University of Alberta

A PALEOLIMNOLOGICAL ASSESSMENT OF ENVIRONMENTAL CHANGE IN EIGHT NORTHEASTERN ALBERTA LAKES

By

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ABSTRACT

Ecological studies conducted in apparently pristine ecosystems throughout the world have shown that these systems are being altered as an unconsidered consequence of human activities. A paleoecological examination of eight lake ecosystems located along a north-south transect through the northern Alberta boreal ecoregion was conducted using siliceous microfossil and geochemical proxies. The structure of microfossil assemblages has undergone substantial shifts in some of the study lakes, but remains largely unaltered in others. This heterogeneous ecological response suggests that the effects of these stressors are mediated on a local scale, by processes occurring in the lake and drainage basin. This proximal mediation of environmental stressors is particularly important in relation to surface water acidification. Although the rate of acid deposition associated with bitumen extraction and processing has increased substantially over the past thirty years, there is so far no indication that this has caused acidification of any of the study lakes.

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PREFACE TO THE THESIS

This thesis was first conceived as an investigation into the variability of acid sensitivity in northeastern Alberta lakes of low alkalinity. The intent was to buttress modelling efforts, which at the time of this writing are being conducted to estimate the flux of acid anions and base cations through these lakes and their catchments. We have also undertaken to examine potential causes of limnological change that is apparently unrelated to acidification, but has clearly occurred in several of the study lakes. This research was conducted primarily with funding received from the Cumulative Environmental Management Association (CEMA), an initiative of government, industry, and community members that addresses environmental issues related (primarily) to petroleum extraction in northeastern Alberta.

This thesis is in paper format, and consists of four chapters. The first is a general introduction, which includes some background on some of the research conducted to date in northeastern Alberta, with specific reference to acid deposition. This chapter was written primarily for the benefit of researchers and committee members involved in the ongoing work of the NO_x-SO_x Management Working Group under CEMA. The second and third chapters specifically address the primary data, and the fourth is a conclusion with recommendations for further study.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: General introduction

This study is intended primarily to provide information to resource managers in northern Alberta on the history of a selected group of lakes in the Athabasca oil sands airshed, with specific respect to pH and related variables (e.g. alkalinity). In order to assess the susceptibility of these lakes to acid deposition, their acid sensitivities must be evaluated against current and potential volumes of atmospheric acid flux. Certain assumptions must therefore be drawn regarding the present capacity of the lakes to neutralise acids, and the variability of this capacity in time. It is also important to consider whether these lakes have already become acidified, or whether current acid neutralising capacity reflects a true baseline value. We use paleolimnological techniques to address these assumptions. These techniques are particularly suited in this regard, as the ecological proxy that we use to assess changes in the study lakes is widely considered to be very sensitive to pH and, by extension, to alkalinity. We begin by summarising, in part, the current state of knowledge of rates of acid deposition in the region, and of the susceptibility of surface waters to acidification.

A relatively small proportion (<5%) of Alberta lakes are considered to be acid sensitive, with alkalinities of less than 10 $mg{\cdot}L^{-1}$ $CaCO_3$ (Saffran and Trew 1996). These lakes tend to be geographically constrained to the peatland-dominated northeastern upland regions, the Canadian Shield, and the Rocky Mountains. The acid sensitivity of lakes within these regions is highly variable, owing primarily to catchment geology, recharge characteristics, and cation sequestration in sphagnum-dominated wetlands (Erickson 1987; Halsey *et al.* 1997). In the northern upland and Canadian Shield regions, alkalinity is derived both from the influx of base cations, a significant proportion of which are generated by cation exchange resulting from the oxidation of sulphur mobilised within the catchment (Erickson 1987), and from the biological reduction of sulphate. As a result, sulphate and carbonate are the dominant anions in many of these lakes. Peatlands are the major source of organic acidity in the upland lakes, where peatland cover can approach 85% per 100 km^2 (Halsey *et al.* 1996). The acidifying influence of peatlands is evident in the dark staining of many north-eastern Alberta lakes, and occurs by cation exchange and by the contribution of humic and fulvic acids resulting from the decay of peatland vegetation.

Acidifying emissions

The intensifying exploitation of oil sands deposits in north-eastern Alberta has led to the emergence of acid deposition as a source of acidity to lakes in the region. Estimates of nitrogen and sulphur emissions from oil sands extraction and processing activities, based on existing production capacity, exceed 384 t/d NO_x (NO and NO_2) and 246 t/d SO_2 (Albian Sands Energy Inc. 2005). Actual SO_2 emissions are substantially higher, as reported SO_2 emissions compiled over the region from the National Pollutant Release Inventory (NPRI) were 20% higher in 2004 (296 $T \bullet day^{-1}$) than the 2005 projections. These values reflect a significant increase in SO_2 and NO_x emissions over the past 30 years. Nitrogen emissions in particular have increased by nearly an order of magnitude since 1970 (16.5 t/d NO_x), while sulphur emissions reached a maximum of 495 t/d SO_2 in 1980, and have since declined (Golder Associates Ltd. 2002). The recent decline in sulphur emissions is largely due to improvements in pollution control infrastructure, most notably the implementation in 1996 of flue gas desulphurisation (FGD) at the Suncor generating plant that resulted in a significant decline in sulphur emissions. Notwithstanding these recent reductions, cumulative sulphur emissions from all existing and approved projects, as well as those that are planned or pending approval, could approach 298 t/d SO_2 (Albian Sands Energy Inc. 2005). This represents a 20% increase over present (2005) levels.

The geometric increase in nitrogen emissions since the early 1990s reflects increased production levels as well as a shift in oil sands extraction operations to a diesel-fuelled mobile mining fleet (Suncor Energy Ltd. 1998). Under the projected development scenario, the present level of nitrogen emissions is expected to increase by 40%, to 538 t/d NOx (Albian Sands Energy Inc. 2005).

Acid deposition

Deposition of nitrogen and sulphur oxidation products occurs either by scavenging and subsequent deposition as liquid water and ice (wet deposition), or by interaction of particles and gasses with fog droplets, dust, aerosols, and surface features such as vegetation (dry deposition). The importance of the dry deposition of sulphate (SO_4^{2-}) in the Fort McMurray region, determined through modelling, exceeds that of wet deposition by a factor of 3.18 (Kociuba 1984). Caiazza *et al.* (1978) derived a similar figure of 4.8, relative to atmospheric nutrient deposition in central Alberta.

Experimental studies emphasise the importance of dry deposition in the region. In a study of sulphur deposition conducted at fifteen sites in the oil sands region, Nyborg *et al.* (1985) found that sulphate deposition from throughfall and stemflow was substantially greater than from wet deposition alone. Average annual SO_4^{2-} in throughfall and stemflow in 1976, recalculated from Nyborg *et al.* (1985) by Bronaugh (1993), was approximately 30.6 $kg{\cdot}h^{-1}{\cdot}1yr^{-1}$ SO_4^{2-}. Subtraction of SO_4^{2-} in wet deposition from throughfall and stemflow gives an average dry deposition of 26.2 $kg{\cdot}h^{-1}{\cdot}1yr^{-1}$ SO_4^{2-}, from which is derived a ratio for dry to wet deposition of 6.0. Although slightly higher than the ratios derived by Kociuba (1984) and Caiazza (1978), the ratio derived from the experimental study of Nyborg *et al.* (1985) shows the relative importance of dry deposition. Experimental figures for nitrate (NO_2^-) deposition have not been reported.

The acidifying potential of wet and dry deposition is a function of charge balance. Strong mineral acid cations derived from atmospheric pollutants (SO_4^{2-}, HNO_3^-) are balanced by base cations, typically as mineral carbonates in dust (e.g. calcite and dolomite) and as NH_4^+ from terrestrially-derived NO_3^{2-} (Stumm and Morgan 1996). The remainder of the balance is achieved by the dissociation of protons or by the dissolution of CO_2 as CO_3^{2-} and HCO_3^-. An excess of strong acids, determined by charge balance, is expressed as acidity; an excess of carbonate species is expressed as alkalinity. Acidifying potential is equivalent to H-acidity (mineral acidity), which in turn is characterised as negative alkalinity.

Alberta Environment has adopted potential acid input (PAI) as an expression of acidifying potential (Cheng *et al.* 1997). PAI is a simple mass balance calculation of the proton (H^+) equivalence of base cations (Na^+,

Mg^{2+}, Ca^{2+}, K^+, and NH_4^+) and strong acids (SO_4^{2-} and NO_3^-) in wet and dry deposition, and is synonymous with H-acidity. This expression was adopted by the target loading subgroup of the Clean Air Stategic Alliance (CASA) in the establishment of acid loading guidelines for Alberta, as a means by which to evaluate the acidifying potential of industrial emissions (Target Loading Subgroup 1996; Alberta Environment and Clean Air Strategic Alliance 1999). The expression used by CASA is modified from a similar approach used in the estimation of atmospheric acid loads in European countries (Erismann *et al.* 1995), but excludes Cl- ions, which are associated predominantly with sea spray.

Wet deposition of sulphate and nitrate is determined from precipitation chemistry. There are two precipitation chemistry monitoring stations in the region, one near Fort McMurray and the other near Fort Chipewyan. Samples collected at these stations by automated precipitation collectors are retrieved weekly for analyses of acidity and major ions. Average wet deposition of sulphate in Fort McMurray ($4.9\ kg{\cdot}h^{-1}{\cdot}1yr^{-1}$), calculated from precipitation chemistry, was among the highest in the province in 1996, while nitrate deposition ($2.3\ kg{\cdot}h^{-1}{\cdot}1yr^{-1}$) was relatively low. Potential acid input at Fort McMurray was 0.09 $keq{\cdot}h^{-1}{\cdot}1yr^{-1}$. The acidity of precipitation collected near Fort McMurray appears to have increased by an order of magnitude between 1985 and 1996, as evidenced by a decrease from pH 5.8 in 1985 to 4.9 in 1996 (Myrick and Hunt 1998). However, it is unclear whether this apparent change reflects a regional trend. Bronaugh (1993) points out that from 1977 to 1986, the precipitation collector was located at the Fort McMurray airport, where dust from unpaved roads likely contaminated the samples. Base cations in the dust may have contributed unrepresentative amounts of alkalinity, thus artificially elevating the pH in precipitation samples. Nonetheless, the average pH of precipitation collected at Fort McMurray in 1996 (pH=4.9) was the lowest of eleven monitoring sites located throughout the province (Myrick and Hunt, 1998). The average pH of precipitation in 1996 at Fort Chipewyan was 5.3.

While wet deposition may be characterised by precipitation volume and chemistry, dry deposition is contingent on surface factors, and cannot be measured explicitly. Dry deposition occurs through the interaction of a surface (e.g. soil surface, leaf surface, water surface) with the surrounding air. The intensity of dry deposition is controlled by turbulent diffusion near the surface, as well as by the chemical, physical, and biological properties of the surface itself. These factors are difficult to duplicate in a measuring device, although dry deposition is sometimes reported as that fraction which can be lifted from a surface. Measurement of through-fall, for example using ion exchange resins or precipitaton collectors, is generally considered to be more representative of actual dry or total deposition. Estimates of dry deposition are often derived by inferential modelling of measured aerial concentrations of gasses and aerosols. The models incorporate local meteorological factors and surface characteristics to produce estimates that are very much site-specific.

The Wood Buffalo Environmental Association (WBEA) recently published estimates of dry deposition for the ten Terrestrial Environmental Effects Monitoring (TEEM) passive monitoring stations located in the oil sands region, and for an additional passive monitor, co-located with WBEA continuous monitoring equipment near Fort MacKay (EPCM Associated Ltd. 2002). The estimates were derived from monthly integrated measurements of SO_2 and NO_2 obtained in 1999 and 2000 by passive monitors using a numerical model (TEEMDEP) developed for the WBEA. Because of the surface specificity associated with dry deposition, model estimates were derived for different receptors, characterised by vegetation type and density. The range of average yearly dry deposition in 1999-2000 at the ten TEEM sites, given as the total proton (H^+) equivalence of strong acids and base cations (potential acid input, or PAI), was estimated as 0.109 $keq \cdot h^{-1} \cdot 1yr^{-1}$ to 0.337 $keq \cdot h^{-1} \cdot 1yr^{-1}$, at sites respectively characterised by deciduous forest (east of Fort McMurray) and medium density coniferous forest (west of Fort MacKay). Average dry deposition for all eleven sites was 0.210 $keq \cdot h^{-1} \cdot 1yr^{-1}$.

Of the PAI in dry deposition estimated from data collected by the eleven passive monitors, approximately 80% was due to sulphur deposition, while the remainder (20%) was due to nitrogen deposition. Annual average SO_4^{2-} in dry deposition ranged from 2.43 $kg \cdot h^{-1} \cdot 1yr^{-1}$ (Saskatchewan, east of Fort McMurray) to 9.4 $kg \cdot h^{-1} \cdot 1yr^{-1}$ (north-west of Fort McMurray) with an overall average of 5.31 $kg \cdot h^{-1} \cdot 1yr^{-1}$, while annual average NO_3^- ranged from 0.53 $kg \cdot h^{-1} \cdot 1yr^{-1}$ (Saskatchewan, esst of Fort McMurray) to 5.95 $kg \cdot h^{-1} \cdot 1yr^{-1}$ (Fort MacKay) with an overall average of 1.63 $kg \cdot h^{-1} \cdot 1yr^{-1}$. These values are substantially less than the values measured in 1976 by Nyborg et al (1985), from which Bronaugh (1993) derived estimates for dry deposition of SO_4^{2-} at an average of approximately 26.2 $kg{\cdot}h^{-1}{\cdot}1yr^{-1}$, with a range of 2.7 $kg{\cdot}h^{-1}{\cdot}1yr^{-1}$ to 74.8 $kg{\cdot}h^{-1}{\cdot}1yr^{-1}$. While the locations of the TEEM passive monitoring sites and the study sites used in the Nyborg *et al.* (1985) study do not correspond, both studies are representative of the same general area. Given that SO_2 emissions in 1976 (251 t/d) were only slightly lower than in 1999 (261.6 t/d) and 2000 (265.6 t/d; Golder Associates Ltd. 2002), this discrepancy should be addressed.

Deposition modelling

Deposition modelling has also been conducted in the oil sands region using the Regional Lagrangian Acid Deposition (RELAD) model. RELAD, a dispersion and transport model, was run using meteorological and emissions data for 1990 (Cheng and Angle 1993). There is substantial discrepancy between the predictions of total acid input in the Fort McMurray area (112° longitude, 56° latitude) generated by RELAD and those generated from site-specific monitoring data using the TEEMDEP model. Total acid deposition, expressed in proton (H^+) equivalents, for the entire Fort McMurray area predicted by the RELAD model for 1990 (0.05-0.1 $keq{\cdot}h^{-1}{\cdot}1yr^{-1}$) falls below both the average (0.210 $keq{\cdot}h^{-1}{\cdot}1yr^{-1}$) and the minimum (0.109 $keq{\cdot}h^{-1}{\cdot}1yr^{-1}$) dry deposition predicted by the TEEMDEP model for TEEM passive monitoring sites in 1999-2000. Given that total SO_2 and NO_x emissions were substantially higher in 1990 (436.5 t/d) than in 1999 (323 t/d) and 2000 (340.7 t/d; Golder Associates Ltd. 2002), it appears either that the RELAD model under-predicts the intensity of acid deposition, or that the TEEMDEP figures are excessive. Because the computational grid for the RELAD model is limited to intervals of 1° latitude by 1° longitude, point source emissions are averaged over a very large area. The coarse grid resolution therefore tends to under-represent the intensity of pollutants within the cells in which pollutants are generated, and to over-represent the intensity of pollutants in cells over which pollutants are dispersed (Petro-Canada 1999). This may in part be the source of the apparent discrepancy.

The most recently published assessment of the deposition of NO_x and SO_2 emitted by extraction and processing activities in the oil sands region was conducted for the Albian Sands (Shell Canada) Muskeg River Mine expansion project (Albian Sands Energy Inc. 2005). The assessment was conducted using

CALPUFF 3-D, an explicitly spatial, non-steady-state (dynamic) dispersion model with the capability to characterise wet and dry deposition of oxidised sulphur and nitrogen compounds. Although RELAD also simulates wet and dry partitioning of sulphur and nitrogen oxides, its computational grid is limited to areas of 1° latitude by 1° longitude, and to three vertical layers. In contrast, the size of the computational grid for CALPUFF simulations is effectively unlimited, such that its resolving power is much greater than that of RELAD. The meteorological grid spacing established for the CNRL simulation in CALMET, the CALPUFF meteorological pre-processor, was set at 5 km with ten vertical layers. Output from the CALPUFF model was generated at intervals that varied from 20 m to 15 km, according to the proximity of sources.

The CALPUFF simulation was conducted over a 160, 000 km^2 area (the modelling domain) extending from Cold Lake to the Northwest Territories, and well into Saskatchewan. The large modelling domain was used as a buffer to reduce edge effect within the 'regional study area' of 195 km by 270 km, established within the modelling domain to contain the 0.17 keq $H^+ \cdot ha^{-1} \cdot yr^{-1}$ PAI isopleth. Sulphur and nitrogen emissions from sources existing and approved as of 2005 form the basis for the simulation of present levels of acidifying deposition. This level of emissions is equivalent to licensed emissions limits than can occur without any further regulatory approval, and may not be realised for several years. While this approach is appropriate in the context of regulatory approval it precludes model validation, as observed data for the simulation period are not obtainable. Validation is therefore limited to a comparison of results to those generated using other models. Such a circular validation process is of dubious value.

In addition to local SO_2 and NO_x emissions, the Albian Sands simulation was conducted against a background of acidifying emissions originating from sources outside of the study area, simulated using the RELAD model based on a provincial emissions inventory for 1995. Ambient concentrations of base cations, used in the calculation of PAI, were inferred from precipitation chemistry monitoring stations in the region.

The Albian Sands simulation was conducted using meteorological data for the 1995 calendar year collected at meteorological stations within the modelling domain and generated using the Fifth-Generation NCARR/Penn State Mesoscale Model (MM5), a continental scale meteorological model. The selection of the 1995 calendar year was a practical consideration, as MM5 wind field modelling was conducted for this year only. There is, however, no discussion in the Albian Sands application of the degree to which the 1995 calendar year is representative of meteorological conditions in other years. The proponents (Albian Sands Energy Inc. 2005) indicate that precipitation was slightly greater in 1995 than the long-term average, but do not address the presumed effects that this may have on the intensity and extent of acid deposition. Similarly, while wind conditions simulated for 1995 correspond well to observed conditions, no information is provided that would place these conditions in a long-term context.

Acid neutralising capacity

Acid neutralising capacity (ANC) is a measure of the capacity of a system to resist an increase in strong acidity, that is, an increase in free protons (decrease in pH) when titrated to a given end point with a strong acid. In natural aquatic systems, ANC is measured as alkalinity, defined as the capacity of a system to absorb protons when titrated to the point of equivalence between $[HCO_3^-]$ and $[H^+]$ (Stumm and Morgan 1996).

The generation and depletion of alkalinity in aquatic systems can be defined as the charge balance between conservative cations and anions, the remainder of which is attributed to carbonate species (Stumm and Morgan 1996). In this sense, alkalinity is analogous (but opposite) to potential acid input (PAI) resulting from acid deposition. An increase in base cation concentrations resulting from catchment weathering, atmospheric deposition, or diffusion from sediments results in a shift in the charge balance and a subsequent shift in the carbonate equilibrium in favour of increased HCO_3^- and CO_3^{2-}. Contributions from cations such as iron and manganese are negligible in an oxidising environment as they are quickly precipitated. An influx of strong acid anions results in a decreased concentration of carbonate species and a corresponding decrease in alkalinity.

