Amphora copulata	0	0	0	0	0	0	1	0	0	2	0	0
Amphora inariensis	0	0	0	0	0	0	0	0	0	0	0	0
Amphora dusenii	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira distans sensu lato	0	0	0	0	1	3	0	0	0	0	0	0
Caloneis bacillum	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis fasciata	0	7	0	0	0	0	0	0	0	0	0	0
Caloneis fusus	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis lepidula cf	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis silicula	8	4	0	0	0	0	0	0	0	0	0	6
Cyclotella antiqua	0	0	0	0	0	0	0	3	0	0	1	2
Cyclotella ocellata	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	4	5	25	102	14	2	0	0	0	0	0	0
Cymbella affinis	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella botellus	24	53	0	1	0	0	78	49	85	33	44	14
Cymbella clece-eulerae	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella latens	0	0	0	0	0	0	0	0	0	3	0	0
Cymbopleura amphicephala	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura angustata	33	33	0	2	0	0	0	1	0	0	0	1
Cymbopleura cuspidata	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura fluminea cf	0	2	0	0	0	0	0	0	0	0	0	0
Cymbopleura aff. *hybrida*	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura incerta	0	0	0	0	0	0	0	0	0	0	0	0
Cymbopleura stauroneiformis	1	0	0	0	0	0	0	0	0	0	0	0
Encyonema designata	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema fogedii	6	0	0	0	0	0	55	22	46	0	6	10
Encyonema lange-bertalotii/ventricosum	4	7	0	0	0	0	0	0	0	0	0	0
Encyonema minutum	3	0	0	0	0	0	7	0	1	60	0	0

APPENDIX H: (continued)

Type of sample	Sed	Sed	Rock	Rock	Sed	Sed	Rock	Rock	Rock	Rock	Sed	Sed
Site	West Lake	West Lake	260 m Lake	260 m Lake	260 m Lake	260 m Lake	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond
Year	1987	1983	2009	1987	1987	1983	2009	2007	2001	1998	2007	2004
Encyonema naviculiformis	0	0	0	0	0	0	0	0	0	0	3	0
Encyonema paucistratum cf	0	0	0	0	0	0	0	0	0	0	0	0
Encyonema reichardtii	1	0	0	2	0	0	0	0	0	0	0	0
Encyonema silesciacum cf	1	1	0	0	0	0	1	0	2	4	0	0
Encyonopsis cesatii	0	0	0	2	0	0	0	0	0	2	0	2
Encyonopsis descripta	1	0	0	0	0	0	0	0	0	0	0	0
Encyonopsis microcephala	0	2	0	0	0	0	47	92	41	21	65	26
Reimeria sinuata	0	0	0	0	0	0	0	0	0	0	0	0
Denticula tenuis	0	0	0	2	0	0	11	68	20	0	36	9
Eunotia arcubus	0	0	0	0	0	1	0	0	0	0	0	0
Eunotia praerupta	0	0	1	7	0	1	5	2	0	2	2	26
Eunotia musicola var. *tridentula*	0	0	1	1	2	0	0	0	0	0	0	0
Fragilaria capucina	51	0	20	11	1	0	33	12	30	25	2	16
Fragilaria exigua var virescence	0	0	0	3	0	0	0	0	0	0	0	0
Fragilaria perminuta cf	0	0	0	1	0	0	0	0	0	0	0	0
Fragilaria tenera cf	1	0	0	5	0	0	0	0	0	0	0	0
Staurosira venter	8	0	0	1	0	0	0	0	0	0	0	0
Pseudostaurosira brevistriata var. *papillosa*	2	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens	1	0	0	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var pinata	0	0	1	4	0	0	0	0	0	0	0	0
Staurosirella pinnata var intercedens	0	0	0	0	0	0	0	0	0	0	0	0
Staurosirella lapponica	0	0	0	0	0	0	0	0	0	0	0	0
Hannaea arcus	0	0	0	0	0	0	0	0	0	0	0	0
Frustulia rhomboides var. *saxonica*	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema acuminatum	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema clavatum cf	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema kaweckanum	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum	7	0	0	2	0	0	0	2	0	0	0	0
Adlafia bryophila	0	19	0	2	0	0	0	0	0	0	0	0
Brachysira vitrea	0	0	0	0	0	0	0	0	0	0	0	0
Diadesmis gallica	0	0	0	0	0	2	0	0	0	0	0	0
Geisseleria boreosiberica cf	0	0	0	0	0	0	0	0	0	0	0	0
Geisseleria schoenfeldii	0	0	0	0	0	0	0	0	0	0	0	0
Navicula bjoernoeyaensis	0	0	0	0	0	0	0	0	0	0	0	0
Navicula cincta	0	0	0	0	0	0	0	0	0	0	0	0
Navicula cryptocephala	0	56	0	0	0	0	0	2	2	0	2	8
Navicula digitulus	0	2	0	4	0	0	0	0	0	0	0	0
Navicula jonssonii	0	0	0	0	0	0	0	0	0	0	0	0
Navicula ingrata	1	90	0	0	0	0	0	0	0	1	0	0
Navicula minusculoides	0	0	0	0	0	0	0	0	0	0	0	0
Navicula phyllepta cf	0	0	0	0	0	0	0	0	0	0	0	0
Navicula pseudotenelloides	0	0	0	2	0	0	0	0	0	15	0	0
Navicula schmassmanii	2	4	3	20	4	11	0	0	0	0	0	0
Sellaphora seminulum	4	0	0	2	0	0	0	0	0	0	0	0
Navicula variostriata	0	0	0	0	0	0	0	0	0	0	0	0
Navicula ventralis	4	10	1	6	0	8	4	0	6	0	0	0
Navicula vulpina	0	3	0	0	0	0	0	5	0	5	0	7

APPENDIX H: (continued)

Type of sample	Sed	Sed	Rock	Rock	Sed	Sed	Rock	Rock	Rock	Rock	Sed	Sed
Site	West Lake	West Lake	260 m Lake	260 m Lake	260 m Lake	260 m Lake	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond
Year	1987	1983	2009	1987	1987	1983	2009	2007	2001	1998	2007	2004
Navicula sp.1	0	0	0	0	0	0	0	0	0	0	0	0
Cavinula pseudocutiformis	0	0	0	0	0	0	0	0	0	2	0	0
Cavinula cocconeiformis	0	0	0	0	0	0	0	0	0	0	0	0
Sellaphora pupula sensu lato	3	0	0	0	0	0	0	0	0	0	0	0
Stauroneis anceps complex	2	36	0	0	0	3	0	0	0	1	0	0
Aneumastus tusculus	0	0	0	0	0	0	0	0	0	0	0	4
Luticola mutica	0	0	0	0	0	0	0	0	0	0	0	0
Luticola palaearctica	0	0	0	0	0	0	0	0	0	0	0	0
Luticola ventricosa	0	0	0	0	0	0	0	0	0	0	0	0
Microcostratus egregius	0	0	0	0	0	0	0	0	0	0	0	0
Microstatus krasskei	0	0	0	0	0	0	0	0	0	0	0	0
Neidium affine	0	0	0	0	1	0	0	0	0	0	0	0
Neidium bergii	0	18	0	0	0	0	0	0	0	0	0	0
Neidium decoratum	0	0	0	0	0	0	0	0	0	0	0	0
Neidium distincte-punctatum	0	0	2	0	0	0	0	2	0	0	1	2
Neidium septentrionale	0	6	0	0	0	0	0	0	0	0	0	0
Neidium sp.1	0	6	0	0	0	0	0	0	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	0	0	1	1
Nitzschia denticula	0	0	0	0	0	0	6	4	2	0	1	11
Nitzschia fonticola	1	0	0	0	0	0	0	0	0	0	0	0
Nitzschia frustulum	0	0	6	1	0	0	0	0	0	7	0	0
Nitzschia homburgiensis	0	0	0	0	0	1	0	0	0	0	0	0
Nitzschia inconspicua	6	2	0	2	0	0	0	0	0	3	0	0
Nitzschia palea	0	11	0	0	0	0	0	0	0	0	0	0
Nitzschia perminuta	100	67	30	1	1	7	120	228	305	426	285	261
Nitzschia pusilla	0	0	0	0	0	0	0	0	0	0	0	0
Hantzschia abundans	0	0	1	0	0	0	0	0	0	0	0	0
Pinnularia brebissonii	0	0	0	0	0	1	0	0	0	0	0	0
Pinnularia gibba var. mesogongyla cf	0	0	2	0	0	0	0	0	0	0	0	0
Pinnularia humilis	0	0	0	0	0	0	0	0	0	2	0	0
Pinnularia intermedia	0	0	7	3	0	10	0	0	0	0	0	0
Pinnularia interrupta	0	2	0	3	0	0	0	0	2	0	0	0
Pinnularia microstauron cf	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia obscura	0	8	0	0	0	0	0	0	0	0	0	0
Pinnularia perrinterrupta	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia sp.1	0	0	0	0	0	0	0	0	0	0	0	0
Chamaepinnularia gandrupii	0	0	0	0	0	0	0	0	0	0	0	0
Muelleria gibbula	0	0	0	1	0	0	0	0	0	0	0	0
Muelleria latima	0	0	0	0	0	0	0	0	0	0	0	0
Muelleria linearis	0	0	0	0	0	0	0	0	0	0	0	0
Hygropetra balfouriana	37	0	20	0	0	3	0	0	0	16	0	44
Tryblionella debilis	0	0	0	0	0	0	0	0	0	0	0	0
Tabellaria flocculosa	0	1	0	1	0	0	4	17	8	6	7	5
Diploneis oculata	0	0	0	0	0	0	0	0	0	0	0	0
Diatoma tenuis	0	0	0	0	0	0	14	1	24	21	0	2
Amphipleura kriegeriana	0	0	0	0	0	0	0	0	0	0	0	0
Total number of valves	564	524	328	452	533	511	573	579	649	727	481	530
Number of taxa	36	33	27	40	15	24	16	18	19	26	15	26

APPENDIX H: (continued)

Type of sample	Sed	Sed	Rock	Rock	Sed	Sed	Rock	Rock	Rock	Rock	Sed	Sed
Site	West Lake	West Lake	260 m Lake	260 m Lake	260 m Lake	260 m Lake	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond	Greely Pond
Year	1987	1983	2009	1987	1987	1983	2009	2007	2001	1998	2007	2004
Total number of cysts	27	9	76	264	22	14	4	13	14	10	6	2

APPENDIX H: (continued)