Alkalinity is also modulated by the generation or consumption of H^+ and OH^- through biological and redox processes (Table 1.1). Notwithstanding its contribution to the positive side of the charge balance equation, the addition of the NH_4^+ cation causes a net decrease in alkalinity through nitrification. Conversely, the decrease in alkalinity caused by addition of the SO_4^{2-} anion is moderated by biological sulphate reduction, which, by the consumption of protons, is an alkalinity generating process.

Table 1.1. H^+ and OH^- generating/consuming processes. (adapted from Stumm and Morgan 1996)

Net primary production and decomposition (algal biomass is represented as a Redfield molecule $\{(CH_2O)_{106}(NH_3)_{16}H_3PO_4\}$*):*

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \rightarrow \{(CH_2O)_{106}(NH_3)_{16}H_3PO_4\} + 138O_2$$

$$106CO_2 + 16NH_4^+ + HPO_4^{2-} + 108H_2O \rightarrow \{(CH_2O)_{106}(NH_3)_{16}H_3PO_4\} + 107O_2 + 14H^+$$

Nitrification:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$

Denitrification:

$$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 5CO_2 + 2N_2 + 7H_2O$$

Sulphide oxidation:

$$HS- + 2O_2 \rightarrow SO_4^{2-} + H^+$$

$$FeS_2(s) + \frac{15}{4}O_2 + \frac{7}{2}H_2O \rightarrow Fe(OH)_3(s) + 4H^+ + 2SO_4^{2-}$$

Sulphate reduction:

$$SO_4^{2-} + 2CH_2O + H^+ \rightarrow 2CO_2 + HS^- + H_2O$$

$CaCO_3$ dissolution:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$

Experimental manipulation of these processes at the Experimental Lakes Area (ELA) in north-western Ontario has been used to investigate their relative contributions to total alkalinity. In an alkalinity budget prepared for Lake 239, internal alkalinity generation (64 $keq \cdot yr^{-1}$) exceeded alkalinity derived from the catchment (55 keq·yr^{-1}), indicating that internal processes were a major source of alkalinity (Schindler *et al.* 1986). Of the internal alkalinity generating processes, sulphate reduction contributed the major portion (53%), followed by sedimentary $CaCO_3$ dissolution (39%) and NO_3^- reduction (26%). The nitrification of ammonia generated by the decomposition of organic matter was the most important alkalinity consuming process (-18%). The addition of H_2SO_4 to Lake 223, a lake similar to Lake 239 in the predominance of internal alkalinity generating processes, caused a substantial increase in microbial sulphate reduction, to the extent that sulphate reduction accounted for 92% of internal alkalinity generation (Schindler *et al.* 1979; Schindler *et al.* 1986). The anoxia in Lake 223 sediments also permitted the mobilisation of ferrous iron and the precipitation of iron monosulphide, the formation of which is an alkalinity generating (proton consuming) process(Cook *et al.* 1986; Schindler and Turner 1982). The increased rate of denitrification in Lake 302 N following the addition of HNO_3 substantially increased the generation of alkalinity associated with that process, such that the added acidity was effectively neutralised (Schindler 1985).

Humic acids also contribute acid neutralising capacity, although their contribution is generally only significant at low pH, where carbonate alkalinity has been consumed. Their contribution depends on the dissociation of acid functional groups, the activity of which varies widely. A certain fraction act as strong acids, readily dissociating and causing darkly stained lakes to be more acid sensitive than clear lakes with equivalent base cation concentrations. Other functional groups are weak acids, acting as proton sponges and thus contributing acid neutralising capacity. In addition to the wide variation in the activity of acid functional groups, the conformation of the parent molecule affects the activity of a given functional group, as does the polyelectrolytic nature of the parent molecule which, as it acquires protons, becomes more positively charged and therefore more resistant to the further acquisition of protons (Stumm and Morgan 1996).

While it is generally agreed that the direct contribution of humic acids to acid neutralising capacity is low, their indirect contribution in sediments is more important. The experimental acidification of limnocorral enclosures in dystrophic lake 114 and oligotrophic lake 302 with H_2SO_4, HNO_3, and HCL showed that accumulated organic material in sediments plays a significant role in the generation of acid neutralising capacity (Schiff and Anderson 1987). Although Lake 114 has significantly less water column alkalinity than Lake 302, once water column acidity was depleted, Lake 114 was more efficient in neutralising added acidity. This was due primarily to the release of NH_4^+ from the sediments of Lake 114. Although nitrification is an acidity generating process, its importance was apparently negligible; therefore, the net effect of an increased sediment NH_4^+ flux was to increase basic cation concentrations in the water column. Schiff and Anderson (1987) indicate that the increase in water column NH_4^+ may have been an experimental artefact. Nonetheless, their experiment indicates the importance of sediment processes in acid neutralisation, suggesting that water column ANC determinations are not necessarily good indicators of acid sensitivity.

Critical loads

In the context of acidifying deposition, alkalinity and acidity generating processes are evaluated relative to some benchmark to define a critical load. The critical load is the amount of acid loading, typically expressed as $keq \cdot ha^{-1} \cdot yr^{-1}$, that will bring about a threshold condition, the exceedence of which will overwhelm the capacity of a system to mitigate the harmful effects of acid loading. The threshold condition for aquatic systems is typically defined relative to pH or base saturation. As such, the critical load is not a rigorously defined concept.

The broad application of critical loads in Alberta relates to soil sensitivity, on the assumption that acid neutralising capacity in surface waters reflects that of the surrounding catchment (Schindler 1996; Target Loading Subgroup 1996, Foster *et al.* 2001). This application is a component of the acid deposition management framework under Alberta's Clean Air Strategic Alliance (CASA), the purpose of which is to guide research and management efforts in areas most likely to be affected by acid deposition. The critical loads adopted by CASA are derived using a steady state mass balance model, on the basis of the establishment in soils of a time-independent equilibrium between acids and bases (Posch *et al.* 1995). They are defined in relation to soil acidity and texture classes, and range from < 0.25 to > 1.5 $keq \cdot ha^{-1} \cdot yr^{-1}$ (WHO 1994). The loads established for interim use in Alberta were adopted based on the contention that mineral soils in Alberta are no more sensitive to acidifying deposition than are European soils (Maynard 1996). Based on the WHO (1994) guidelines, the critical loads for Alberta are: <0.25 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ in sensitive areas, <0.5 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ in moderately sensitive areas, and 1.0 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ in areas of low sensitivity.

The sensitivity classes used in the evaluation of critical loading in Alberta are established from maps that define the sensitivity of topsoils to acidification, and the capacity of subsoils to neutralise acidity (Holowaychuk and Fessenden 1987). Sensitivity classes are applied over areas of 1° latitude by 1° longitude, and represent the most sensitive soils that occupy a minimum of 5% of the total area (Alberta Environment and Clean Air Strategic Alliance 1999). The oil sands area is predominantly classified as sensitive (critical load < 0.25 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$), with the exception of the more resistant areas of the Peace and Slave River floodplain (critical load = 0.5 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$). This is consistent with soil critical load modelling conducted by Syncrude Canada Ltd. (1998) using the ForSust steady-state mass balance model, from which critical loads of 0.21 to 0.69 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ were derived.

The critical loads adopted for the oil sands region are based on soil sensitivity, and as such are not explicitly protective of aquatic systems. Following the adoption of the interim critical loads by the Target Loading Subgroup (1996), Environment Canada employed a series of mass balance models, all variants of the Cation Denudation Rate (CDR) model and the Trickle Down (TD) model, to evaluate the response of 105 lakes to SO_4^{2-} loads of 6.0 to 30 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ (0.12 to 0.72 keq $H^+\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$), relative to pH thresholds of 6.0, 5.5, and 5.0 (Jeffries 1997). All of the models effectively apply a precipitation mass balance approach to inputs of cations and strong acids, but differ in their approach to the organic content of receiving waters (Lam *et al.* 1992; Western Resource Solutions 2000). The SO_4^{2-} loads relative to the pH thresholds of 6.0, 5.5, and 5.0 were shown to be relatively invariant, suggesting that once the pH 6 threshold is exceeded, there will be little residual ANC in the system. While relatively few lakes in the oil sands region are likely to become acidified under SO_4^{2-} loads of < 6 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$, the impacts on the sensitive lakes may be severe. The population of 105 lakes was relatively insensitive to changes in the simulated SO_4^{2-} loads of 6.0 to 30 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$. This indicates that while a small proportion of lakes (~7%) are sensitive to SO_4^{2-} loads of < 6 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$, a large proportion are highly resistant. Under the interim critical load of 0.25 $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$, approximately 8% of lakes are unprotected. In the context of the Environment Canada modelling this is a conservative figure, as lakes that were already below the pH thresholds are excluded (Jeffries 1997). As approximately 5% of lakes in the area have a pH of <7 (Saffran and Trew 1996), and assuming that 5% of the 105 lakes were excluded from the Environment Canada analysis, the proportion of lakes that are unprotected (at a threshold of pH=6) by a critical load of 0.25 keq$\cdot$ha$^{-1}\cdot$yr^{-1} could be as high as 12%.

Because of the soil specificity of the critical loads presently in force in Alberta, critical loads in recent environmental impact assessments have also been calculated for individual water bodies. These loads are calculated using the Steady State Water Chemistry (SSWC) model (Henricksen *et al.* 1992). The SSWC model differs from the precipitation mass balance approach used in the Environment Canada study (Jefferson 1997), in that it is explicitly based on existing water chemistry data, and has recently been modified to account for the buffering effects of organic acids (RAMP 2005). The SSWC approach permits evaluation of acid loading against a threshold condition. The threshold adopted by the NOx-SOx Management Working Group for northeastern Alberta lakes is a pH of 6.0, taken to be the pH below which many species of freshwater fish exhibit a chronic stress response (ESSA 1987, AENV 1990). Although this approach has limited ecological significance in the context of lakes that are fishless or are naturally acidic, it has provided a reasonable relative measure of acid sensitivity, in units that permit direct comparison with acid loading estimates. By this approach, 25 (52%) of the 48 acid sensitive lakes had critical loads of less than the 0.25 keq$\cdot$ha$^{-1}\cdot$yr^{-1} critical loading limit for sensitive areas (RAMP 2005). As well, 17 (35%) of the 48 acid sensitive lakes had critical loads below the CALPUFF modelled acid deposition rate, indicating incipient acidification (RAMP 2005).

In addition to the critical loads, target and monitoring loads have been selected for the purpose of emissions management. The target loading concept effectively affords resource managers the full latitude of the political process in the establishment of loading guidelines. Presently, target loads are set at 90% of critical loads, although these figures are subject to revision (Alberta Environment and Clean Air Strategic Alliance 1999; Foster *et al.* 2001). The monitoring load is determined as the 70% fraction of the critical load, which for sensitive systems has been set at a PAI of 0.25 keq $H^{+}\cdot$ha$^{-1}\cdot$yr^{-1}. Exceedence of the 0.17 keq $H^{+}\cdot$ha$^{-1}\cdot$yr^{-1}

monitoring load would impel a more intensive evaluation on the part of Alberta Environment of the sensitivity of an area to acidifying deposition. The monitoring load is effectively a trigger for validation of model predictions, its numerical value being somewhat arbitrary.

Acid sensitivity

Since 1966, a large volume of water chemistry data has been generated for an extensive suite of lakes in the oil sands region. From an early survey of 20 lakes in the region for the Alberta Oil Sands Environmental Research Program (AOSERP), Hesslein (1979) concluded that terrestrially-derived carbonates were the major contributors to alkalinity. A simple water balance model was also developed to assess the effect of acid titration on the alkalinity of the 20 survey lakes. On the basis of this model, Hesslein (1979) argued that even the most weakly buffered lake (0.34 $meq \cdot l^{-1}$) was unlikely to be affected by precipitation with a pH greater than four.

On the initiative of the Technical Committee on Western Canada - Long Range Transport of Atmospheric Pollutants (LRTAP), extensive sensitivity maps were prepared for Alberta lakes by Erickson (1987), on the basis of calcium concentrations, pH, and alkalinity. Erickson found that the most potentially sensitive lakes are situated in alpine areas, and in north-central and north-eastern Alberta. Erickson characterised the north-eastern Alberta lakes according to four geographic zones, lumping several physiographic zones on the basis of basin geology. Lakes that occurred in the Canadian Shield region generally had low calcium concentrations, but variable alkalinity. This was attributed primarily to contributions of magnesium salts. The shield lakes had varying acid sensitivities, but it was noted that since the bedrock is not easily weathered, the watershed would have little moderating effect on the acidity of deposition. The Wood Buffalo region, located along the western plain of the Slave River and in the Athabasca River delta, contains lakes that are strongly bicarbonate or sulphate buffered, with a predominance of calcium and/or magnesium cations. The chemical composition of these lakes is strongly groundwater-influenced. The Caribou Mountain region, located west of the Wood Buffalo region, contains lakes set in old slump features. Lakes on the plateau are predominantly bicarbonate buffered, some being potentially sensitive, while lakes on the slopes are strongly buffered by the oxidation of catchment-derived sulphur. The Fort McMurray region, located south of the wood buffalo and shield regions, contains lakes that are underlain predominantly by carbonate-rich materials. These lakes tend to be well buffered. The notable exception to these are the lakes located in the Birch and Muskeg Mountain Upland, which can have very low alkalinity, due primarily to inputs of organic acids and to low groundwater influx. Technically located in part in the Wood Buffalo region, about 25% of lakes in the Birch Mountain upland have <0.10 meq·l^{-1} alkalinity, low TDS, and low pH. These characteristics, as well as a high humic acid content, are attributable to extensive peatland cover (Halsey *et al.* 1997).

Erickson (1987) also examined the alkalinity to magnesium and calcium ratio, and the calcium to pH ratio to infer potential acidifying trends (Alymer *et al.* 1978; Henriksen 1982). Although several lakes in the Wood Buffalo and Canadian Shield regions are clearly acidified by these measures, acidification of the Wood buffalo lakes is due primarily to inputs of organic acids from peatlands. As well, the pH to calcium ratio as an index of acidification is based on the assumption that calcium and magnesium, as indicators of carbonate weathering, are present in equivalent concentrations, a condition that does not hold for the shield lakes (Erickson 1987).

Further analyses of additional lakes in the sensitive physiographic regions identified by Erickson (1987) were used to generate sensitivity maps that generally conform to the original analysis (Trew 1995; Saffran and Trew 1996). Lakes of moderate (alkalinity from 0.20 meq·l^{-1} to 0.10 meq·l^{-1}) to high (alkalinity less than 0.10 meq·l^{-1}) acid sensitivity typically occur in the Birch Mountain upland, the Muskeg Mountain upland, the Caribou Mountain upland, and the shield region, including the Kazan upland and the Athabasca Plain. Four lakes in the Birch Mountain uplands had alkalinities of 0 meq·l^{-1} (Saffran and Trew 1996), probably resulting from minimal groundwater inflow coupled with the acidifying presence of peatlands, as indicated by their high DOC content and low pH. Of the 109 north-eastern Alberta lakes sampled between 1987 and 1993, 11% have an alkalinity of <0.10 meq·l^{-1} (Saffran and Trew 1996). This is consistent with the estimates generated by Jeffries (1997) using steady state models.

Schindler (1996) examined pH, alkalinity, and major ion data collected from lakes in the region for temporal trends relating to acidification. No significant and consistent changes in pH were detected. Examination of other parameters such as alkalinity, and major cations showed either an absence of consistent change with time, or a slight increase. The same is true of the alkalinity to magnesium and calcium ratio, which as an aggregate index of acid neutralising properties tends to be more sensitive than any of these parameters alone.

The Regional Aquatic Monitoring Program (RAMP) initiated an extensive lake sampling program in 1999 to monitor acidifying trends in sensitive lakes in the oil sands region. Forty-nine lakes of moderate to high acid sensitivity (alkalinity < 0.20 meq·l^{-1}) were selected based on the available data to represent a range of colouration and proximity to emissions sources (Golder Associates Ltd. 2000). Of these, 22 (45%) are very sensitive (alkalinity < 0.10 meq·l^{-1}), while 14 (29%) are moderately sensitive (alkalinity between 0.10 and 0.20 meq·l^{-1}). There are no significant regionally or temporally consistent trends in either pH or alkalinity. Although there are clear inter sample-differences, in particular between older and more recent data, these can be attributed to seasonal variability (e.g. mixing, changes in the water balance) and uncertainty with regard to the quality of the data. This is consistent with Schindler's (1996) observations. As well, the alkalinity to magnesium and calcium ratio is less than one in all of the acid sensitive lakes and appears to be relatively stable over time, indicating that the level of cation leaching from the watershed is not increasing.

All 49 lakes in the acid sensitive lakes survey have a moderate to high level of DOC (8.4 to 55.5 mg·l^{-1}), which appears to be a significant component of the anion balance, as indicated by the positive correlation of DOC with the anion deficit (Golder Associates Ltd. 2003). Although in some cases the DOC is autochtonous, peatlands contribute substantial amounts of allochtonous carbon, and appear to have a strong influence on acid sensitivity. This distinction is evident in data collected from the 49 acid sensitive lakes. In general, the more productive lakes, as evidenced by elevated chlorophyll *a* concentrations in the euphotic zone, have a higher ratio of DOC to colour than do the less productive, arguably dystrophic, lakes (Golder Associates Ltd. 2003). The higher DOC to colour ratio probably represents an aggregate carbon pool with a lower average molecular weight. The lower DOC to colour ratio in the apparently dystrophic lakes probably represents a more refractory pool of higher molecular weight humic and fulvic matter that results from the decomposition of organic material produced in peatlands.

Peatlands clearly exert a strong influence the acid sensitivity of lakes in the region, primarily through the production of organic acids and the exchange by *Sphagnum spp.* of cations for protons. Through-flow in *Sphagnum*-dominated, geogenous poor fens may tend to be acidified through cation exchange, while in ombrogenous bogs (also *Sphagnum*-dominated), in which the water residence time may be rather longer, through-flow acquires organic acids (Halsey *et al.* 1997). The influence of peatlands appears to be largely responsible for the acidification during the mid-to late Holocene of Lake Otasan, a low-alkalinity lake located in the Birch mountain uplands (Prather and Hickman 2000). From the stratigraphy of diatoms and chrysophyte stomatocysts, Prather and Hickman (2000) identified four distinct historic phases based on inferred pH and productivity for the 8200 year history of the lake.

From an initially alkaline, oligotrophic condition, pH declined to ca. 5000 yrs. BP and remained slightly depressed to ca. 3000 yrs. BP, after which pH increased slightly and has remained relatively constant throughout the past 3000 years. To a large extent this reflects catchment processes, in particular the establishment and expansion of peatlands. The increase in productivity and decline in pH that characterise the period from approximately 7000 to 5000 yrs. BP are unexplained, but could be related to successional changes of catchment vegetation. A decline in productivity beginning approximately 5000 yrs. BP is consistent with the retention of nutrients by peatlands. The increase in benthic diatom species during the past 3000 years is consistent with a decrease in water level and a relative increase in littoral habitat, potentially as a result of the retention of through-flow in the catchment by bogs. It is therefore possible that changes in Lake Otasan over the past 5000 years reflect changes associated with the succession from poor fen, which tends to retain nutrients and cations and to generate acidity, to bog, which tends to retain through-flow and to contribute organic acids, but to have a reduced effect on the generation of acidity (Halsey *et al.* 1997).