Type of sample	Sed	Rock	Sed	Rock	Sed	Rock	Rock	Rock	Sed
Site	Greely Pond	P1 Pond	P1 Pond	P3 Pond	P3 Pond	H Pond	North Pond	North Pond	North Pond
Year	1998	1998	1998	1998	1998	1983	1983	2009	2009
Psammothidium broenlundense	0	0	0	0	0	9	0	0	17
Achnanthes chlidanos	44	11	32	0	0	0	0	0	3
Achnanthes curtissima	0	0	0	0	0	0	0	0	0
Achnanthes daonensis	0	0	0	0	0	0	0	0	0
Achnanthes flexella	4	0	0	0	0	2	0	0	0
Psammothidium helveticum	4	5	6	0	0	4	0	1	0
Achnanthidium holstii	0	0	0	0	0	3	0	0	0
Achnanthidium kriegeri	0	0	0	0	0	0	0	0	0
Psammothidium kryophilum	9	0	0	0	0	17	0	0	15
Psammothidium lacus-vulcani	0	0	0	0	0	0	0	0	0
Psammothidium marginulatum	2	7	13	2	0	2	1	0	29
Achnanthidium minutissimum	121	2	0	171	27	228	285	113	96
Achnanthes petersenii	9	140	5	118	3	18	0	2	12
Achnanthes pusilla	0	0	0	0	0	0	0	0	0
Psammothidium saccula	0	0	0	0	0	0	0	0	0
Achnanthes scotica	0	0	0	0	0	0	0	0	1
Psammothidium submuralis	0	0	0	0	0	0	0	0	0
Achnanthes suchlandti	0	0	0	0	0	0	0	0	0
Eucocconeis laevis	0	5	0	0	0	0	0	0	0
Eucocconeis leptostriata	0	0	0	0	0	0	0	0	0
Amphora copulata	0	0	0	0	0	0	0	0	0
Amphora inariensis	2	0	0	0	0	0	0	0	4
Amphora dusenii	0	0	0	0	0	0	0	0	4
Aulacoseira distans sensu lato	0	0	0	0	0	0	0	0	0
Caloneis bacillum	0	2	2	0	0	0	0	0	0
Caloneis fasciata	0	0	0	0	0	0	0	0	4
Caloneis fusus	0	0	0	0	0	0	0	0	0
Caloneis lepidula cf	0	0	0	0	0	0	0	0	0
Caloneis silicula	6	0	5	0	0	0	0	0	0
Cyclotella antiqua	0	0	0	0	0	0	0	2	0
Cyclotella ocellata	0	0	0	0	0	0	0	0	0
Cyclotella radiosa	0	0	0	0	0	0	0	0	0
Cymbella affinis	0	0	0	0	0	0	0	0	1
Cymbella botellus	8	0	0	29	23	30	74	54	13
Cymbella clece-eulerae	0	0	0	0	0	0	2	2	0
Cymbella latens	6	2	1	0	0	0	0	0	0
Cymbopleura amphicephala	0	0	0	0	0	0	0	0	7
Cymbopleura angustata	3	2	2	45	69	0	7	0	0
Cymbopleura cuspidata	2	0	0	0	0	0	0	0	1
Cymbopleura fluminea cf	0	0	0	0	0	0	0	0	0
Cymbopleura aff. *hybrida*	0	0	0	0	0	0	0	0	10
Cymbopleura incerta	0	0	0	0	0	0	0	0	4
Cymbopleura stauroneiformis	0	0	0	0	0	0	0	0	0
Encyonema designata	0	0	0	0	0	1	0	0	0
Encyonema fogedii	9	0	0	99	101	0	0	137	33
Encyonema lange-bertalotii/ventricosum	2	0	0	0	0	0	0	0	5
Encyonema minutum	16	0	0	0	0	0	15	0	2

APPENDIX H: (continued)

Type of sample	Sed	Rock	Sed	Rock	Sed	Rock	Rock	Rock	Sed
Site	Greely	P1	P1	P3	P3	H	North	North	North
	Pond	Pond	Pond	Pond	Pond	Pond	Pond	Pond	Pond
Year	1998	1998	1998	1998	1998	1983	1983	2009	2009
Encyonema naviculiformis	0	0	0	0	0	0	0	0	2
Encyonema paucistratum cf	0	0	0	0	0	0	0	0	0
Encyonema reichardtii	0	0	0	0	0	0	0	0	0
Encyonema silesciacum cf	2	0	0	0	0	0	0	0	2
Encyonopsis cesatii	2	0	0	0	0	19	8	25	14
Encyonopsis descripta	0	0	0	0	0	0	2	0	0
Encyonopsis microcephala	9	1	0	0	0	17	0	47	21
Reimeria sinuata	0	0	0	0	0	0	0	0	0
Denticula tenuis	0	0	0	0	0	0	1	6	9
Eunotia arcubus	0	0	0	0	0	0	0	0	0
Eunotia praerupta	1	3	0	0	0	0	0	2	2
Eunotia musicola var. *tridentula*	0	0	0	0	0	0	0	0	0
Fragilaria capucina	11	5	8	0	0	0	0	3	0
Fragilaria exigua var virescence	0	0	0	0	0	4	0	0	0
Fragilaria perminuta cf	0	0	0	0	0	0	0	0	0
Fragilaria tenera cf	0	0	0	0	0	0	0	0	0
Staurosira venter	0	0	0	0	0	0	0	0	0
Pseudostaurosira brevistriata var. *papillosa*	0	0	0	0	0	0	0	0	0
Pseudostaurosira pseudoconstruens	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var pinata	0	0	0	0	0	0	0	0	0
Staurosirella pinnata var intercedens	0	0	0	0	0	0	0	0	0
Staurosirella lapponica	0	0	0	0	0	0	0	0	0
Hannaea arcus	0	0	0	0	0	0	0	0	0
Frustulia rhomboides var. *saxonica*	0	0	0	0	0	0	0	0	0
Gomphonema acuminatum	0	0	0	0	0	0	0	0	0
Gomphonema clavatum cf	0	0	0	0	0	2	0	0	0
Gomphonema kaweckanum	0	0	0	0	0	0	0	0	1
Gomphonema parvulum	0	0	0	0	0	6	0	0	1
Adlafia bryophila	2	0	0	0	0	0	0	2	20
Brachysira vitrea	0	0	0	0	0	0	1	0	0
Diadesmis gallica	0	0	0	0	0	0	0	0	0
Geisseleria boreosiberica cf	0	0	0	0	0	0	0	0	0
Geisseleria schoenfeldii	0	0	0	0	0	0	0	0	4
Navicula bjoernoeyaensis	0	0	0	0	0	0	0	0	0
Navicula cincta	0	0	0	0	0	0	0	0	2
Navicula cryptocephala	78	0	0	0	0	0	0	2	18
Navicula digitulus	0	0	0	0	0	0	8	0	2
Navicula jonssonii	0	0	0	0	0	0	0	0	0
Navicula ingrata	5	0	0	0	0	0	0	0	0
Navicula minusculoides	0	0	0	0	0	0	0	0	6
Navicula phyllepta cf	0	0	0	0	0	0	0	0	0
Navicula pseudotenelloides	0	0	0	0	0	0	0	0	0
Navicula schmassmanii	0	0	0	0	0	0	2	0	0
Sellaphora seminulum	0	0	0	0	0	0	0	0	0
Navicula variostriata	0	0	0	0	0	0	0	0	0
Navicula ventralis	2	7	147	0	0	0	2	0	18
Navicula vulpina	3	0	0	0	0	0	1	0	0

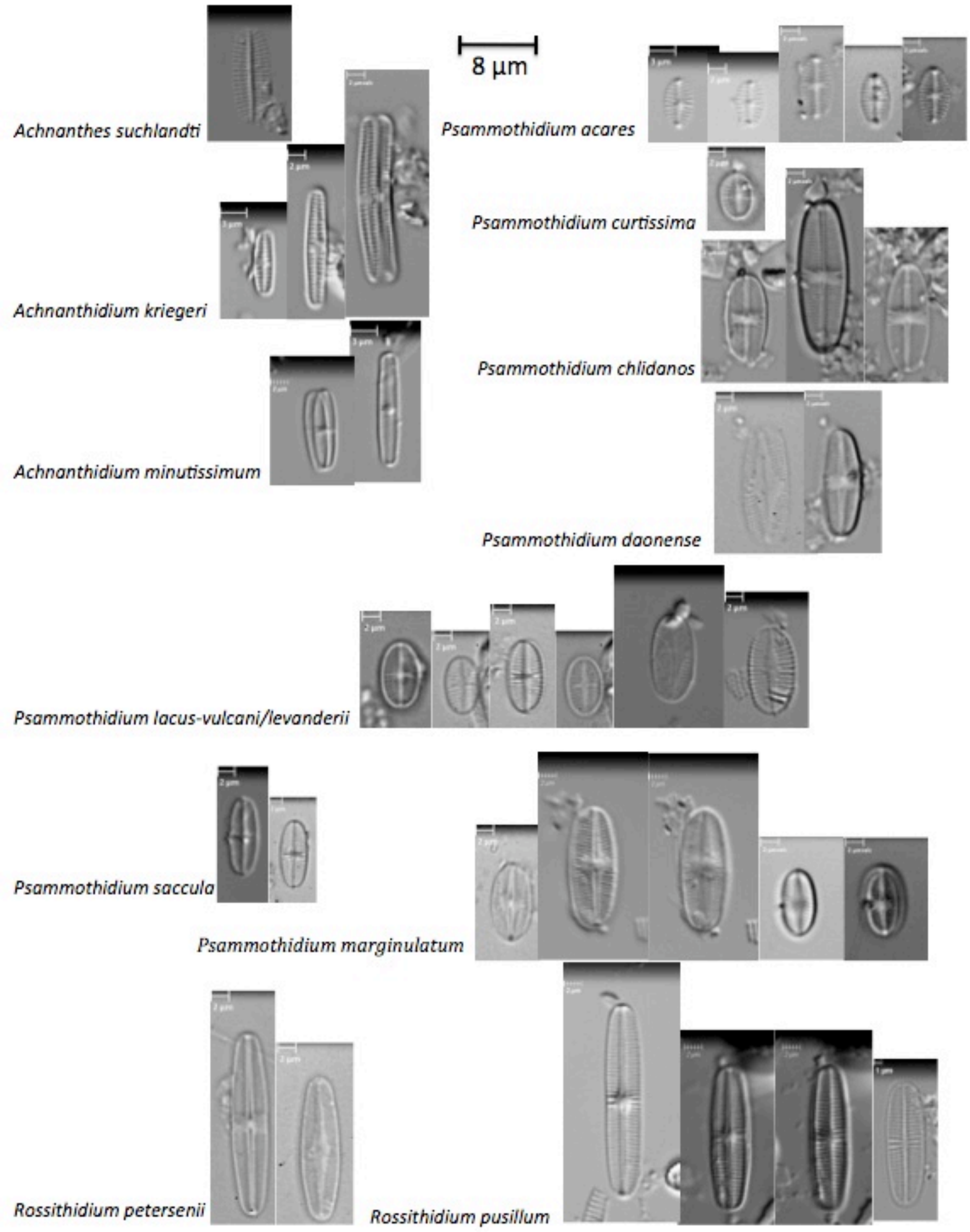
APPENDIX H: (continued)