Outline of the thesis

This thesis is presented in four chapters, of which the second and third represent an interpretation of the data, and are intended as manuscript submissions for publication in the peer reviewed literature. Although the data in both chapters overlap, the approach to the interpretation differs in that the first (Chapter 2) specifically addresses the issue of acid deposition, while the second (Chapter 3) addresses broader issues of environmental change relating to the ecological shifts observed in the stratigraphic record. In Chapter 2, the composition of diatom assemblages forms the basis of a pH inference model, developed specifically for application to lakes in the region. The pH reconstructions indicate that none of the study lakes have become acidified as a result of acid deposition, and that there is relatively little variability in pH over a 250 year time scale. However, two of the study lakes appear to have gradually become more alkaline over the course of the twentieth century, for reasons that are not immediately apparent. The apparent heterogeneity of response of the study lakes relative to acid deposition prompted an exploration in Chapter 3 of other potential causes of the observed ecological shifts. We examine the potential effects of climate warming, forest fire, nitrogen deposition, and cascading trophic interactions on diatom and chrysophyte communities. The divergent response of the study lakes to these environmental stressors suggests that proximal factors play an important role in mediating their ecological effects.

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CHAPTER TWO: Paleolimnology of northeastern Alberta lakes: an assessment of the effects of 30 years of acid deposition

ABSTRACT

The rate of bitumen extraction in northeastern Alberta is outpacing the state of ecological understanding in the region, and our appreciation of the extent of disturbance caused by atmospheric pollution and landscape disruption on a massive scale. Atmospheric SO_2 emissions (296 $T{\cdot}day^{-1}$ in 2004) currently constitute almost 5% of Canadian emissions, and are believed to be deposited locally. Combined with current estimated NO_x emissions of 384 $T{\cdot}day^{-1}$, these emissions collectively have the potential to cause surface waters in the region to become acidified. We examine diatom microfossils from 8 acid-sensitive lakes along a north-south transect to determine the extent to which locally-generated acidifying emissions have altered lake ecosystems. Although diatoms are very sensitive indicators of ecological change, we find no evidence that these lakes have become acidified. This conclusion diverges from the predictions of acid mass balance (critical load) modelling that indicate that current levels of deposition exceed the acid buffering capacity of at least three of the eight study lakes. We speculate that the apparent lack of sensitivity of these eight lakes to acid deposition reflects, in part, the acid buffering conferred by biological NO_3^- and SO_4^{2-} reduction and assimilation at the catchment and basin level.

INTRODUCTION

Activities directly related to oil sands extraction and processing in northeastern Alberta currently generate an estimated 246 $T{\cdot}day^{-1}$ SO_2 and 384 $T{\cdot}day^{-1}$ NO_x in atmospheric emissions (Albian Sands Energy Inc. 2005). At projected rates of expansion, existing, approved, and proposed facilities are expected to produce 298 $T{\cdot}day^{-1}$ SO_2 and 538 $T{\cdot}day^{-1}$ NO_x. The projected SO_2 emissions may in fact already be realised at current levels of production, as reported 2004 SO_2 emissions compiled over the same region from the National Pollutant Release Inventory (NPRI) were higher than the projected emissions from facilities that are still in the approval phase (296 $T \cdot day^{-1}$). Current and projected levels of acid emissions raise the possibility that lakes in the region will become acidified.

The majority of Alberta lakes are underlain by calcareous tills that confer sufficient carbonate buffering to prevent acidification. However, surveys in northeastern Alberta have identified a number of lakes of moderate to high acid sensitivity (< 20 $mg \cdot L^{-1}$ and < 10 $mg \cdot L^{-1}$ $CaCO_3$, respectively; Hesslein 1979, Erickson 1987, Saffran and Trew 1996). These lakes are located in four distinct physiographic regions (Fig. 2.1). The Birch and Stony uplands are underlain by dark grey and silty pyritic Cretaceous shales draped by fine loamy to clayey ground moraine. The Caribou Mountains are underlain by Cretaceous shales and coarse glacial drift and, like the Birch and Stony uplands, contain extensive peatlands interspersed with dense mixed wood forest. The northeastern corner of the province is underlain by the Archaean crystalline lithologies of the Canadian Shield, with open canopy mixed wood forest and lowland peatlands. The Muskeg uplands are characterised by late Cretaceous shales, sandstones, and siltstones that form a transition between the exposed Canadian Shield and the Cretaceous shales of the Birch and Stony uplands, and by a vast expanse of muskeg and sparse, open canopy forest (Lindsay *et al.* 1960, Turchenek and Lindsay 1982). The heightened sensitivity of these regions is due in part to the low concentration of dissolved base cations in groundwater, and to the altered groundwater flow caused by extended periods of soil frost (Ozoray *et al.* 1980). Much of the region north of Fort McMurray is underlain by isolated and sporadic permafrost, which effectively isolates groundwater flow from the underlying geology. Peatlands also influence the acid sensitivity of these lakes by the contribution of organic acids, an important factor in the peatland-dominated catchments of the northern Alberta uplands (Vitt *et al.* 1996, Halsey *et al.* 1997).

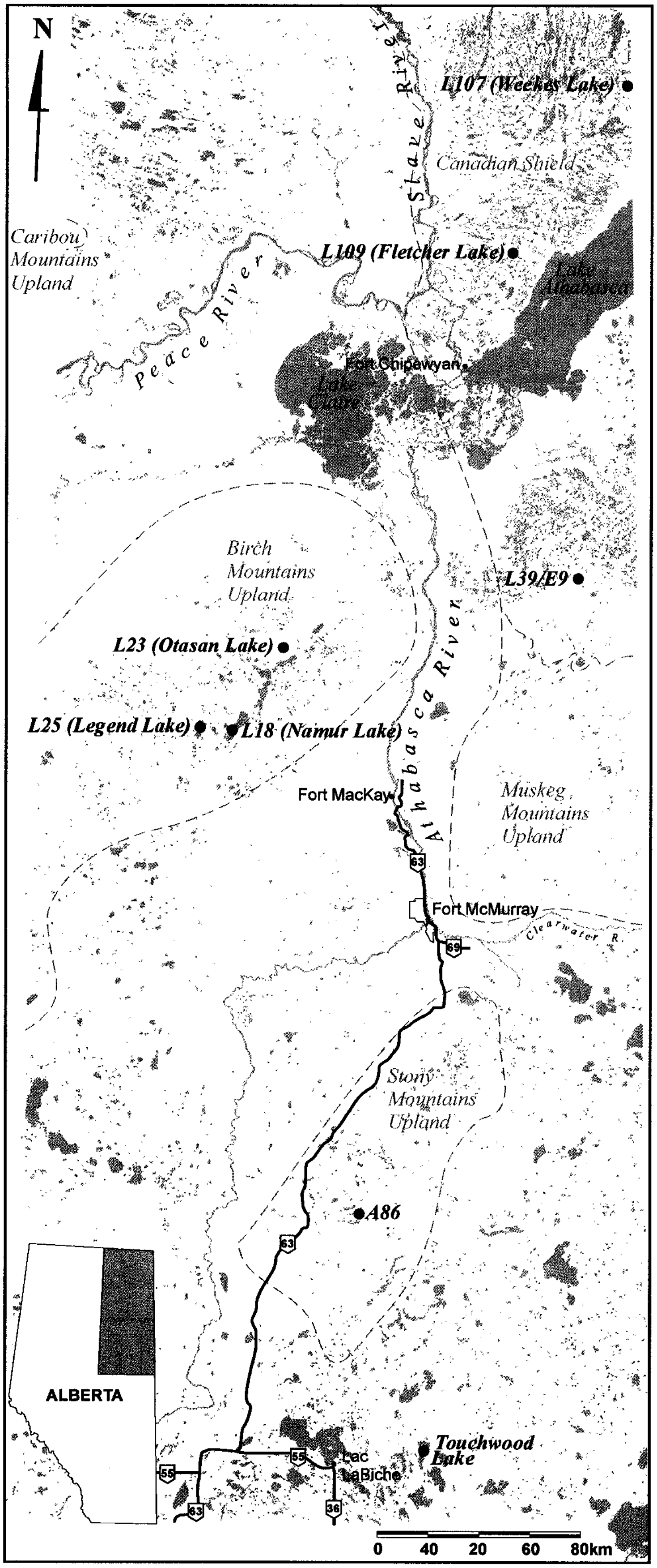


Figure 2.1. Map of northeastern Alberta, Canada, showing the location of the eight study sites

Acidifying deposition is currently deemed to exceed critical loads for A86, L25 (Legend), and L23 (Albian Sands Energy Inc. 2005). However, there is so far no indication that these or other lakes in the region have become acidified (Erickson 1987, Schindler 1996, RAMP 2005b). Few of the acid sensitive lakes have a bicarbonate to base cation ratio of less than one, and of these, the remainder of the charge balance appears to be comprised of organic acids. However, prior to the initiation of an intensive lake sampling program under the Regional Aquatics Monitoring Program (RAMP) in 1999, acid sensitive lakes identified during regional surveys (Erickson 1987, Saffran and Trew 1996) were monitored infrequently, or not at all. In this limited historical context, it is impossible to determine with certainty whether present acid loads have exceeded critical loads. Based on emissions from existing and approved operations (Albian Sands Energy Inc. 2005), acid deposition exceeds current critical load estimates calculated from Henriksen and Braake's (1988) Steady State Water Chemistry (SSWC) Model for several of the acid sensitive lakes monitored under the RAMP sampling program (RAMP 2005b). Theses critical load estimates were calculated using a critical threshold of 3.75 $\text{mg}{\cdot}\text{L}^{-1}$ $CaCO_3$, a figure derived from linear regression of pH against alkalinity, based on a threshold condition of pH 6. Because they are based on recent alkalinity measurements, current critical load estimates are founded on the assumption that surface water acid-base equilibriums have remained unchanged. We test this assumption, and hence the robustness of current critical load estimates, by inferring historical pH variability from diatom microfossils that have accumulated in lake sediments.

This approach has gained wide currency as a means of inferring the nature and extent of limnological change, and as a non-derivative index of ecological change. Hustedt (1937-1939) first recognised the sensitivity of diatoms to surface water acidity, and the distribution of individual species along pH gradients. A large body of literature has since developed around the study of diatom microfossils as indicators of lake acidification (e.g. Charles and Whitehead 1986, Smol *et al.* 1986, Charles and Smol 1990, Battarbee and Renberg 1990). Assemblages of diatom microfossils from Christina Lake, located 130 km south of Fort McMurray (Philibert *et al.* 2003) and Rainbow Lake 'A', located 400 km north of Fort McMurray in Wood Buffalo National Park (Moser *et al.* 2002) were examined in relation to wildfires and climate warming. Although modest floristic variation has occurred in both lakes over the past 200 years, this variability is clearly not related to acidification. Prather and Hickman (2000) conducted a similar study of Otasan Lake, located 130 km northeast of Fort McMurray, concluding that pH has remained relatively unchanged over the past ca. 3100 years. However, their analysis was not conducted at a resolution that would detect recent change associated with anthropogenic impacts. We revisit this lake and seven others, examining diatom assemblages at higher temporal resolution to determine the extent of recent change in relation to the long-term record, and obtaining a better regional representation. We specifically address floristic change as it relates to acidification, and use this information to evaluate the variability in lake acidity as it relates to the determination of critical loads.

Study sites

The study area spans several distinct physiographic regions of northeastern Alberta, comprising upland areas composed of dark grey and silty Cretaceous shales draped by fine glaciofluvial till, and the Archaean granite of the Canadian Shield to the north (Fig. 2.1). The northern half of the study area lies within a zone of discontinuous permafrost, and ground frost persists for much of the year throughout the region, resulting in discontinuous groundwater flows. Peatlands predominate in the catchments of upland lakes and the wetlands surrounding the shield lakes. The influence of ground frost, permafrost, and peatlands yields groundwater that is rich in dissolved organic material and often has low concentrations of inorganic solutes due to limited contact with subsurface minerals. These characteristics are reflected in the water chemistry of the study lakes, which tend to be dilute, with moderate DOC concentration (Table 2.1).

The study lakes are generally moderately productive, although both L39 and L25 (Legend) are eutrophic (TP > 35 $\mu g \cdot L^{-1}$) and frequently produce extensive cyanobacterial blooms, while L107 (Weekes) is oligotrophic (TP < 10 $\mu g \cdot L^{-1}$). Cyanobacterial blooms are not uncommon in the region, although thermal stratification is apparently transient. This presumably reflects rapid remobilisation of nutrients in sediments or an elevated flux of allochthonous organic matter, as reflected in the relatively high DOC concentrations (Table 2.1). Although the majority of the study lakes are moderately to highly acid-sensitive, the pH of these lakes is circumneutral (pH~7). pH also appears to be uncorrelated with DOC, although given the relatively narrow pH gradient, this is to be expected.

	deg. N	deg. W	m asl	ha	m	mg·L^{-1}	mg·L^{-1}	mg·L^{-1}		mg·L^{-1} as CaCO^{3}	keq·ha^{-1}·yr^{-1}	keq·ha^{-1}·yr^{-1}
L25 (Legend)	57.4122	112.9336	789	1685	9.1	523.44	37.58	9.21	6.82	9.61	0.135	0.099
L18 (Namur)	57.4444	112.6211	724	4322	31.3	351.83	20.47	8.91	7.22	21.00	0.126	0.226
L23 (Otasan)	57.7072	112.3875	747	348	10.7	576.62	17.95	14.15	6.82	8.82	0.117	0.065
L109 (Fletcher)	59.1210	110.8200	287	103	12.9	785.20	13.43	20.02	7.06	19.60	n/a	0.341
L107 (Weekes)	59.7180	110.0140	340	340	27.4	507.26	5.22	11.45	7.22	23.75	n/a	0.114
L39/E1	57.9583	110.3833	356	116	1.2	1632.50	41.97	15.40	6.85	11.05	0.104	0.144
A86	55.6811	111.8268	670	148	3.0	1237.71	31.50	16.62	6.63	6.93	0.117	0.057
Touchwood	54.8250	111.4042	632	2900	40.0	767.14	18.40	11.17	8.31	141.21	0.131	n/a

[†] Albian Sands Cumulative Effects Assessment

[‡] RAMP 2005

Table 2.1. Selected limnological characteristics of the study lakes, including estimated acid loads and critical loads

Seven of the eight study lakes represent a subset of the acid-sensitive lakes presently monitored under the direction of the Regional Aquatics Monitoring Program (RAMP), and are generally representative of the larger set of RAMP lakes in productivity and chemistry. Although Touchwood Lake is not monitored under RAMP, we include it for comparison, as its relatively alkalinity (Table 1) makes it insensitive to acid deposition, and thus it serves as a reference lake. With the exception of Touchwood Lake, access to the lakes is limited by their distance from roads and populated areas, and by peatlands, which are impassable during the ice-free season. Touchwood Lake lies within the Lakeland Provincial Recreation area, and is not subject to the intense catchment disturbances. Human disturbance within the study catchments is therefore minimal. Namur Lake (L18), the largest of the study lakes, is host to a fly-in fishing lodge and a modest winter fishery, and a large colony of cormorants that has become established over the past decade. There is also a small subsistence fishery on Legend Lake (L25). Touchwood Lake is subject to intense fishing pressure that has caused the collapse of several sportfish populations over the past century. The location of the study lakes reflects the regional distribution of acid sensitive lakes along a 550km north-south transect about the sources of acidifying emission. The potential for sediment mixing was a significant consideration in the selection of these lakes, excluding many of the shallow lakes located in the muskeg mountain uplands east of Fort McMurray.

METHODS

Sediment coring and chronology

Sediment cores were retrieved in 2003 and 2004 from a central point in the basin, with a modified Kajak-Brinkhurst gravity corer (Glew 1989). The cores were extruded immediately upon retrieval and sectioned at 0.25 cm increments to 10 cm, 0.50 cm increments from 10 to 20 cm, and 1.00 cm increments thereafter, with the exception of the cores from Touchwood Lake and A86, which were sectioned at 0.50 cm increments to 20 cm, and 1.00 cm increments thereafter. Samples were frozen upon return from the field, and freeze-dried for further analysis and archiving. Sediment chronology was estimated by α-spectrometry of ^{210}Po, a radioactive decay product of ^{210}Pb. Assuming a constant rate of ^{210}Pb deposition (Constant Rate of Supply, CRS) and adjusting for a variable rate of sediment accumulation, the decay of ^{210}Pb (half-life = 22.3 years) is used to estimate the age of lake sediments to approximately 100-120 years (~5 half-lives), after which the measurement uncertainty becomes greater (Appleby and Oldfield 1978, Appleby 2001).

Diatoms

Prior to mounting, organic matter was oxidised by digestion with H_2O_2. A small amount (0.1 – 0.2 g) of freeze-dried sediment was heated to 70°C in 30% H_2O_2 for the time required to remove organic colouration (2-14 days), centrifuged, rinsed, and diluted to 10 mL. A 200µL aliquot was diluted with distilled water (usually 5 to 10 mL) to produce a sufficiently dilute suspension for counting. A 200µL aliquot of the dilute sediment suspension was placed on a coverslip, air dried, and permanently mounted in a high refractive index mounting medium (Naphrax®). Diatoms and chrysophyte cysts and scales were counted in full transects under 1000x magnification oil immersion. A minimum of 400 diatom valves were identified and counted per slide, using standard freshwater floras (Krammer and Lange-Bertalot 1986-1991, Simonsen 1987, Camburn and Charles 2000, Fallu *et al.* 2000). Identification of diatoms in Touchwood Lake was conducted independently, and the taxonomy harmonised by comparison of photomicrographs. Results are presented as percent relative abundance. Only species that comprise >5% of the total assemblage are shown (Fig. 2.3).

Multivariate analysis

Multivariate analysis simplifies the interpretation of inter-sample relationships by reducing the large number of species data in a sample to a single sample score. The relative difference among sample scores reflects diatom species turnover, effectively indicating ecological change along an environmental gradient. The magnitude of ecological change is reflected in the length of the gradient. Diatom assemblages in sediments retrieved from the study lakes are analysed using DCA (Detrended Correspondence Analysis), detrending by segments. This approach assumes a unimodal species response to environmental gradients, and extracts the maximum variance within the data, rather than constraining the data to a known environmental gradient. This approach was selected over other techniques because the variance extracted is explicitly expressed as beta diversity, or species turnover, in units of standard deviation (SD), simplifying interpretation of the results. Coherent stratigraphic change among sample scores suggests limnologic change reflected in species assemblages, but gives no indication as to the nature of the change. The magnitude of this stratigraphic change is reflected in the length of the first DCA axis (Fig. 2.5). The unexplained variance is expressed in subsequent DCA axes (not shown). DCA was performed on square root transformed diatom species data using CANOCO V. 4.5 (ter Braak and Šmilauer 2002), including all species that comprise more than 1% of any one sample.

pH reconstructions

Inference of surface water pH was conducted by weighted averaging partial least squares (WA-PLS) 2-component regression and calibration (Birks *et al.* 1990), using pH optima calculated from log-transformed diatom assemblage data from 46 lakes included in the RAMP acid sensitive lakes sampling program, and from Touchwood Lake. Diatom taxa in this training set were identified and enumerated by Sergi Pla (Pla and Curtis 2006), and augmented with data from the eight study lakes. Rare taxa (<2% maximum relative abundance) were excluded from the model. The number of WA-PLS model components retained minimises bootstrap root mean squared error of prediction (RMSEP) and bias, and maximises the regression coefficient of bootstrap pH estimates versus observed pH.