Type of sample	Sed	Rock	Sed	Rock	Sed	Rock	Rock	Rock	Sed
Site	Greely Pond	P1 Pond	P1 Pond	P3 Pond	P3 Pond	H Pond	North Pond	North Pond	North Pond
Year	1998	1998	1998	1998	1998	1983	1983	2009	2009
Navicula sp.1	0	0	0	0	0	0	0	0	0
Cavinula pseudocutiformis	2	0	0	0	0	0	0	0	0
Cavinula cocconeiformis	0	0	0	0	0	0	0	0	0
Sellaphora pupula sensu lato	0	0	0	0	0	0	0	0	0
Stauroneis anceps complex	2	32	14	0	0	2	1	0	1
Aneumastus tusculus	2	0	0	0	0	0	0	0	0
Luticola mutica	0	0	0	0	0	0	0	0	0
Luticola palaearctica	0	0	0	0	0	0	0	0	0
Luticola ventricosa	0	0	0	0	0	0	0	0	0
Microcostratus egregius	0	0	0	0	0	0	0	0	0
Microstatus krasskei	2	0	0	0	0	0	0	0	0
Neidium affine	0	0	0	0	0	0	0	0	0
Neidium bergii	0	0	0	0	0	0	0	0	0
Neidium decoratum	0	0	0	0	0	0	0	0	3
Neidium distincte-punctatum	0	0	0	0	0	0	0	0	1
Neidium septentrionale	0	0	0	0	0	0	0	0	0
Neidium sp.1	0	0	0	0	0	0	0	0	0
Nitzschia alpina	0	0	0	0	0	0	0	0	0
Nitzschia denticula	0	0	0	0	0	0	0	0	0
Nitzschia fonticola	0	0	0	0	0	0	2	0	0
Nitzschia frustulum	0	0	0	0	0	0	0	2	0
Nitzschia homburgiensis	0	0	0	0	0	0	0	0	0
Nitzschia inconspicua	0	0	0	0	0	0	1	0	0
Nitzschia palea	3	7	32	4	23	0	0	2	2
Nitzschia perminuta	153	92	23	5	1	47	74	142	72
Nitzschia pusilla	4	0	0	0	0	0	0	0	0
Hantzschia abundans	0	10	15	0	0	0	0	0	1
Pinnularia brebissonii	0	0	0	0	0	0	0	0	0
Pinnularia gibba var. mesogongyla cf	0	0	0	0	0	0	0	0	0
Pinnularia humilis	0	0	0	0	0	0	0	0	0
Pinnularia intermedia	0	5	0	0	0	0	0	0	1
Pinnularia interrupta	2	2	0	0	0	1	0	0	0
Pinnularia microstauron cf	0	0	0	0	0	0	0	0	0
Pinnularia obscura	0	0	0	0	0	0	0	0	0
Pinnularia perrinterrupta	0	0	0	0	0	0	0	0	0
Pinnularia sp.1	0	0	0	0	0	0	0	0	0
Chamaepinnularia gandrupii	0	0	0	0	0	0	0	0	0
Muelleria gibbula	0	22	87	0	0	0	0	0	1
Muelleria latima	0	2	0	0	0	0	0	0	0
Muelleria linearis	0	0	6	0	0	0	0	0	2
Hygropetra balfouriana	18	0	0	0	0	0	0	0	0
Tryblionella debilis	0	0	0	0	0	0	0	0	0
Tabellaria flocculosa	2	0	0	0	0	0	0	0	0
Diploneis oculata	0	0	0	0	0	0	0	0	0
Diatoma tenuis	2	0	0	0	0	0	0	0	0
Amphipleura kriegeriana	0	0	0	0	0	0	0	0	1
Total number of valves	555	364	398	473	247	414	487	544	468
Number of taxa	38	22	17	8	7	18	18	18	44

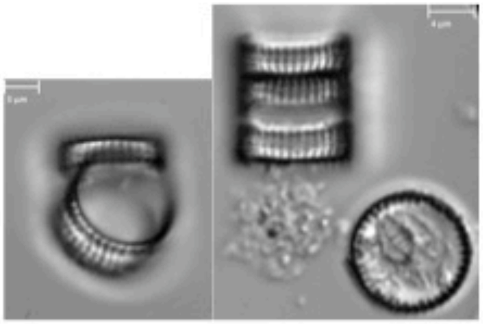
APPENDIX H: (continued)

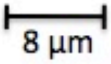
Type of sample	Sed	Rock	Sed	Rock	Sed	Rock	Rock	Rock	Sed
Site	Greely Pond	P1 Pond	P1 Pond	P3 Pond	P3 Pond	H Pond	North Pond	North Pond	North Pond
Year	1998	1998	1998	1998	1998	1983	1983	2009	2009
Total number of cysts	5	9	2	4	3	188	12	3	0

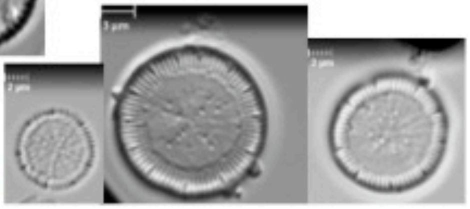
APPENDIX I: Differential interference contrast microphotographic plates of the main taxa found in the modern assemblages at Pim Island and in the sedimentary profiles from West Lake and 260 m Lake.



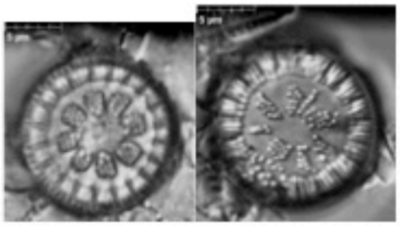
APPENDIX I: (continued)


Aulacoseira tethera

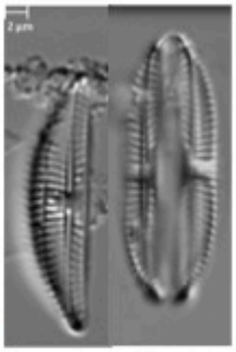



Cyclotella radiosa

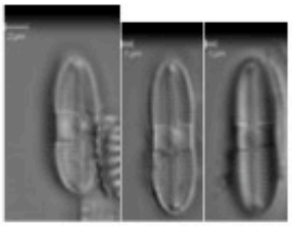

Aulacoseira distans



Cyclotella antiqua



Amphora inariensis


Caloneis fasciata

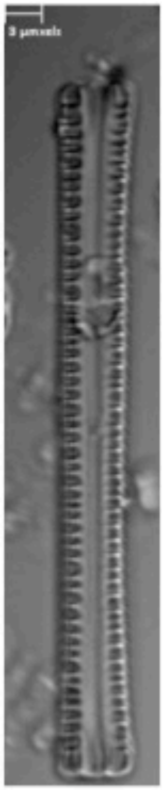
Caloneis silicula

APPENDIX H: (continued)

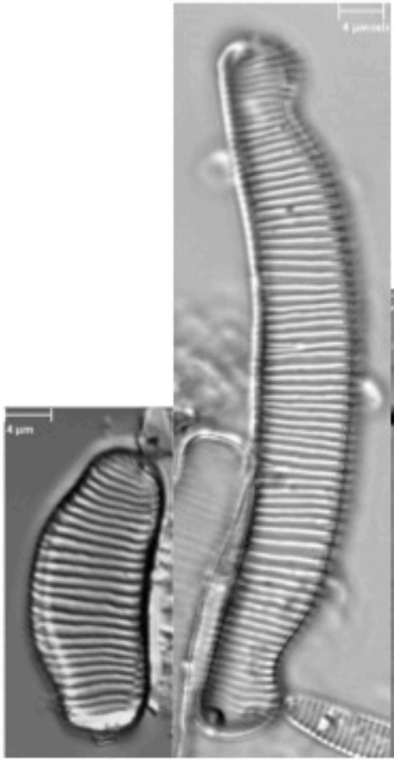
Denticula tenuis

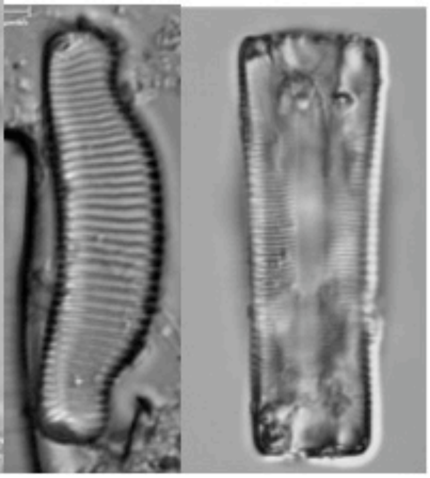
8 µm

Eunotia musicola var tridentula



Diatoma tenuis

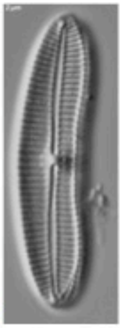


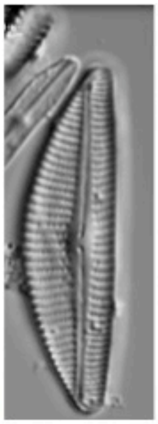


Eunotia arcubus/praerupta

APPENDIX I: (continued)