Additional pH inference models from lakes in the region (Philibert *et al.* 2003) and from primarily acidic lakes in the northeastern United States (Camburn and Charles 2000) provide independent validation of the model, and demonstrate the robustness of the approach. These models were selected for their inclusion of dominant diatom species and for the similarity of model lakes to study lakes, with specific regard to pH data. The performance of the inference models is evaluated relative to the accuracy with which they reconstruct measured pH from surface sediment assemblages.

RESULTS

Chronology

Sediment deposition rates vary substantially among the study lakes, with the unsupported ^{210}Pb inventory ranging from 10 cm (L39) to 30 cm (Touchwood; Fig. 2.2). There are no significant reversals in unsupported ^{210}Pb activity, suggesting that sedimentation rates remain unchanged. Unsupported ^{210}Pb activity does not decline as expected in sediments deeper than 10-15 cm in L23 (Otasan), L25 (Legend) and Touchwood, a condition that could be caused by sediment mixing. The presence of chironomid tubes and burrows in surface sediments suggests that sediment stratigraphy could have been disturbed by the macrobenthos. However, diatom stratigraphic changes and ^{210}Pb suggest this not to be the case.

Diatom Stratigraphy

A total of 280 diatom taxa were identified during the course of the study. The composition of diatom assemblages varies substantially among lakes, reflecting a broad range of limnological characteristics. Prior to c. 1950, diatom assemblages in L109 (Fletcher) and L25 (Legend) were dominated by small colonial *Fragilaria spp. sensu lato* (*Staurosirella pinnata* and *Staurosira construens* var. *venter, sensu* Round *et al.* 1990) and *Aulacoseira subarctica* (Figure 2.3). L23 (Otasan) and A86 were also dominated by small *Fragilaria* spp. (*F. pinnata* and *F. construens var. venter*) to the extent that these species frequently comprised more than 50% of the diatom assemblage. Sediment assemblages from L39 and L107 (Weekes) were not dominated by any one species, but contained consistently low concentrations of eurytopic *Achnanthes minutissima*, *Navicula kuelbsii*, *Nitzschia fonticola* and *F. construens* var. *venter*, in addition to *Cyclotella ocellata* and *Cymbella descripta* in L107.

Of these six lakes, the most pronounced stratigraphic change occurs in L109 (Fletcher), with an abrupt increase in the relative abundance of *Cyclotella pseudostelligera* from trace abundance prior to c. 1985 to 50% in surface sediments. Other taxa, notably *F. construens* var. *venter* and *A. subarctica*, show a

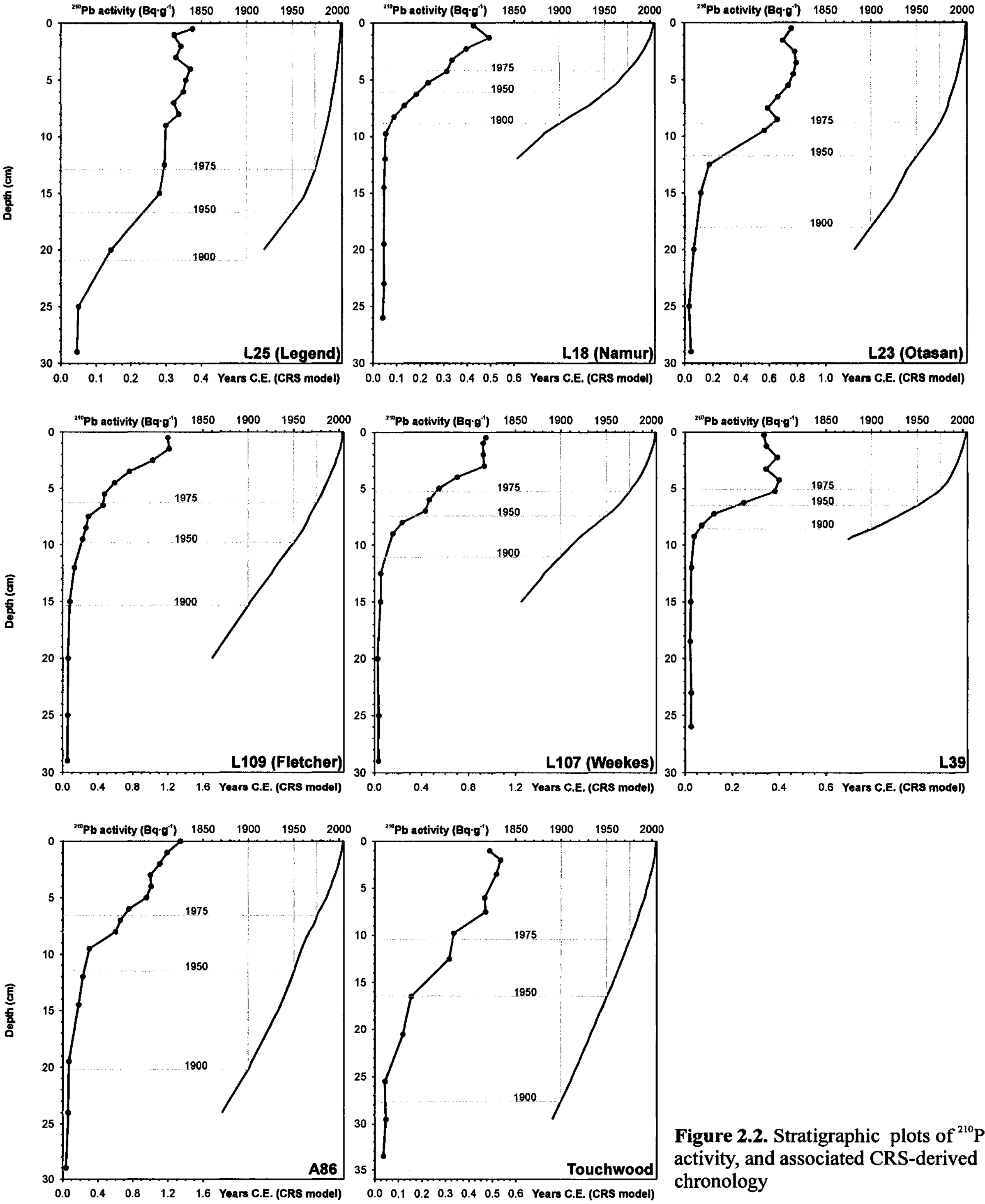


Figure 2.2. Stratigraphic plots of ^{210}Pb activity, and associated CRS-derived chronology

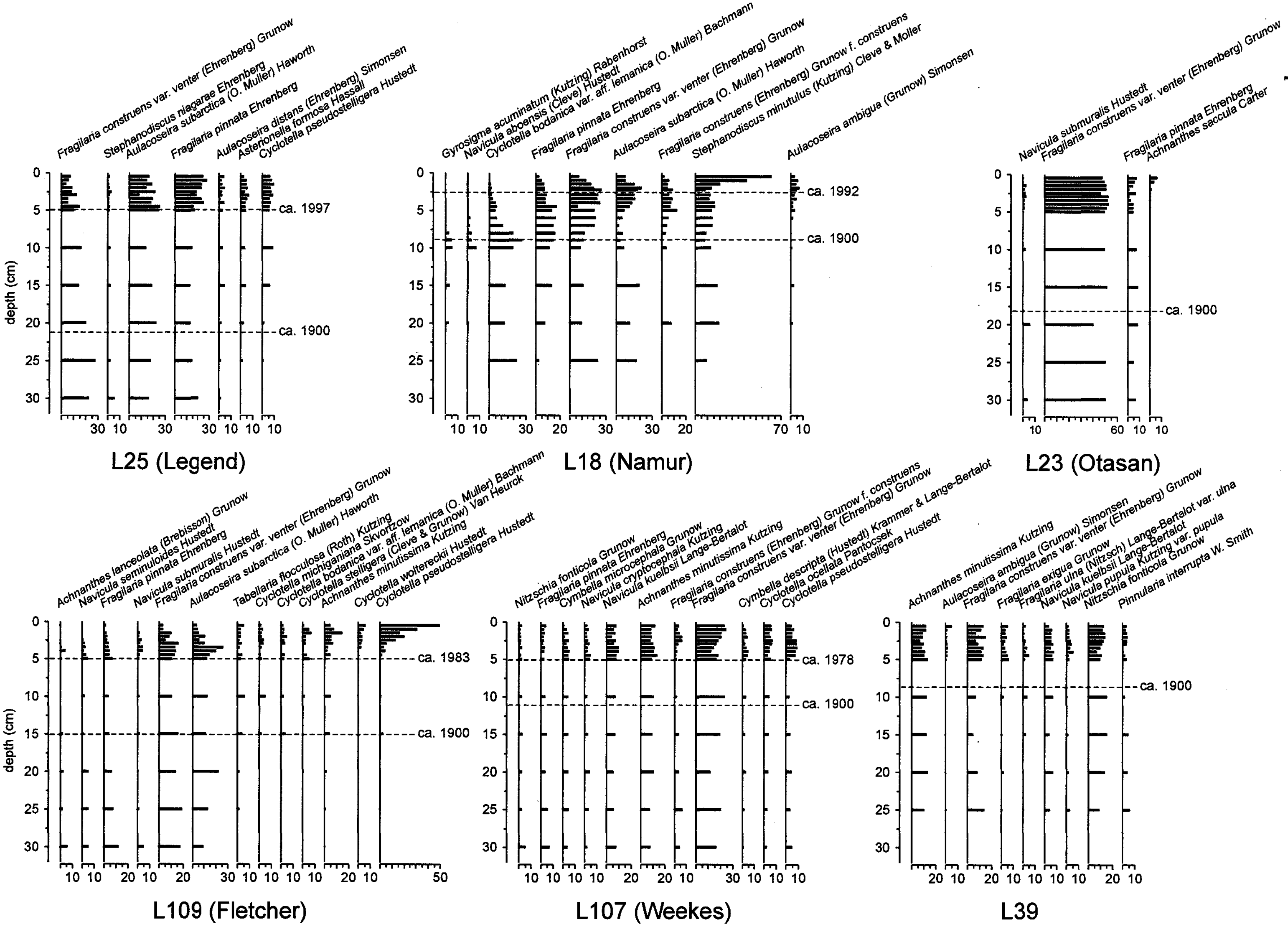
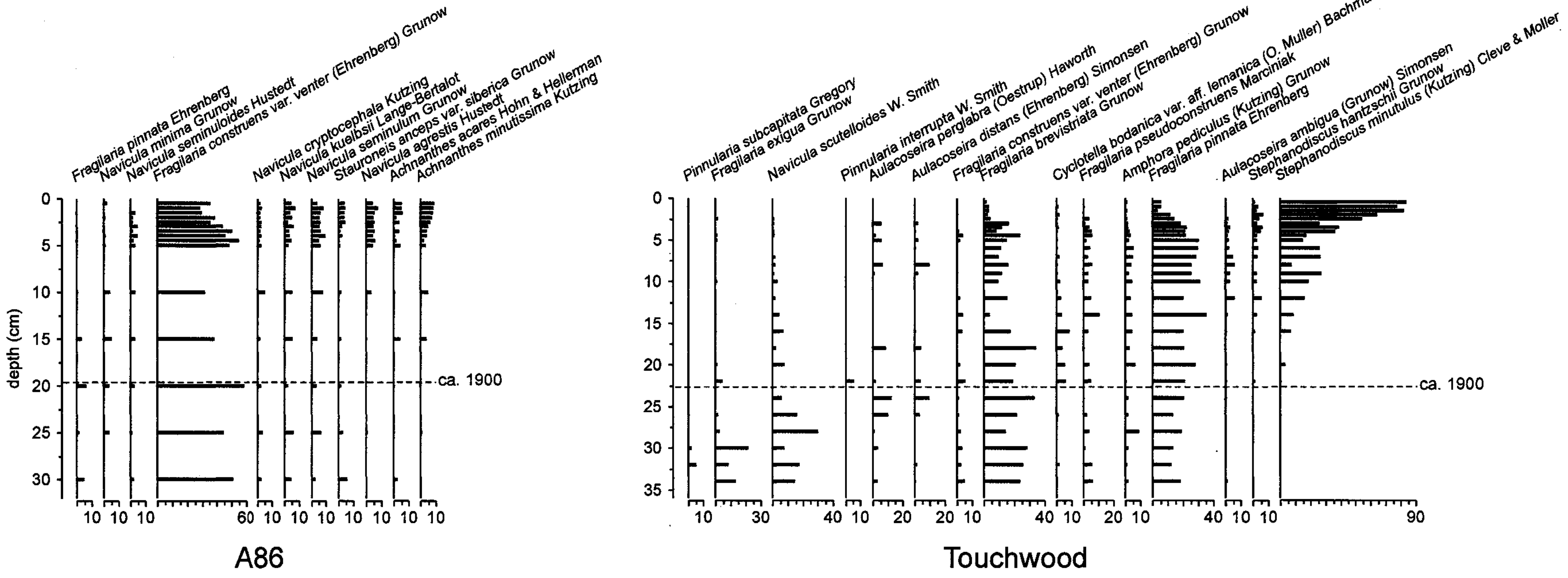


Figure 2.3. Diatom stratigraphy for the eight study lakes. Only species with relative frequency >5% shown.


Fragilaria pinnata Ehrenberg
Navicula minima Grunow
Navicula seminuloides Hustedt
Fragilaria construens var. venter (Ehrenberg) Grunow
Navicula cryptocephala Kutzing
Navicula kuelbsii Lange-Bertalot
Navicula seminulum Grunow
Stauroneis anceps var. siberica Grunow
Navicula agrestis Hustedt
Achnanthes acares Hohn & Hellerman
Achnanthes minutissima Kutzing
depth (cm)
0
5
10
15
20
25
30
ca. 1900
10 10 10 60 10 10 10 10 10 10 10
A86
Pinnularia subcapitata Gregory
Fragilaria exigua Grunow
Navicula scutelloides W. Smith
Pinnularia interrupta W. Smith
Aulacoseira perglabra (Oestrup) Haworth
Aulacoseira distans (Ehrenberg) Simonsen
Fragilaria construens var. venter (Ehrenberg) Grunow
Fragilaria brevistriata Grunow
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann
Fragilaria pseudoconstruens Marciniak
Amphora pediculus (Kutzing) Grunow
Fragilaria pinnata Ehrenberg
Aulacoseira ambigua (Grunow) Simonsen
Stephanodiscus hantzschii Grunow
Stephanodiscus minutulus (Kutzing) Cleve & Moller
0
5
10
15
20
25
30
35
ca. 1900
10 30 40 10 20 20 10 40 10 20 10 40 10 10 90
Touchwood

concomitant decline over the same period. Stratigraphic changes in L25 (Legend) are more subtle, and occur on a timescale that extends slightly beyond those in L109 (Fletcher). The relative abundance of *Asterionella formosa* and *Cyclotella pseudostelligera* shows a modest increase accompanied by a decrease in *F. construens var. venter* beginning c. 1950, although the structure of diatom assemblages remains relatively unchanged from c. 1980 to present. The remaining four lakes (L23, L107, L 39 and A86) have relatively little stratigraphic change over the period of record. *F. construens var. venter* declines consistently from c. 1985 to present in A86, however this shift is well within normal variability. This is also true of the apparent increase in the same species in L107 (Weekes), which occurs over the same period. Nonetheless, with the exception of L23 (Otasan), all lakes show a consistent trend along the first DCA axis (Fig. 2.5), suggesting coherent shifts in sediment diatom assemblages that are not adequately reflected in the most abundant taxa (Fig. 2.3).

Changes in the diatom stratigraphy of L18 (Namur) and Touchwood Lake antedate those in other study lakes by about 50 years. Prior to c. 1900, sediment diatom assemblages in L18 (Namur) were typical of a deep, moderately productive, alkaline northern lake, and were comprised of more or less equivalent concentrations of *Fragilaria* spp. (*F. pinnata* and *F. construens var. venter*), *Cyclotella bodanica var. aff. lemanica*, *A. subarctica*, and *Stephanodiscus minutulus*. Touchwood Lake was dominated in more or less equal proportion by small *Fragilaria spp. s.l.* (*S. pinnata, Stauroforma exiguiformis* and *Pseudostaurosira brevistriata, sensu* Round *et al.* 1990) and *Navicula scutelloides*.

Progressive change in sediment diatom assemblages begins in L18 (Namur) and Touchwood around 1900. In L18 (Namur), *C. bodanica var. aff. lemanica* declines dramatically from a maximum of 27% c. 1900 to less than 1% in surface sediments, accompanied by a similar decline in the less abundant *Gyrosigma acuminatum* and *Navicula aboensis* (Fig. 2.3). A concomitant increase in the relative abundance of *F. construens var. venter* and *A. subarctica* is followed by a sudden decline in these species c. 1990, accompanied by a notable increase in *S. minutulus* from approximately 15% prior to c. 1990 to 62% in surface sediments (Fig. 2.3).

The stratigraphic changes in Touchwood Lake are structurally similar to those in L18 (Namur), although on a slightly different time scale. *F. exigua* and *N. scutelloides* decline from respective maxima of 22% and 31% c. 1900 to apparent absence in surface sediments. *F. brevistriata* and *F. pinnata* are both relatively abundant (20-30%) until c. 1990, after which they decline to less than 6% in surface sediments. The decline of these small *Fragilaria spp.* in part reflects the ascendance of *S. minutulus*, which first occurred c. 1930 and increased exponentially in abundance to 84% in surface sediments (Fig. 2.3).