Cymbopleura angustata

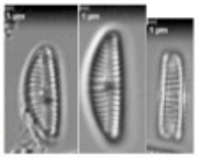

Cymbopleura incerta

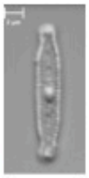

Encyonema elginese

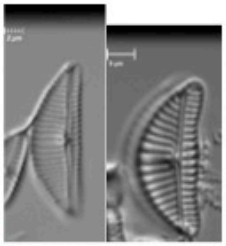
8 µm

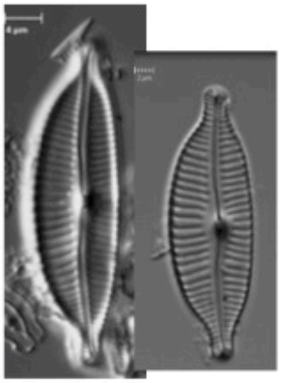

Encyonema silesciacum

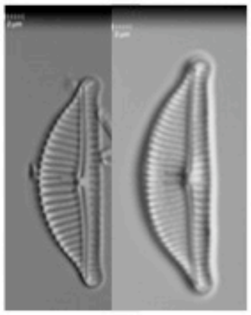

Cymbella cleve-eulerae

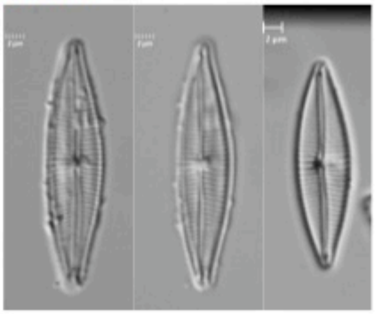

Encyonema reichardtii

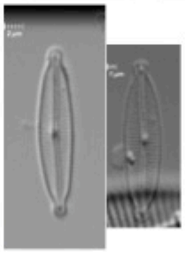

Encyonema gaeumanii


Encyonema minutum

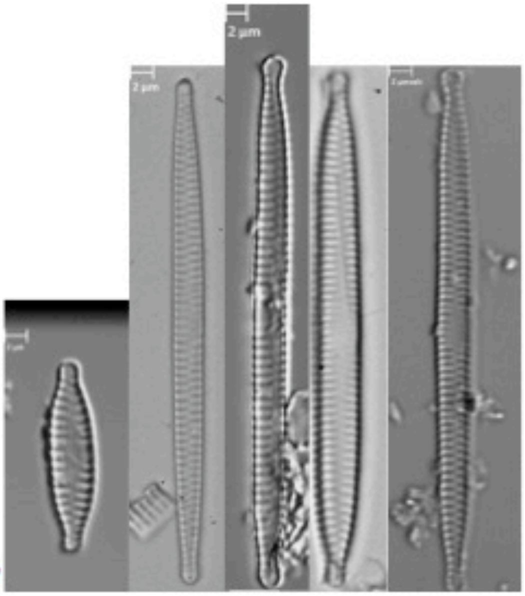

Encyonema naviculiformis


Encyonema lange-bertalotii /ventricosum

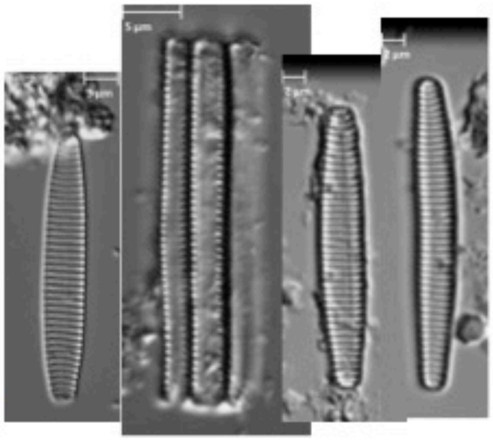

Encyonopsis cesatii


Encyonopsis microcephala

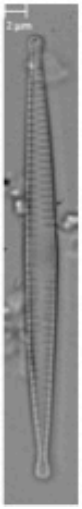
APPENDIX I: (continued)



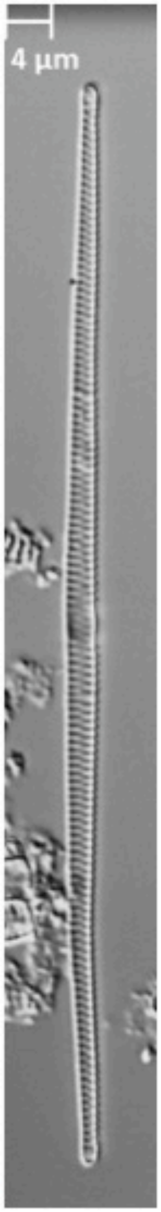
Fragilaria capucina sensu lato



Fragilariforma virescens



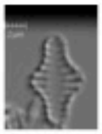
Fragilaria delicatissima



Fragilaria tenera

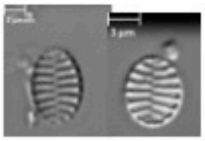
APPENDIX : (continued)

Staurosira construens

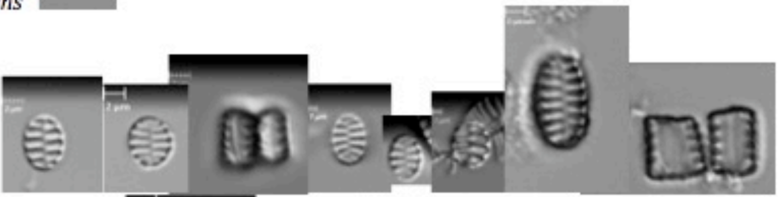


Staurosirella pinnata var. *intercedens*

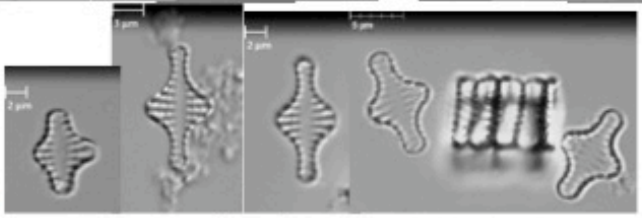
Staurosira construens var. *venter*



Staurosirella pinnata var. *pinata*

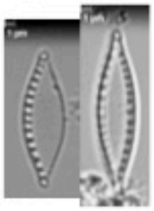


Pseudostaurosira pseudoconstruens

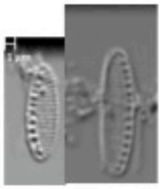


Nitzschia alpina

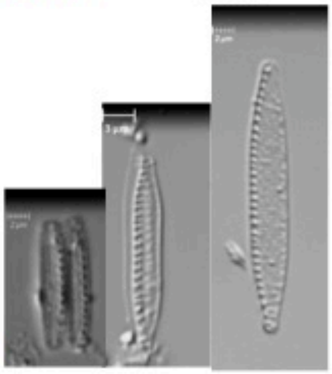
Nitzschia fonticola



Nitzschia inconspicua



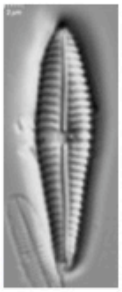
Nitzschia perminuta



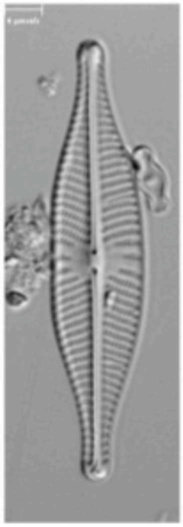
8 µm

APPENDIX I: (continued)

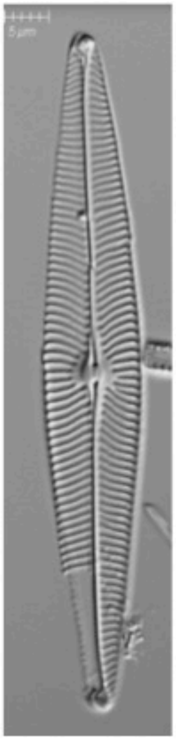
8 µm



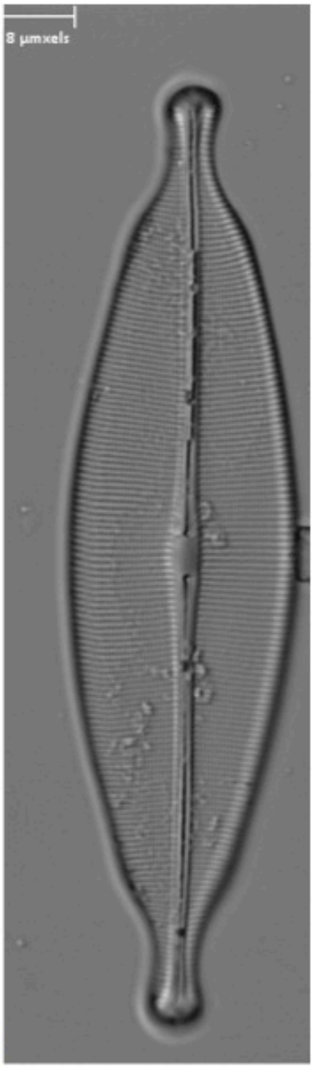
Gomphonema parvulum



Navicula expecta



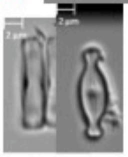
Navicula radiosa



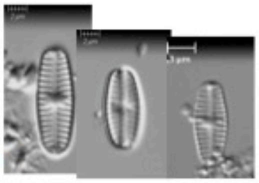
Navicula cuspidata

Adlafia bryophila

Sellaphora pupula var mutata

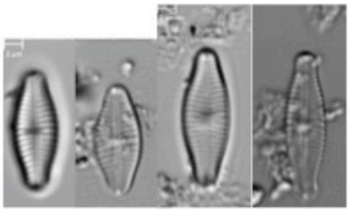


Navicula schmassmannii

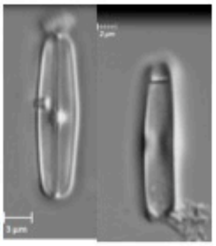


Sellaphora seminulum

Navicula bacillum



Navicula circumborealis

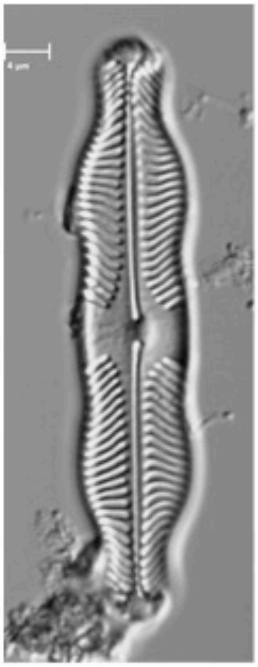


Naviculadicta digitulus

APPENDIX I: (continued)

8 µm


Pinnularia intermedia

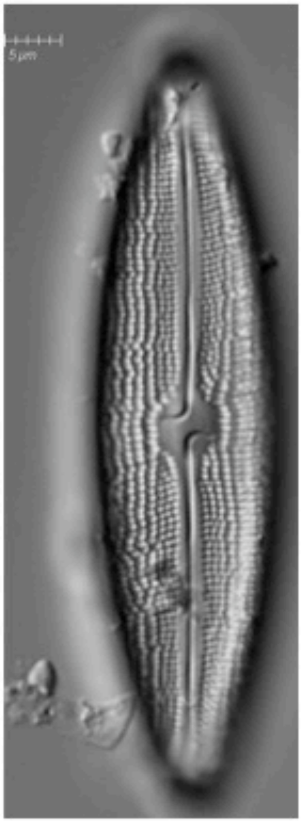


Pinnularia interrupta/grunowii complex


Hygroptera balfouriana


Tabellaria flocculosa

Stauroneis anceps



Neidium decoratum