With the exception of L23 (Otasan), all of the study lakes show a directional shift in the structure of sediment diatom assemblages, as indicated by the first axis DCA sample scores (Fig. 2.5). The magnitude of this shift is indicated by the gradient length, expressed in standard deviations. Although the gradient length in L39 and L107 (Weekes) is short (<1 SD), the directionality of the change in the first DCA axis as a function of depth suggests that there are community shifts not evident among dominant taxa, over a period of at least 100 years. Changes along the first DCA axis are more significant among the remaining lakes (L25, L18, L109, A86, and Touchwood) as indicated by the longer gradient lengths (>1 SD), and reflect the floristic changes already discussed in relation to Figure 2.3. Notable among these changes is a sharp inflection of the first DCA axis in A86 at 3 cm (c. 1995). This deflection is less apparent in the diatom stratigraphy, but appears to reflect a decline in *F. construens var. venter*, accompanied by an increase in *A. minutissima,* both eurytopic taxa.

pH Reconstructions

The performance of the inference model derived from the RAMP study lakes is indicated by the quality of the linear relation between bootstrap pH estimates and observed pH (Fig. 2.4), expressed as the multiple regression correlation coefficient ($r^2 = 0.84$), and as the root mean square error of prediction ($RMSEP_{boot} = 0.38$). The plot of residuals versus observed pH shows a slight but systematic bias in the model predictions, as indicated by a maximum bias of pH 0.65. This suggests that the model tends to over-predict pH in acid lakes, and to under predict pH in alkaline lakes, by a maximum of 0.65 for the bootstrap validation. The central tendency of pH estimates is effectively an artefact of the weighted averaging calibration approach,

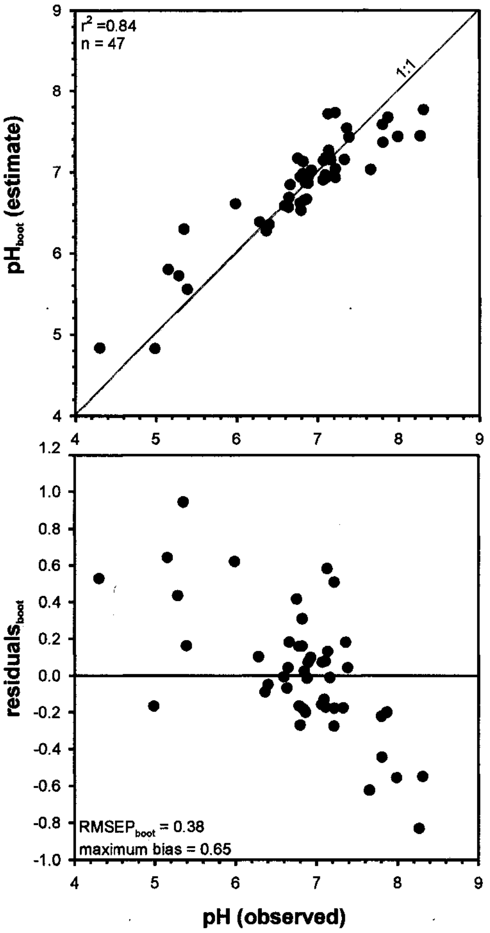


Figure 2.4. Performance of the bootstrap ASL WA-PLS 2-component inference model estimates (a.), and bootstrap residuals (b.) as a function of observed pH

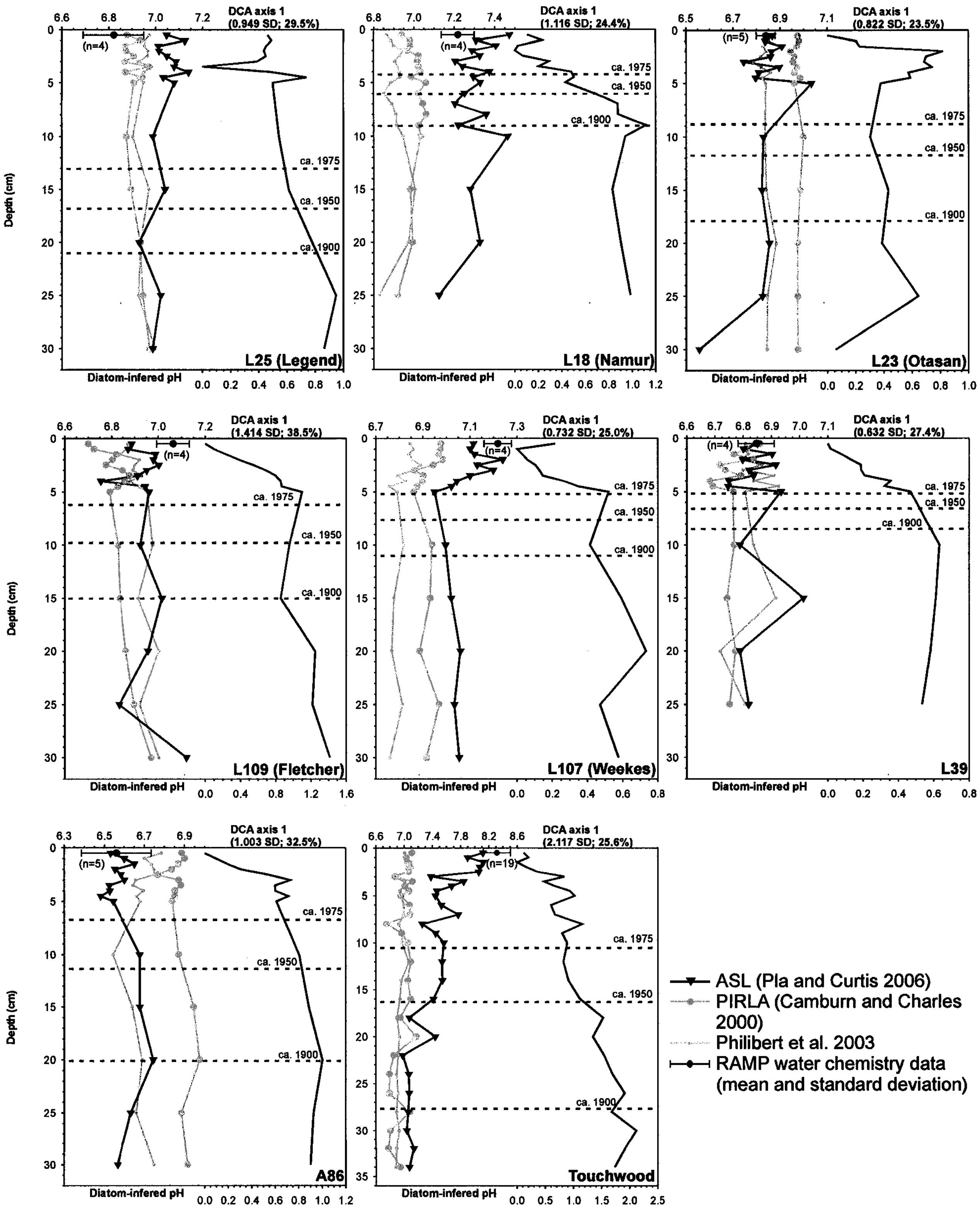


Figure 2.5. pH inferred from diatom stratigraphy using models derived from lakes in northeastern Alberta (Pla and Curtis 2006, Philibert et al. 2003) and northeastern USA (Canburn and Charles 2000), and first DCA (Detrended Correspondence Analysis) axis scores for diatom assemblage composition

but will generally impart predictive bias only to samples at the ends of the pH gradient. The range for optimal prediction appears to be between pH 6.0 and 7.5; only Touchwood Lake lies outside of this range.

The accuracy with which the inference models predict observed pH varies among the sample lakes. Predictions derived from the ASL model lie within one standard deviation of observed pH in L23 (Otasan), L39, A86, and Touchwood. The ASL model under-predicts mean observed pH by 0.18 in L109 (Fletcher) and by 0.10 in L107 (Weekes), and over predicts mean observed pH by 0.23 in L25 (Legend) and by 0.26 in L18 (Namur). Discrepancies between inferred and measured pH may arise from seasonal bias in the measured data, which were typically collected in late August through October, and from bias in the calibration model.

Although the pH inference models are regionally distinct, the concordance among them is excellent. Touchwood Lake and L18 (Namur) are notable exceptions, although the dominant taxon in both lakes (*Stephanodiscus minutulus*) is absent from both the PIRLA (Camburn and Charles 2000) and Philibert *et al.* (2003) training sets. The discrepancies among inferred trends reflect the divergent taxonomic composition of the models relative to the fossil assemblages, and the bias imparted by differences in training sets. The PIRLA training set, in particular, comprises predominantly acidic lakes, although does not appear to consistently under-predict observed pH. Nonetheless, the performance of the ASL model relative to the others underscores the value of a regionally representative inference model.

There is no indication that any of the lakes are becoming acidified. Although inferred pH in L25 (Legend), L109 (Fletcher), L107 (Weekes), and A86 trends downward at the surface, these trends remain within natural variability. Touchwood Lake appears to have become increasingly alkaline over an extended period beginning in the early 20th century, based on pH inferred by the ASL (Pla and Curtis 2006) model. This trend effectively rests upon a dramatic increase in the abundance of *Stephanodiscus miutulus*, but does not appear to include other alkaliphilous taxa. Because the pH optimum (9.32) of *Stephanodiscus minutulus* in the ASL model is effectively defined by Touchwood and L18 (Namur), the apparent trend may be an artefact of bias in the inference model. Although the model accurately predicts observed pH, inferences further down the sediment core generally rest on eurypotic taxa (e.g. *Fragilaria spp. s.l.*), and may be subject to positive bias in the inference model.

Although L18 (Namur) undergoes a similar increase in the abundance of *Stephanodiscus miutulus* to Touchwood Lake, pH inferred from the ASL model does not indicate such a dramatic alkalinisation. L107 (Weekes) shows a slight alkalinising trend beginning ca. 1975, but the trend is very weak, as indicated by the relatively low first axis DCA score (0.746 SD). There is also little floristic evidence for pH change in L107.

Correspondence between inferred pH and the first DCA axis is good for Touchwood Lake, although, as discussed, the inferred pH trend for Touchwood Lake may be exaggerated or artifactual. For L18 (Namur), A86, and L109 (Fletcher), a significant portion of the floristic variance captured by the first DCA axis is unexplained by pH, suggesting recent environmental change unrelated to acidification. In particular, the dominance of *S. minutulus* in L18 (Namur) and Touchwood appears to be part of a broader trend occurring on a longer timescale (c. 100 yrs.), reflected in the first DCA axis. The same is true of the dominance of *Cyclotella pseudostelligera* in L109 (Fletcher). Although the first DCA axis suggests stratigraphic change in L25 (Legend), L23 (Otasan), L107 (Weekes), and L39, the length of the gradient is very small (≤1 SD), indicting a very weak trend. Thus, while there is significant species turnover in several of the study lakes, these generally involve taxa with similar pH optima.

DISCUSSION

The diatom flora in several of the study lakes, most notably L109 (Fletcher), L18 (Namur), and Touchwood Lake, has undergone pronounced stratigraphic change during the past century. The magnitude of this change, expressed in the length of the first DCA axis, varies from 2.56 standard deviations in Touchwood Lake, indicating a near complete turnover of species composition along the length of the first DCA axis, to 0.68 standard deviations in L39, indicating a far subtler shift (Fig. 2.5). The chronology of the change is consistent with intensifying agricultural and industrial activity in western Canada. However, the shifts do not appear to be related to acidification.

Floristic shifts in the study lakes are generally characterised by an increase in circumneutral and alkiliphilous taxa (*Stephanodiscus minutulus*, *Cyclotella pseudostelligera*, *Achnanthes minutissima*), and by the scarcity or absence of acidophilic taxa (e.g. *Eunotia spp.*, *Pinnularia spp.*, *Stenopterobia spp.*) These shifts are most pronounced in L18 (Namur), L109 (Fletcher), and Touchwood Lake, all of which are moderately to strongly alkaline (Table 2.1). Touchwood Lake, in particular, has very high alkalinity (Alk. = 141.21 $mg{\cdot}L^{-1}$ as $CaCO_3$), yet undergoes the largest shift in diatom assemblage composition. Conversely, L25 (Legend), L23 (Otasan), L39, and A86 have undergone relatively little change (DCA axis one $\leq$ 1 SD), yet they are highly acid sensitive (Table 2.1). There also appears to be no relationship between the location of study lakes and the magnitude of floristic change. While the diatom flora in L18 (Namur) undergoes a dramatic shift beginning ca. 1900, the diatom flora in L23 (Otasan), which is located within 30 km of L18 (Namur), remains relatively unchanged. The same is true of L109 (Fletcher) and L107 (Weekes), which are located within 80 km of each other. While L109 has changed substantially over the past 20 years, L107 has remained relatively unchanged. The absence of regional trends strongly suggests that these lakes are not influenced by acid deposition.

The absence of floristic indicators for acidification is consistent with the pH reconstructions, which indicate that pH in Touchwood Lake and L18 (Namur) is increasing, but has remained relatively unchanged in the other study lakes. There are two possible explanations for the pH trends inferred from diatom assemblages in Touchwood Lake and L18. Diatom assemblages in Touchwood Lake and L18 are dominated by *S. minutulus*, an alkaliphilous, eutraphentic species that occurs in only four samples in the ASL training set, and is abundant only in Touchwood Lake and L18 (Namur). Therefore, the calibrated pH optimum for this species is effectively determined by these two lakes. Because Touchwood Lake is alkaline (pH 8.31), the calibrated pH optimum of *S. minutulus* is relatively high (pH 9.32). The inferred pH increase in Touchwood Lake and L18 (Namur) may therefore be artifactual. Alternatively, the pH increase could reflect a transient shift in dissolved inorganic carbon (DIC) speciation in these two lakes. Provided that the rate of fixation of dissolved CO_2 exceeds the rate of CO_2 dissolution, the more acidic carbonate species (H_2CO_3) become diminished relative to the more basic species (HCO_3^- and CO_3^{2-}), causing an increase in pH. This change does not constitute a permanent gain in alkalinity, but is sufficient to produce a distinctly clinograde pH profile in moderately productive lakes. Such a profile is typical of Touchwood Lake during the stratified period, suggesting that the observed increase in diatom-inferred pH is related to carbon fixation. The diatom-inferred pH trend is therefore related either to increasing primary productivity or to increasing thermal stratification, which reduces the rate with which the DIC pool is replenished by vertical mixing. The potential cause of increasing productivity in these two lakes is not clear, although excessive fishing pressure in Touchwood has caused dramatic changes in fish communities, suggesting some means of trophic mediation. Alternatively, climate warming may be causing an increase in the duration and stability of thermal stratification (McCormick 1990, DeStasio *et al.* 1996, Livingstone 2003, Jankowski *et al.* 2006), a trend supported by the available climate data for the region (Chaikowsky 2000, Zhang *et al.* 2000).

The paleolimnological evidence is entirely consistent with surface water chemistry data, which show no recent temporal trends in pH or alkalinity (RAMP 2005b, Schindler 1996, Saffran and Trew 1996). There is some evidence of a decline in base cations in L39, L23 (Otasan), L107 (Weekes) and L109 (Fletcher) in surface water chemistry data collected since 1999, which has been interpreted as an indication that the catchment buffering capacity is becoming depleted (RAMP 2005b). However, this apparent decline is uncorrelated with alkalinity and accompanied by a similar decline in sulphate concentration, suggesting that the cause may be related to hydrology rather than to solute mobility. The reported increase in the base cation concentration in A86 (RAMP 2005b) follows a fire in the spring of 2002, and is likely due to related changes in solute mobility in the catchment rather than increased cation exchange resulting from acid deposition. This change does not appear to be captured in the pH inferred for A86, which is well within natural variability.

The apparent lack of evidence for acidification of any of the study lakes is surprising, given the intensity of acid emission in the region. The rate of SO_2 emission in northeastern Alberta (296.2 $T \cdot day^{-1}$ in 2004;

NPRI) corresponds to approximately 5.2% of Canadian point source SO_2 emissions (5478.3 $T{\cdot}day^{-1}$ in 2004; NPRI) and approximately 4.6% of total Canadian SO_2 emissions (6445.0 $T{\cdot}day^{-1}$ in 2000; NPRI 2002). Dispersion modelling and localised air monitoring/deposition modelling indicates that these pollutants are not exported from the region, but deposited locally (Albian Sands Energy Inc. 2005, EPCM Associated Ltd. 2002).

Estimated rates of total acid deposition for the study lakes, based on regional emissions of 298.3 $T{\cdot}day^{-1}$ SO_2 and 538.4 $T{\cdot}day^{-1}$ NO_x, range from less than 0.104 to 0.135 $keq{\cdot}ha^{-1}{\cdot}yr^{-1}$ (Table 2.1; Albian Sands Energy Inc. 2005). Acid loading to northeastern Alberta lakes has been extensively evaluated in the context of critical loads, calculated using Henriksen and Brakke's (1988) steady state water chemistry model and modified to account for the influence of organic acids calculated as a function of dissolved organic carbon and pH (Cantrell 1990, Roila *et al.* 2004, WRS 2004, RAMP 2005a). This approach permits evaluation of acid loading against a threshold condition. The threshold adopted by the NOx-SOx Management Working Group for northeastern Alberta lakes is a pH of 6.0, taken to be the pH below which many species of freshwater fish exhibit a chronic stress response (ESSA 1987, AENV 1990). Although this approach has limited ecological significance in the context of lakes that are fishless or are naturally acidic, critical loads have provided a reasonable relative measure of acid sensitivity, in units that permit direct comparison with acid loading estimates. While current levels of SO_4^{2+} deposition exceed critical loads for A86, L25 (Legend) and L23 (Otasan), these lakes have clearly not reached the pH 6 threshold condition. Nor do the paleolimnological data provide any floristic evidence for acidification, as indicated by the pH reconstructions. This suggests either that the deposition estimates are inaccurate, that the critical load model does not adequately reflect acid buffering processes, or that geochemical of base cations within the catchment is providing a counterbalance to acidification in the short term.

In the absence of measured rates of acid deposition, estimates have been generated by advective modelling using CALPUFF (Earth Tech, Inc.), an explicitly spatial, non-steady-state dispersion model. Predictions based on emissions generated by existing and approved operations indicate that the dispersion of SO_2 and NO_x will be localised relative to the emission sources. Validation of predicted SO_2 and NO_x dispersion has been conducted using data from Wood Buffalo Environmental Association (WBEA) Terrestrial Environmental Effects Monitoring (TEEM), and Alberta Environment/Environment Canada National Air Pollution Surveillance (NAPS) Network air quality monitoring stations. With the exception of the NAPS station at Fort Chipewyan, all of these stations are in close proximity to the bitumen extraction and processing facilities (URS and Highwood Environmental Management Ltd. 2002). Predicted SO_2 concentrations at Fort Chipewyan consistently fall below measured values (Albian Sands Energy Inc. 2005), suggesting that CALPUFF under-predicts the spatial extent of SO_2 transport. Conversely, the CALPUFF model appears to predict dry deposition with reasonable accuracy. Dry deposition is the most significant component of acid deposition in the region (Nyborg 1985, Bronaugh 1993), but, because of differences in the efficiency of surfaces in scavenging sulphurous gasses and aerosols, is difficult to measure. Estimates of dry deposition at TEEM passive monitoring stations in 1999 and 2000, generated using an inference model (TEEMDEP) developed for the Wood Buffalo Environmental Association, are generally consistent with CALPUFF predictions of total acid deposition (EPCM Associated Ltd. 2002).

A potential reason for the apparent intransigence of the study lakes to acid deposition is biological alkalinity generation. Some fraction of atmospherically derived nitrates and sulphates may be attenuated by biological processes that are not explicitly reflected in critical load models. Fertilisation experiments have demonstrated that peatlands are efficient attenuators of NO_3^- and SO_4^{2-} deposition (Bayley *et al.* 1987, Morgan and Mandernack 1996). The primary mode of NO_3^- attenuation in peatlands is assimilatory, reflecting the nitrogen limitation that is common in wetland ecosystems (Sanville 1988, Urban *et al.* 1988, Thormann and Bayley 1997). This is evident in regions of northeastern Alberta that experience elevated rates of nitrogen deposition (2.13-3.26 kg $N \cdot ha^{-1} \cdot yr^{-1}$), in the increased productivity of *Sphagnum fuscum* (Vitt *et al.* 2003). Given the spatial extent of peatlands throughout the region, the assimilation of atmospheric nitrogen in the landscape is probably a far more important factor in the attenuation of acid loading than is currently supposed. However, while peatlands appear to effectively attenuate nitrogen deposition in the short term, long-term nitrogen fertilisation has the potential to alter peatland communities, thus reducing their capacity to assimilate nitrogen. As well, the capacity for peatlands to assimilate nitrogen can become diminished under water stress (Aldous 2002, Vitt *et al.* 2003), suggesting that climate warming may increase the susceptibility of the region to acid deposition.

The attenuation of SO_4^{2-} in wetlands occurs both by sulphate assimilation and by dissimilatory sulphate reduction (Hemond 1980, Bayley *et al.* 1987, Urban *et al.* 1989). The relative importance of these processes is quite variable, although dissimilatory sulphate reduction may increase with increasing SO_4^{2-} deposition, as the rate sulphur assimilation is related to biomass, and is generally not considered to be growth limiting (Gorham *et al.* 1984). The permanence of sulphur retention in peatlands appears to be controlled by the maintenance of a stable redox profile, and by hydrology. Under conditions of high throughflow, the contact of SO_4^{2-} bearing waters with vegetation and sulphate reducing flora is reduced, and SO_4^{2-} attenuation will be limited. Conversely, drawdown of the water table under drought conditions exposes reduced sulphur to oxidation and subsequent remobilisation (Yan *et al.* 1996, Devito and Hill 1997, Morth *et al.* 1999). It follows that the conveyance of SO_4^{2-} to surface waters will increase under drought conditions.

Similar modes of NO_3^- and SO_4^{2-} attenuation also operate to generate alkalinity in surface waters, effectively lowering the concentration of acid anions by the generation of non-ionic forms of reduced sulphur and nitrogen. As in peatlands, the primary mode of NO_3^- attenuation in lakes occurs by assimilation. Under conditions of phosphorus limitation, the rate of NO_3^- assimilation by algal production is relatively insensitive to NO_3^- loading, and NO_3^- assimilation occurs primarily by denitrification at the sediment-water interface (Schindler *et al.* 1985). The efficiency of this process is limited by the diffusion of NO_3^- to the sediments and, but is generally greater than that of SO_4^{2-} reduction (Rudd *et al.* 1990). Biologically mediated SO_4^{2-} reduction also occurs at a far greater rate in sediments than in the water column (Cook *et al.* 1986, Schiff and Anderson 1987, Rudd *et al.* 1990). As with NO_3^-, SO_4^{2-} assimilation by algae rarely limits the rate of primary productivity, and is not likely to directly impinge on the composition of sediment diatom assemblages. Conversely, bacterial SO_4^{2-} reduction is limited by the rate of SO_4^{2-} diffusion at the sediment-water interface, and can be expected to respond to SO_4^{2-} loading. The removal of reduced sulphur from further biogeochemical cycling occurs either by permanent burial or by evolution of H_2S to the atmosphere. Bacterial SO_4^{2-} reduction generates various organic products and metal sulphides, principally FeS. Provided that there is a sufficient abundance of reduced iron, the formation of iron sulphides will be the dominant mode of SO_4^{2-} attenuation (Schindler 1985).

Whether the study lakes have responded to enhanced NO_3^- deposition with an increase in algal productivity is not clear. While some of the study lakes, notably L18 (Namur) and L109 (Fletcher), have become more productive within a timescale that would be consistent with enhanced of NO_3^- deposition, the productivity of neighbouring lakes (L23, L25, and L107) that are presumably subject to equivalent rates of deposition remains unaltered. Conversely, recent floristic changes in L18 and L109 are characterised by taxa (*Stephanodiscus minutulus and Cytclotella pseudostelligera*) that are associated with nutrient enrichment (Siver 1999, Reavie and Smol 2001). While SO_4^{2-} deposition is unlikely to produce an equivalent change in algal productivity, principle components analysis of water chemistry from 35 boreal lakes in and around Wood Buffalo National Park, located on the border between Alberta and the Northwest Territories, shows a positive correlation of SO_4^{2-} with pH, and an inverse correlation of SO_4^{2-} with Fe and Al, suggesting that sulphate reduction is a significant source of alkalinity in these lakes (Moser *et al.* 1998).

CONCLUSIONS

Although stratigraphic analyses of diatom assemblages suggest that several of the study lakes have undergone significant limnological change, these changes are not consistent with acidification. Diatom-based pH inference models bear out this conclusion, and indicate that several of the study lakes have actually become more alkaline. This may reflect increasing primary productivity or increasing thermal stability associated with climate warming. The absence of paleolimnological evidence for acidification contradicts critical load models that suggest, based on current rates of acid deposition, that at least three of the eight study lakes (A86, L25, and L23) are being acidified. The current mass balance approach to critical loads does not account for the removal of NO_3^- and SO_4^{2-} by assimilatory or dissimilatory reduction, and likely under-represents acid neutralising capacity, particularly at a catchment scale. Although we do not present direct geochemical evidence of biologically-mediated alkalinity generation in the study lakes, the apparent resilience of these lakes under current rates of acid loading demonstrates the importance of these processes. Careful appraisal of the contribution of NO_3^- and SO_4^{2-} reduction to alkalinity budgets should be a consideration in future acid loading assessments.

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CHAPTER THREE: Recent ecological change in northeastern Alberta lakes, inferred from sediment microfossils

ABSTRACT

Sediment cores from eight boreal lakes along a 550 km north-south transect through northeastern Alberta provide a record of non-uniform, directional ecological change occurring during the past 100-150 years. This ecological change, recorded from microfossil assemblages, involves progressive increases in the frequency of chrysophytes and planktonic diatoms, notably the small centrics *Stephanodiscus minutulus* and *Cyclotella pseudostelligera*, which have recently been linked to environmental change in other regions of Canada's north. Not all of the lakes show the same magnitude of change; indeed, three of the lakes have changed very little over the entire period of record. As well, many of the observed changes are non-synchronous, and do not exhibit a strong spatial pattern. These differences reflect the importance of site-specific environmental factors in mediating the effects of environmental change. The chronology of the changes implies several causal factors. Climate change, mediated by physical factors, may be responsible for longer-term ecological shifts. This is indicated by a gradual alkalinising trend in two of the study lakes that suggests stronger, more persistent vertical stratification, and by the greater depth of the affected lakes. Overprinted on these long-term trends are the effects of forest fire, fishing, and nitrogen deposition associated with bitumen extraction. These results provide the first evidence of widespread ecological change in these northern ecosystems.

INTRODUCTION

Boreal lakes and ponds in northeastern Alberta are under intense pressure from a large suite of anthropogenic stressors. Many of these stressors are attributable to the unconstrained expansion of oil sands industry occurring in the area of Fort McMurray and Fort MacKay. There is a common perception that the acute ecological disturbances associated with bitumen extraction are limited to the immediate area of the oil sands leases, such that much consideration has been given to site remediation and reclamation. However, the convergence of climate warming and atmospheric nitrogen and sulphur deposition is yielding incipient ecological change over a far more extensive area (Halsey *et al.* 1995, Moser *et al.* 2002). The scope and magnitude of this change is not immediately apparent in the existing surface water quality record which, although extensive, does not yet permit trends to be distinguished from natural variability (e.g. Schindler 1996, RAMP 2005). Nonetheless, there is paleoecological evidence for environmental change in lakes throughout the region (Moser *et al.* 2002, Pla *et al.* 2006). These changes are not common to all lakes in the region (Prather and Hickman 2000, Philibert *et al.* 2003), suggesting complex mediation by biogeochemical processes at the catchment scale. Many of these processes, particularly those related to climate warming, are poorly constrained in the northern boreal ecoregion, such that their effects on aquatic ecosystems are difficult to predict.

Northeastern Alberta has been subject to gradual warming of nearly 4°C over the past century (Zhang *et al.* 2000, Chaikowsky 2000), a climate trend that is exerting a profound effect on the region. Much of northern Alberta is located within a zone of discontinuous permafrost, the southern boundary of which is being eroded by a long-term warming trend that has extended the frost-free season by 40-60 days over the past century (Halsey *et al.* 1995, Shen *et al.* 2005). Lengthening of the frost-free period, deepening of the active permafrost layer, or permanent degradation of permafrost due to climate warming may alter hydrologic processes to the extent that water bodies within the zone of discontinuous permafrost shrink or disappear entirely (Smith *et al.* 2005). For lake ecosystems, the consequence of continued warming may include a general increase in primary productivity (eutrophication), mediated by such factors as enhanced nutrient cycling, changes in thermal structure, and lengthening of the ice-free season (Rouse *et al.* 1997, Schindler 1997, Hinzman 2005).

Warm and dry conditions stress ecosystems, and may cause an increase in the frequency and intensity of forest fire (Chapin 2000). Fire enhances the mobilisation of plant- and soil-bound nutrients, increasing their fluxes to surface waters and augmenting productivity (Bayley *et al.* 1992, McEachern *et al.* 2000, Charette and Prepas 2003). Fire may also accelerate permafrost melting by removing vegetation that insulates frozen ground, and by increasing the capacity of the landscape to absorb heat. The catchments of several of the study lakes have been subject to fire during the past three decades, providing an opportunity to evaluate the effect of fire relative to other stressors.

Nitrogen deposition may also enhance productivity of lakes in the region, many of which are nitrogen limited (Hickman 1980, Prepas and Trew 1983). While surface water monitoring does not provide any indication of eutrophication, it is not clear that the early data constitute a true baseline or reference state. Emissions of SO_2 and NO_x from bitumen extraction and processing are causing a net increase in the primary productivity of peatlands located near the emission sources (Vitt *et al.* 2003), and may also be causing acidification of some soils (Nyborg *et al.* 1991). Although dispersion and deposition modelling indicates that deposition of atmospheric nitrogen and sulphur pollutants will be relatively localised (Albian Sands Energy Inc. 2005), this claim has yet to be properly validated.

Ongoing monitoring of an extensive suite of lakes (n=50) throughout northeastern Alberta has not yet revealed any trends that would indicate environmental change (RAMP 2005). However, many of the environmental stressors that impinge in these lakes operate on a time scale that exceeds the duration of the sample record. We therefore consider eight of these lakes located along a north-south transect through the discontinuous permafrost zone, using paleoecological techniques to examine ecological changes during the past century. We examine the nature and extent of ecological change relative to the known environmental stressors, and explore the potential linkages between these stressors and the ecological response.

METHODS

Study sites

The study area spans several distinct physiographic and geological regions of northeastern Alberta, comprising upland areas composed of dark grey and silty Cretaceous shales draped by fine glaciofluvial till, and the Archaean granite of the Canadian Shield to the northeast (Fig. 3.1). The entire study area lies within a zone of discontinuous permafrost that varies in areal extent from 0 to 50%. Ground frost persists for much of the year throughout the region, resulting in discontinuous groundwater flows. Peatlands predominate in the catchments of upland lakes and the wetlands surrounding the shield lakes. Lowland areas of the study catchments comprise all peatland types, from a predominance of continental bogs with a closed canopy of black spruce (*Picea mariana*) to wooded fens of black spruce and larch (*Larix larcina*) to open fens. Upland vegetation in the study area generally consists of closed canopy mixedwood forest comprising aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and white spruce (*Picea glauca*), or jack pine (*Pinus banksiana*) in more xeric areas. The influence of ground frost, permafrost, and peatlands yields groundwater that is rich in dissolved organic material and often has low concentrations of inorganic solutes due to limited contact with subsurface minerals.

These catchment characteristics are reflected in the water chemistry of the study lakes, which tend to be dilute and darkly stained (Table 3.1). The study lakes range in productivity from relatively oligotrophic ($TP < 10\ \mu g \cdot L^{-1}$) L107 (Weekes) to eutrophic ($TP > 35\ \mu g \cdot L^{-1}$) L39 and L25 (Legend). The DIN:TP ratio is low in all of the study lakes, particularly those located in the Birch Mountains (L18, L23, and L25) and on the Athabasca Plain (L39), suggesting nitrogen limitation.

The eight study lakes are subject to varying levels of disturbance. Pipeline rights-of-way effectively bisect the catchment of A86, with unknown effects on hydrology. It is not clear when the pipelines were constructed, but it was probably within the last ten years. Although forestry in the region is generally limited to salvage logging, several of the study catchments have burnt during the past quarter century. These fires were typically quite large, resulting in deforestation of at least 50% of the catchment that was still evident at the time of sampling (Table 3.1). Two of the lakes have also been subject to pressure from commercial and recreational fishing, which raises the possibility that trophic interactions could impinge on algal communities. Namur Lake (L18), the largest of the study lakes, is host to a fly-in fishing lodge and a modest subsistence fishery, and has been fished commercially in the past. Touchwood Lake is subject to intense fishing pressure that has caused the collapse of several sportfish populations over the past century,

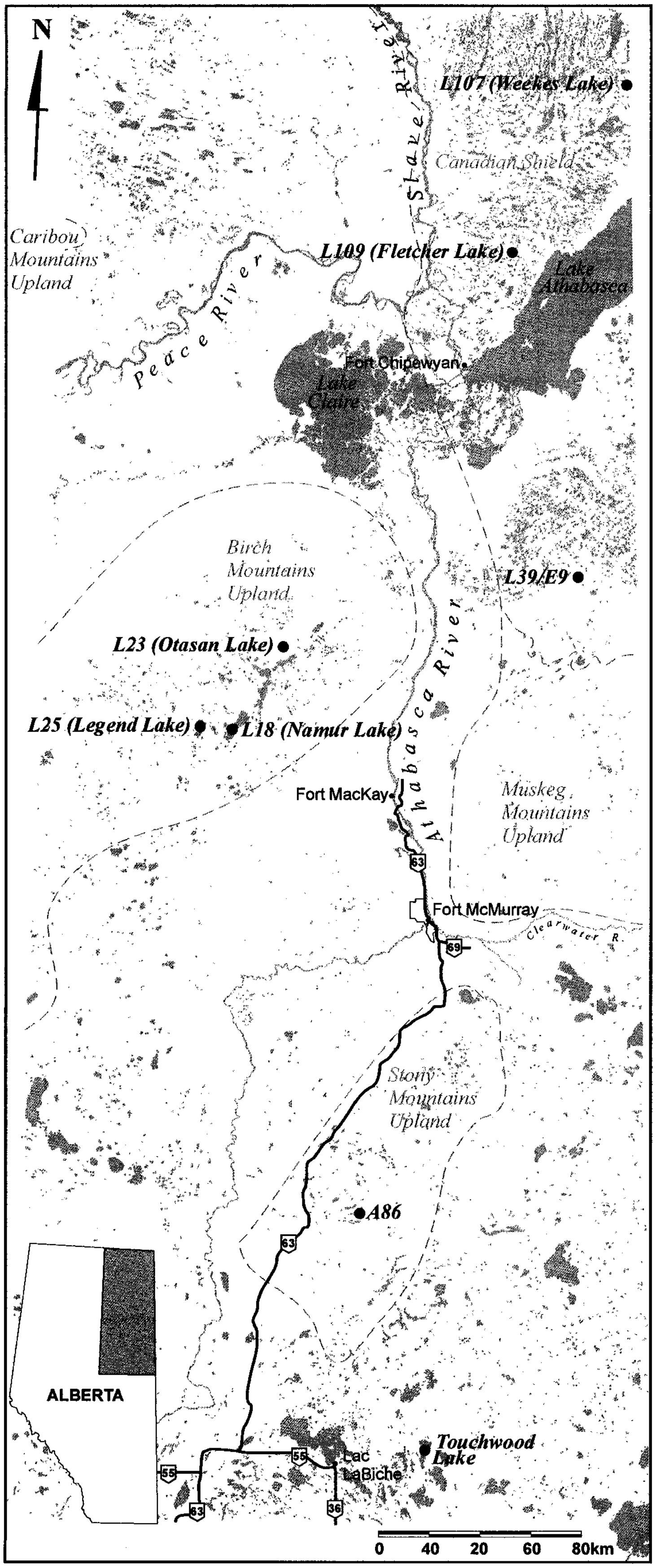


Figure 3.1. Map of northeastern Alberta, Canada, showing the location of the eight study sites

	Latitude deg. N	Longitude deg. W	Elevation m asl	Catchment area ha	Basin area ha	Depth m	DIN $mg \cdot L^{-1}$	TN $mg \cdot L^{-1}$	TP $mg \cdot L^{-1}$	DIN:TP mass ratio	TN:TP mass ratio	DOC $mg \cdot L^{-1}$	pH	Alk $mg \cdot L^{-1}$ as $CaCO^3$	Burnt (year)
L25 (Legend)	57.4122	112.9336	789	6835	1685	9.1	29.6	523.44	37.58	0.79	13.93	9.21	6.82	9.61	1981, 1998
L18 (Namur)	57.4444	112.6211	724	16362	4322	31.3	15.4	351.83	20.47	0.75	17.19	8.91	7.22	21.00	1981, 1998
L23 (Otasan)	57.7072	112.3875	747	3375	348	10.7	16.5	576.62	17.95	0.92	32.12	14.15	6.82	8.82	
L109 (Fletcher)	59.1210	110.8200	287	11129	103	12.9	18.4	785.20	13.43	1.37	58.45	20.02	7.06	19.60	
L107 (Weekes)	59.7180	110.0140	340	1680	340	27.4	8.0	507.26	5.22	1.53	97.18	11.45	7.22	23.75	1979
L39/E1	57.9583	110.3833	356	1714	116	1.2	19.0	1632.50	41.97	0.45	38.90	15.40	6.85	11.05	1981
A86	55.6811	111.8268	670	726	148	3.0	49.9	1237.71	31.50	1.58	39.29	16.62	6.63	6.93	2002
Touchwood	54.8250	111.4042	632	11100	2900	40.0	31.9	767.14	18.40	1.74	41.70	11.17	8.31	141.21	

Table 3.1. Selected limnological characteristics of the study lakes. Data are selected from the 1999-2004 RAMP acid sensitive lakes database and from the Alberta Environment surface water quality database (WDS).

and the extirpation of lake trout (*Salvelinus namaycush*). Of the eight study lakes, only L109 and L23 have not been directly disturbed in some way.

Sediment coring and chronology

Sediment cores were retrieved in 2003 and 2004 from a central point in the basin, with a modified Kajak-Brinkhurst gravity corer (Glew 1989). The cores were extruded immediately upon retrieval and sectioned at 0.25 cm increments to 10 cm, 0.50 cm increments from 10 to 20 cm, and 1.00 cm increments thereafter, with the exception of the cores from Touchwood Lake and A86, which were sectioned at 0.50 cm increments to 20 cm, and 1.00 cm increments thereafter. Samples were frozen upon return from the field, and freeze-dried for further analysis and archiving. Sediment chronology was estimated by α-spectrometry of ^{210}Po, a radioactive decay product of ^{210}Pb (Fig. 3.2). Assuming a constant rate of ^{210}Pb deposition (Constant Rate of Supply, CRS) and adjusting for a variable rate of sediment accumulation, the decay of ^{210}Pb (half-life = 22.3 years) is used to estimate the age of lake sediments to approximately 100-120 years (~5 half-lives), after which the measurement uncertainty becomes greater (Appleby and Oldfield 1978, Appleby 2001).

Microfossils

Prior to mounting, organic matter was oxidised by digestion with H_2O_2. A small amount (0.1 – 0.2 g) of freeze-dried sediment was heated to 70°C in 30% H_2O_2 for the period required to remove organic colouration (2-14 days), centrifuged, rinsed, and diluted to 10 mL. A 200μL aliquot was diluted with distilled water (usually 5 to 10 mL) to produce a sufficiently dilute suspension for counting. A known concentration of *Eucalyptus globulus* pollen was added to this suspension to permit estimation of absolute microfossil abundance. The pollen was suspended in a viscous fructose solution that has the additional property of promoting even distribution of pollen and diatoms during mounting. A 200μL aliquot of the dilute sediment suspension was then placed on a coverslip, air dried, and permanently mounted in a high refractive index mounting medium (Naphrax®). Diatoms and chrysophyte cysts and scales were counted in full transects under 1000x magnification oil immersion. A minimum of 400 diatom valves were identified and counted per slide, using standard freshwater floras (Krammer and Lange-Bertalot 1986-1991, Simonsen 1987, Camburn and Charles 2000, Fallu *et al.* 2000). Chrysopyte scales were identified to the species level (Siver 1991); chrysophyte cysts were only counted, not identified. Identification of diatoms in Touchwood Lake was conducted independently, and the taxonomy harmonised by comparison of photomicrographs. Diatom counts are presented as percent relative abundance, while chrysophyte cysts and scales are presented as absolute abundance. Only species that comprise >5% of the total assemblage are shown (Fig. 3.3).

Geochemistry

Measurements of the total abundance of C and N, as well as their stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$), were conducted to provide an indication of change in the flux and the source of sedimentary organic material. All measurements were made on a continuous flow isotope ratio mass spectrometer (Europa Hydra 20/20 IRMS, UC Davis Stable Isotope Facility, ± 0.3‰ $\delta\,^{15}N$, ± 0.2‰ $\delta\,^{13}C$). Analyses were not conducted on sediments from Touchwood Lake, which was not included in the original suite of seven core samples. Elemental abundance is reported as grams per mass dry weight, while C:N is reported as a molar ratio. Stable isotope ratios are reported in the standard delta notation ($R_{\text{sample}}/R_{\text{standard}}$), where the standards for C and N are PDB and atmospheric nitrogen, respectively.

Multivariate analysis

Cannonical Correspondence Analysis (CCA) constrains species assemblage data to the surface water chemistry data. This approach is indicated by the relatively long first DCA (Detrended Correspondence Analysis) gradient (3.12 λ), and assumes a unimodal response of species data to environmental gradients. Raw diatom and chrysophyte species abundance data were square root transformed, and rare species downweighted. Surface water chemistry data collected between 1999 and 2004 over the course of the RAMP (2005) acid lakes sampling program and, in the case of Touchwood Lake, between 1986 and 2001 by Alberta Environment, contain a large number of highly collinear parameters. Because of substantial collinearity among the environmental parameters, only three parameters were chosen by manual forward selection, using tests of significance under Monte-Carlo permutations. These parameters (pH, TP, and TN) have very low (<2) inflation factors indicating limited co-linearity, and are widely understood to have a significant influence on algal communities. The selected parameters were used to constrain variance only in surface sediment assemblages, while the remaining samples were included as passive variables. The trajectories described by samples arranged stratigraphically therefore reflect change along gradients constrained by the environmental data, without resort to an explicit model. Ordinations were carried out using CANOCO version 4.5 (ter Braak and Šmilauer 2002)

RESULTS

Chronology

Sediment deposition rates vary substantially among the study lakes, with the unsupported ^{210}Pb inventory contained within the upppermost 10 cm (L39) to 30 cm (Touchwood; Fig. 3.2). There are no significant reversals in unsupported ^{210}Pb activity, suggesting that sedimentation rates have remained relatively constant, and that the cores are coherent.

Microfossil Stratigraphy

A total of 280 diatom taxa were identified during the course of the study (*Appendix 1*). The composition of diatom assemblages varies substantially among lakes, reflecting a broad range of limnological characteristics and habitats. Prior to c. 1950, diatom assemblages in L109 (Fletcher) and L25 (Legend) were dominated by small colonial *Fragilaria* spp. *sensu lato* (*Staurosirella pinnata* and *Staurosira construens var. venter, sensu* Round *et al.* 1990) and *Aulacoseira subarctica*. L23 (Otasan) and A86 were also dominated by small *Fragilaria* spp. (*F. pinnata* and *F. construens var. venter*) to the extent that these species frequently comprised more than 50% of the diatom assemblage. Sediment assemblages from L39

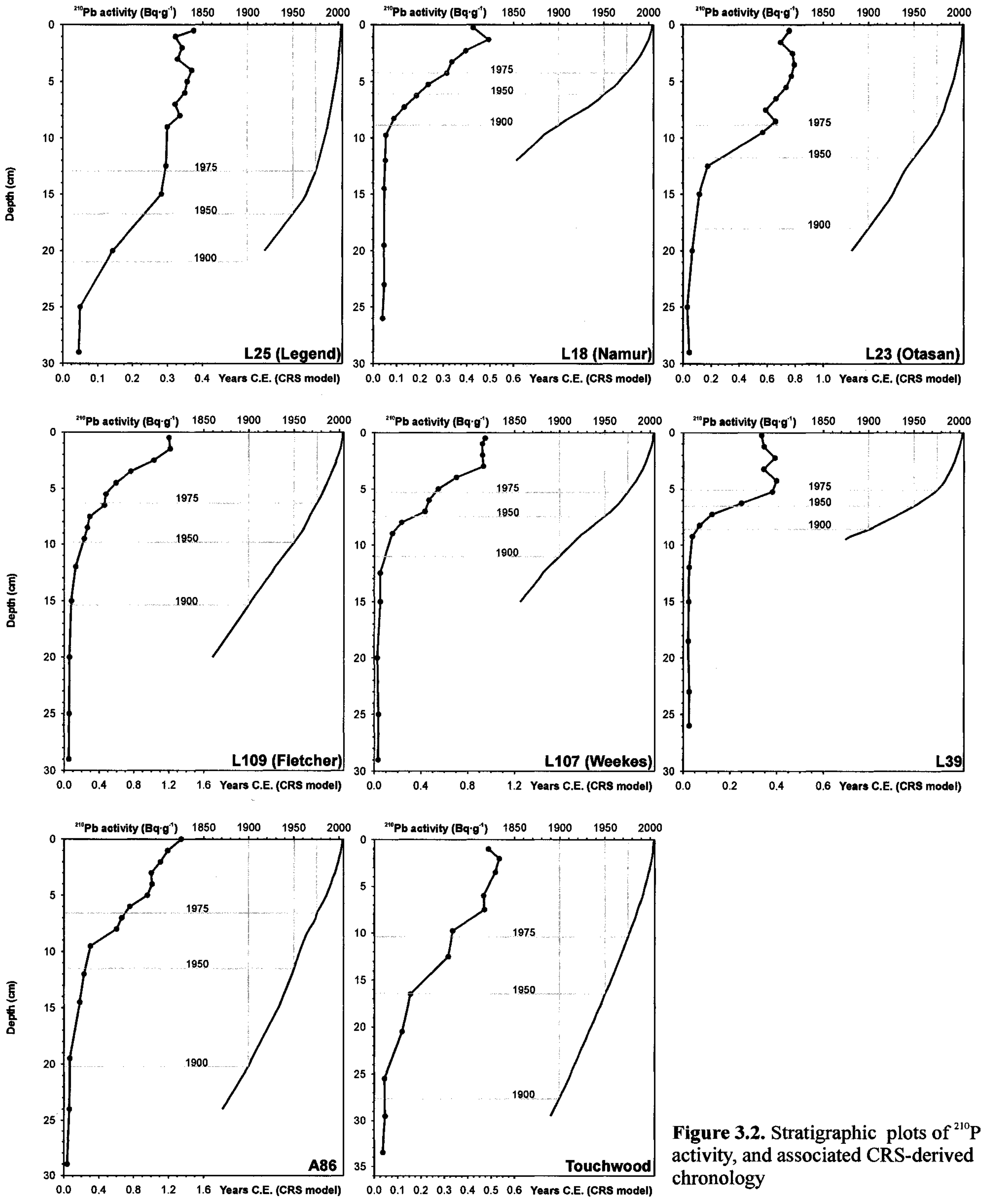


Figure 3.2. Stratigraphic plots of ^{210}Pb activity, and associated CRS-derived chronology

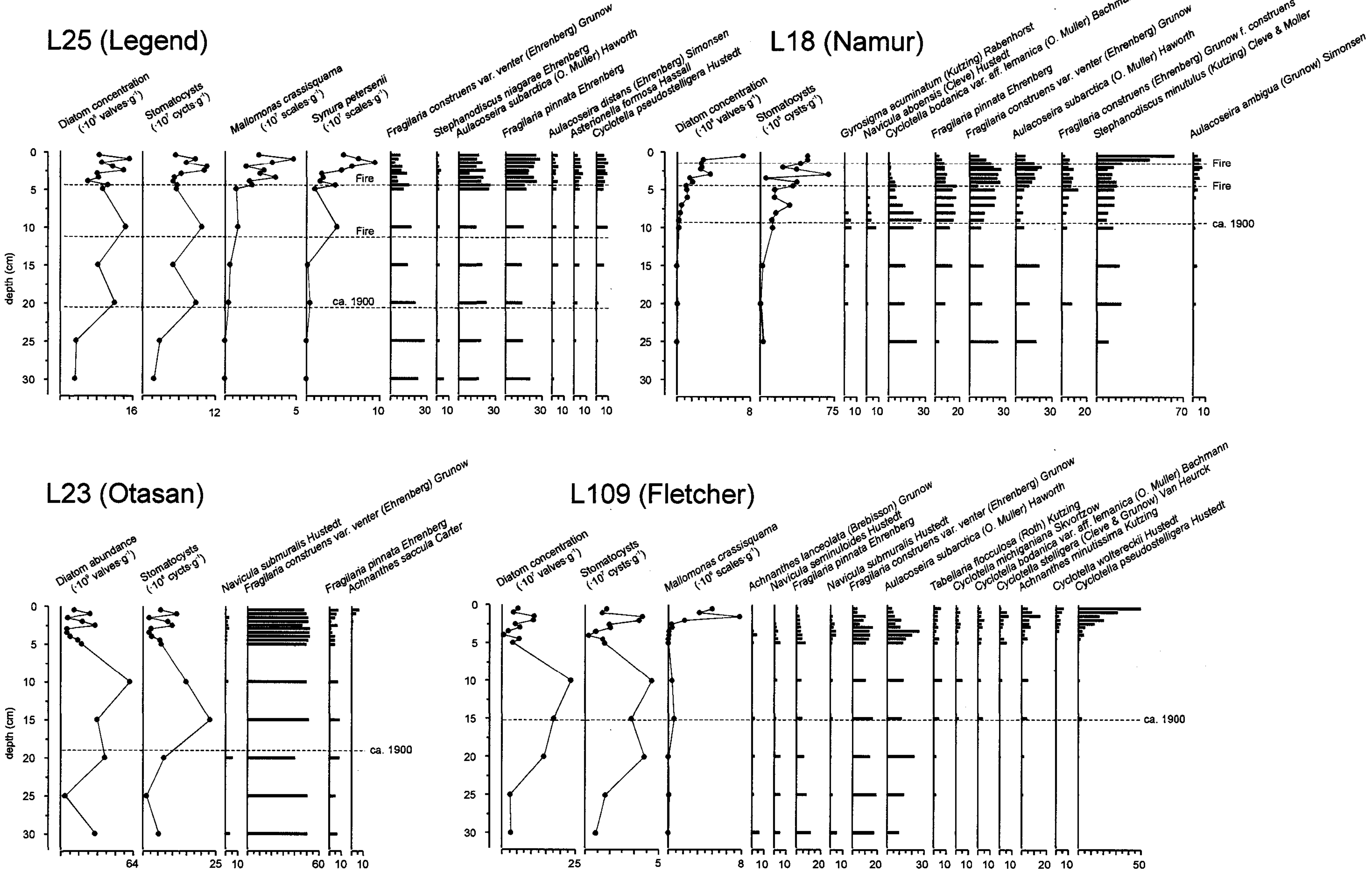
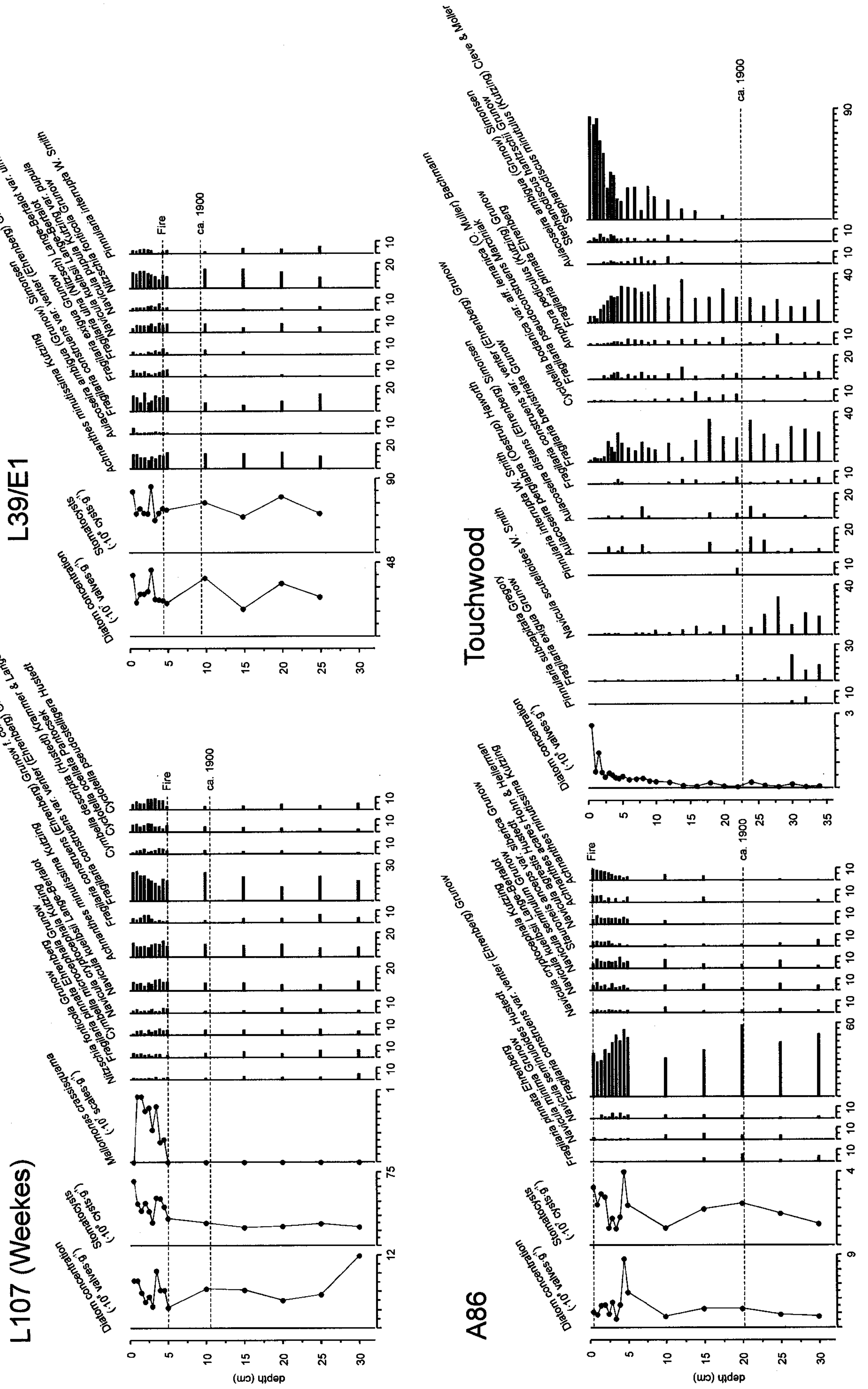


Figure 3.3. Relative frequency of common (>5%) diatom taxa in sediment cores from the eight study lakes. Total abundance of scaled chrysophytes, stomatocycts, and diatom valves is relative to sediment dry mass.


L107 (Weekes)
Diatom concentration (·10⁷ valves g⁻¹)
Stomatocysts (·10⁶ cysts g⁻¹)
Mallomonas crassisquama (·10⁵ scales g⁻¹)
Nitzschia fonticola Grunow
Fragilaria pinnata Ehrenberg
Cymbella microcephala Grunow
Navicula cryptocephala Kützing
Navicula kuelbsii Lange-Bertalot
Achnanthes minutissima Kützing
Fragilaria construens (Ehrenberg) Grunow f. construens
Fragilaria construens var. venter (Ehrenberg) Grunow
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot
Cyclotella ocellata Pantocsek
Cyclotella pseudostelligera Hustedt
Fire
ca. 1900
L39/E1
Diatom concentration (·10⁷ valves g⁻¹)
Stomatocysts (·10⁶ cysts g⁻¹)
Achnanthes minutissima Kützing
Aulacoseira ambigua (Grunow) Simonsen
Fragilaria construens var. venter (Ehrenberg) Grunow
Fragilaria exigua Grunow
Fragilaria ulna (Nitzsch) Lange-Bertalot
Navicula kuelbsii Lange-Bertalot
Navicula pupula Kützing var. pupula
Nitzschia fonticola Grunow
Pinnularia interrupta W. Smith
A86
Diatom concentration (·10⁷ valves g⁻¹)
Stomatocysts (·10⁶ cysts g⁻¹)
Fragilaria pinnata Ehrenberg
Navicula minima Grunow
Navicula seminuloides Hustedt
Fragilaria construens var. venter (Ehrenberg) Grunow
Navicula cryptocephala Kützing
Navicula kuelbsii Lange-Bertalot
Navicula seminulum Grunow
Stauroneis anceps var. siberica Grunow
Navicula agrestis Hustedt
Achnanthes acares Hohn & Hellerman
Achnanthes minutissima Kützing
Touchwood
Diatom concentration (·10⁷ valves g⁻¹)
Pinnularia subcapitata Gregory
Fragilaria exigua Grunow
Navicula scutelloides W. Smith
Pinnularia interrupta W. Smith
Aulacoseira perglabra (Oestrup) Haworth
Aulacoseira distans (Ehrenberg) Simonsen
Fragilaria construens var. venter (Ehrenberg) Grunow
Fragilaria brevistriata Grunow
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann
Fragilaria pseudoconstruens Marciniak
Amphora pediculus (Kützing) Grunow
Fragilaria pinnata Ehrenberg
Aulacoseira ambigua (Grunow) Simonsen
Stephanodiscus hantzschii Grunow
Stephanodiscus minutulus (Kützing) Cleve & Moller
depth (cm)
0
5
10
15
20
25
30
35
1
3
4
9
10
12
20
30
40
48
60
75
90

and L107 (Weekes) were not dominated by any one species, but contained consistently low concentrations of eurytopic *Achnanthes* and L107 (Weekes) were not dominated by any one species, but contained consistently low concentrations of eurytopic *Achnanthes minutissima*, *Navicula kuelbsii*, *Nitzschia fonticola* and *F. construens var. venter*, in addition to *Cyclotella ocellata* and *Cymbella descripta* in L107.

Of these six lakes, the most pronounced stratigraphic change occurs in L109 (Fletcher), with an abrupt increase in the relative abundance of *Cyclotella pseudostelligera* from trace abundance before c. 1985 to 50% in surface sediments. Other taxa, notably *F. construens var. venter* and *A. subarctica*, show a concomitant decline over the same period. Stratigraphic changes in L25 (Legend) are subtler, and occur on a timescale that extends slightly beyond those in L109 (Fletcher). The relative abundance of *Asterionella formosa* and *Cyclotella pseudostelligera* shows a modest increase accompanied by a decrease in *F. construens var. venter* beginning c. 1950, although the structure of diatom assemblages remains relatively unchanged from c. 1980 to present. The remaining four lakes (L23, L107, L 39 and A86) have relatively little stratigraphic change over the period of record. *F. construens var. venter* declines consistently from c. 1985 to present in A86, however this shift is well within normal variability. This is also true of the apparent increase in the same species in L107 (Weekes), which occurs over the same period.

The scaled chrysophytes *Mallomonas crassisquama* and *Synura petersenii*, a colonial form, are present in three of the study lakes where, without exception, they are becoming more abundant. Both species were virtually absent from L25 prior to 1900 but have increased steadily since then, particularly during the past few decades. *Mallomonas crassisquama* first appeared in L107 ca. 1980, but is absent from the surface sediments. As in L25, *M. crassisquama* was absent from L109 prior to 1900, but has increased dramatically during the past decade.

Changes in the diatom stratigraphy of L18 (Namur) and Touchwood Lake predate those in other study lakes by about 50 years. Prior to c. 1900, sediment diatom assemblages in L18 (Namur) were typical of a deep, moderately productive, alkaline northern lake, and were comprised of more or less equivalent concentrations of *Fragilaria* spp. (*F. pinnata* and *F. construens var. venter*), *Cyclotella bodanica var. aff.*

lemanica, *A. subarctica*, and *Stephanodiscus minutulus*. Touchwood Lake was dominated in more or less equal proportion by small *Fragilaria* spp. *s.l.* (*S. pinnata* and *Pseudostaurosira brevistriata, sensu* Round *et al.* 1990, and *Stauroforma exiguiformis sensu* Flower *et al.* 1996) and *Navicula scutelloides*.

Sediment diatom assemblages in L18 (Namur) and Touchwood begin to change progressively around 1900. In L18 (Namur), *C. bodanica var. lemanica* declines dramatically from a maximum of 27% c. 1900 to less than 1% in surface sediments, accompanied by a similar decline in the less abundant *Gyrosigma acuminatum* and *Navicula aboensis* (Fig. 3.3). A concomitant increase in the relative abundance of *F. construens var. venter* and *A. subarctica* is followed by a sudden decline in these species c. 1990, accompanied by a notable increase in hypereutraphentic *S. minutulus* from approximately 15% prior to c. 1990 to 62% in surface sediments (Fig. 3.3). Diatom concentrations rise steadily throughout the 20th century, providing additional evidence for the increase in total productivity indicated by the presence of *S. minutulus*. There is also a steady increase in the abundance of chrysophyte stomatocycts that appears to predate the onset of significant changes in diatom communities. Although this heterogeneous grouping of stomatocysts can provide little in the way of specific ecological information, at the very least this change reflects the apparent increase in productivity indicated in the increasing diatom concentration.

The stratigraphic changes in Touchwood Lake are structurally similar to those in L18 (Namur), although on a slightly different time scale. *F. exigua* and *N. scutelloides* decline from respective maxima of 22% and 31% c. 1900 to apparent absence in surface sediments. *F. brevistriata* and *F. pinnata* are both relatively abundant (20-30%) until c. 1990, after which they decline to less than 6% in surface sediments. The decline of these small *Fragilaria* spp. in part reflects the ascendance of *S. minutulus*, which first occurred c. 1930 and increased exponentially in abundance to 84% in surface sediments (Fig. 3.3). As in L18, the diatom concentration in Touchwood has increased dramatically, particularly during the past decade.

Multivariate analysis

The CCA results are presented as a biplot of the first two CCA axes ($\lambda_1 = 0.46$ or 23.0%; $\lambda_2 = 0.29$ or 14.5%), in which the passive samples indicate the trajectory of the sample lake through the ordination space defined by the eight surface sediment samples and the three water chemistry parameters (Fig. 3.4). The significance of the pH vector, determined by Monte-Carlo permutation, is far greater ($p<0.01$) than that of the TP and TN vectors (Table 3.2). Notwithstanding the relatively low inflation factors, this reflects, in part, the collinearity of the parameters. The length of the trajectories indicates the amount of change that each lake has undergone, relative to the constraints imposed on the ordination space by the environmental parameters. By this measure, Touchwood Lake has clearly undergone the most extensive ecological change. The Touchwood trajectory runs nearly parallel to the pH vector, indicating an increase in pH. By comparison, the other seven study lakes exhibit relatively little change along any of the three eigenvectors, suggesting that the ecological change evident in the microfossil stratigraphy (Fig. 3.3) reflects environmental change that is not necessarily related to measurable change in surface water chemistry. This is consistent with the indications of diatom-based pH inference models applied to the study lakes, which show that the pH in Touchwood Lake and L18 is increasing, while the other study lakes have remained relatively unchanged.

Parameter	P-value	F-value	Inflation factor
pH	0.006	1.66	1.6744
TN	0.440	1.05	1.5611
TP	0.446	1.02	1.1183

Table 3.2. Results of Monte-Carlo permutation (n = 499) of parameters included in CCA

Sediment geochemistry

Stratigraphic trends in the geochemical data tend to be rather weak, and are typically within natural variability (Fig. 3.5). There do not appear to be any significant deflections in sediment $\delta^{15}N$ or in C:N ratios associated with recent increases in NO_x emissions from oil sands industry. With the possible exception of L107, the $\delta^{13}C$ of bulk sediment has also remained fairly constant in all of the study lakes. The apparent depletion of the heavier carbon isotope (^{13}C) by approximately 2‰ in L107 suggests a relatively consistent trend, but this change is not accompanied by anything other than what appears to be a diagenetic fractionation of the sediment $\delta\,^{15}N$.

A significant difficulty in the interpretation of the geochemical stratigraphies consists in distinguishing primary versus diagenetic signals. Diagenetic processing affects the elemental composition of sediments by preferentially depleting the more labile organic fraction, resulting in a gradual increase in the C:N ratio. Diagenesis poses a similar problem in relation to the interpretation of stable C and N isotope ratios in sediments. For example, if the origin of the labile fraction differs from that of the refractory fraction, the bulk sediment stable isotope signal can be altered by preferential degradation of the labile fraction. This undoubtedly occurs in the darkly stained study lakes, for example, where a significant portion of the refractory organic pool is likely to be of allochthonous origin, while the labile pool is more likely to comprise autochthonous material.

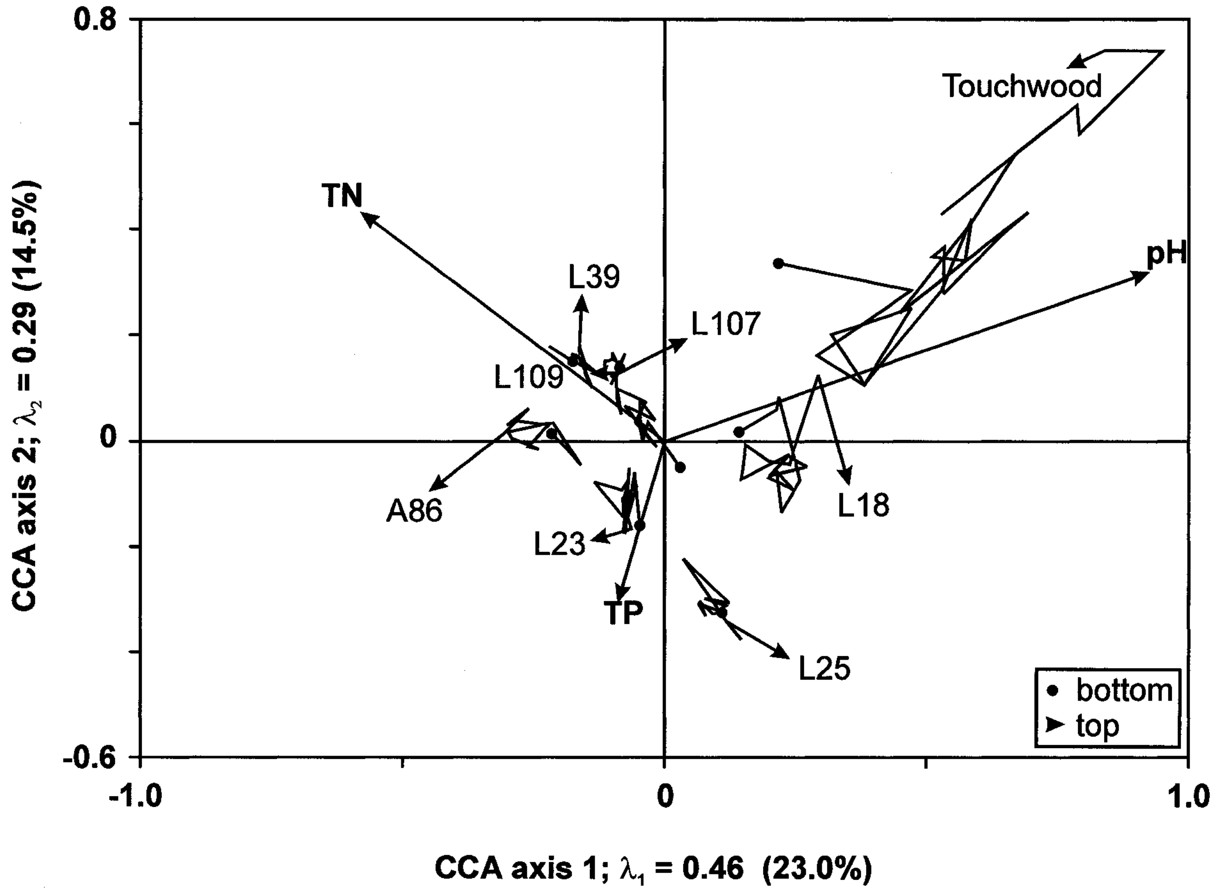


Figure 3.4. Cannonical correspondence analysis using diatom and chrysophyte absolute abundance data. Surface sediment data are constrained to the environmental variables (TP, TN, pH); remaining samples are unconstrained (passive), forming trajectories through the ordination space defined by the environmental variables. The position of a sample along an environmental vector indicates the position of that sample along the environmental gradient defined by that vector, relative to other samples.

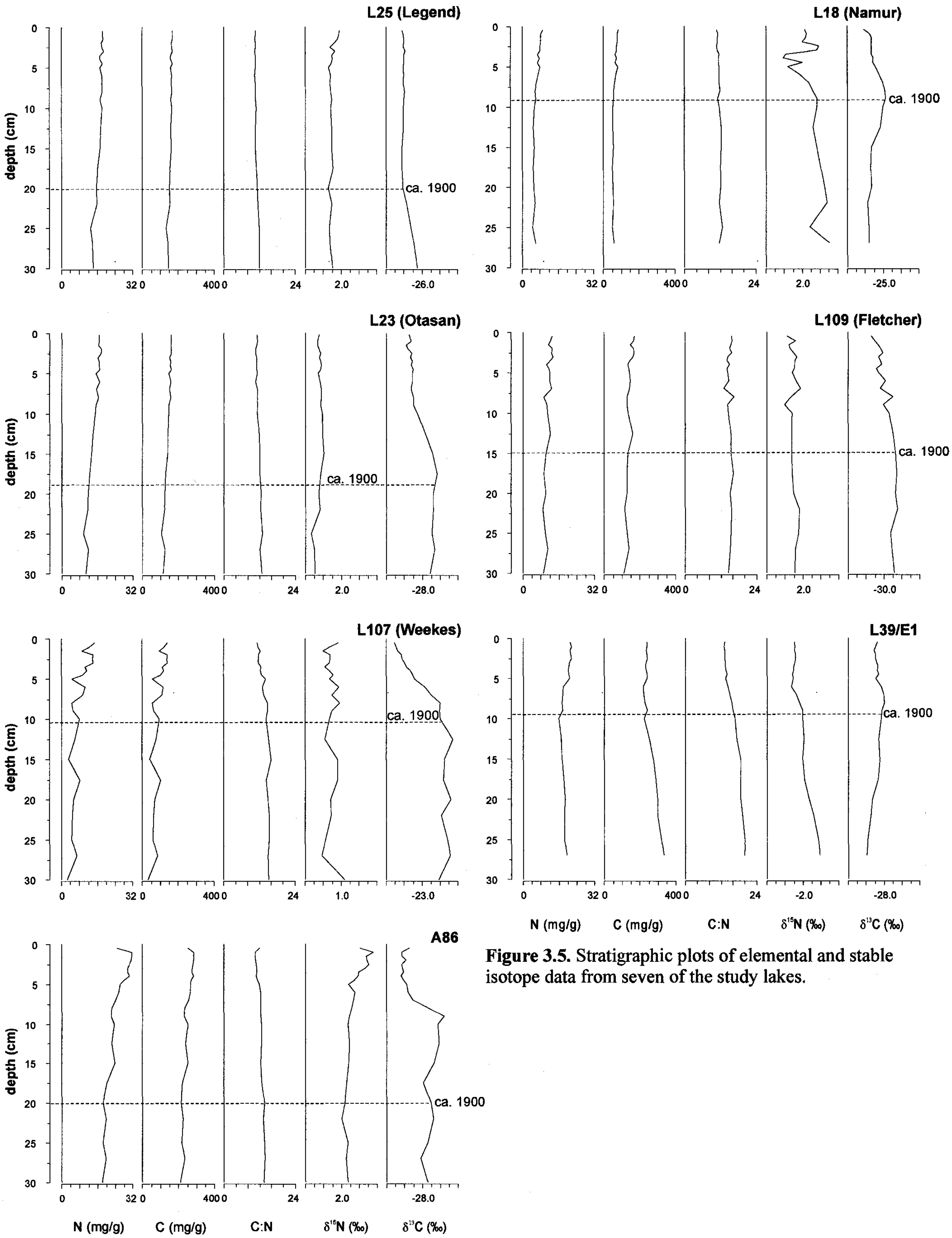


Figure 3.5. Stratigraphic plots of elemental and stable isotope data from seven of the study lakes.

Discussion

To address the floristic changes in the eight study lakes, we present four hypotheses relating to recognised environmental stressors in the region. These hypotheses are not mutually exclusive, and it is likely that the ecological change that has occurred in several of the study lakes is due to the interactive effects of more than one stressor. This significantly complicates the interpretation of the paleoecological record. We therefore take a broad view in discussion of the effects of environmental stressors on lakes in the region, with the expectation that their proximal effects will be examined in greater detail in future studies.

Hypothesis one: Cascading trophic interactions

Changes in the structure of diatom assemblages may be mediated by fish predation of macrozooplankton, in a cascading trophic interaction caused by fishing pressure. The effect of planktivorous fish on zooplankton community structure has been studied extensively, especially in relation to changes in the size structure of the zooplankton community (Brooks and Dodson 1985, Carpenter *et al.* 1985). These interactions can influence the composition of the phytoplankton community through grazing (Vanni 1987), or by altering nutrient cycling processes, especially in relation to the size-specific rate of nutrient cycling in the zooplankton community (Vanni and Findlay 1990). Paleolimnological evidence for the influence of changes in fish populations on the planktonic community has been examined in relation to macrozooplankton (Verschuren and Marnell 1997, Jeppensen *et al.* 2002) and fossil pigments (Leavitt *et al.* 1994), but evidence that the composition of diatom assemblages can be altered through cascading trophic interactions is limited (Drake and Naiman 2000, Wolfe *et al.* 2003). Although there is limited information on fish population dynamics in most of the study lakes, the synchrony of changes in the composition of the fish community in Touchwood Lake, and of potential changes in fish communities in L18 (Namur), with changes in the composition of sediment diatom assemblages implies a potential trophic linkage.

Fish populations in Touchwood Lake have been subject to considerable pressure from anglers and commercial fishers throughout the twentieth century. Despite efforts in the late 1920s to close the commercial fishery, the government did not act, and by the early 1930s the lake trout (*Salvelinus namaycush*) population was extirpated (Chipeniuk 1975). Efforts to reintroduce lake trout in 1967 and 1968 failed, possibly as a result of degradation of limited spawning habitat. Surveys of the sport fishery at Touchwood Lake indicated that the productivity of the walleye (*Sander vitreus*) population did not support the angling effort in 1991, which was already diminished following an apparent reduction in catch rates and the institution of catch size restrictions in 1989 (Sullivan 1991). Continued fishing pressure caused the collapse of the walleye fishery shortly thereafter, and put serious pressure on the northern pike (*Esox lucius*) population (C. Davis, personal communication, 26 October 2005). The walleye fishery has remained closed since 1998.

The collapse of the walleye fishery coincides with changes in the structure of diatom assemblages an increase in the diatom valve concentration. The relative abundance of *Stephanodiscus minutulus*, in particular, has increased exponentially from approximately 20% ca. 1997 to almost 90% in surface sediments (2004). Over the same period, the diatom valve concentration increased by nearly an order of magnitude from approximately $4.2 \cdot 10^7$ ca. 1997 to $2.5 \cdot 10^8$ in surface sediments. *Stephanodiscus minutulus* is typical in size and habit of the food preferred by the herbivorous macrozooplankton, so the greater relative abundance of this taxon in surface sediments suggests a reduction in grazing intensity.

The linkage between a reduction in grazing intensity and the collapse of the walleye and northern pike populations may be mediated through several intermediate trophic layers. An examination of stomach contents of walleye and northern pike during a 1991 creel survey revealed a predominance of yellow perch (*Perca flavescens*) in the diet of northern pike, and an even distribution of yellow perch, spottail shiners (*Notropis hudsonius*), and coregonids (*Coregonus sp.*) in the diet of walleye (Sullivan 1991). Invertebrates represented a relatively minor component of the stomach contents of the adult fish. It is therefore possible that the collapse of the pike and walleye population has caused an increase in the abundance of zooplanktivores (e.g. yellow perch or spottail shiners), and a subsequent decline in the abundance of grazers.

The collapse of the walleye and northern pike populations could also have affected the phytoplankton community directly, by altering nutrient cycling dynamics. This has been observed in relation to planktivorous fish, that affect nutrient cycling both by increasing the availability of dissolved nutrients by excretion or egestion, and by altering the rate of nutrient cycling by zooplankton through size-selective predation (Vanni and Findlay 1990, Schindler 1992). This mechanism could be mediated in Touchwood Lake by some trophic intermediary (e.g. yellow perch).

L18 (Namur) supports a slightly different fish community from Touchwood Lake, comprising lake trout, lake whitefish (*Coregonus clupeaformis*), tullibee (*Coregonus artedii*), northern pike, and arctic grayling (*Thymallus arcticus*). L18 has supported a commercial fishery in the past; however the lake is fairly remote and the scale of the fishery was probably limited. The lake presently supports a commercial fly-in fishing lodge and a small recreational fishery. Although the fish community was surveyed only once (Turner 1968, Griffiths 1973), there is no indication that sportfish populations are under undue pressure. However, the recent establishment of a colony of double-crested cormorants (*Phalacrocorax auritus*) on an island at the north end of L18 could indicate a shift in fish predation. The cormorants have presumably increased in numbers since the most recent survey (312 active nests in 1998; Cottonwood Consultants Ltd. 2000), having since displaced a resident colony of American white pelicans (L. Rhude, personal communication, 27 October 2005).

While there is a popular perception, particularly among anglers, that cormorant predation can alter the structure of fish communities (Rudstam *et al.* 2004), the predominant scientific view is that cormorants have little or no effect on natural fish populations (Engström 2001, Wires *et al.* 2003). The causal relation may actually be reversed in some Alberta lakes, notably Lac La Biche, where fishing pressure has resulted in the increased abundance of smaller prey species (notably yellow perch; *Perca flavescens*), to the advantage of the cormorant population. In L18, the non-selective predation of small fish by cormorants may have a cascading effect through lower trophic levels, resulting in the recent proliferation of *S. minutulus*. As in Touchwood Lake, an increase in *S. minutulus* in L18 accompanies an abrupt increase in diatom total abundance. These changes appear to be distinct from a broader trend originating in the early

1900s that includes an increase in diatom abundance including small *Fragillaria* spp., *Aulacoseira* spp., and Chrysophyte stomatocysts, and a decrease in *Cyclotella bodanica.* This trend cannot be explained by cormorant-driven trophodynamics.

An added consequence to the presence of cormorants on L18 may be the fertilisation of the lake by ammonium nitrogen contained in their excreta. Of the eight study lakes, L18 has the highest NH_4^+ concentration, and the highest DIN:TP ratio (Table 3.1), suggesting elevated rates of nitrogen loading or recycling. However, there is no recent deflection in the sediment nitrogen stratigraphy, and no significant change in the nitrogen stable isotope ratio, suggesting no net change in the rate of inorganic nitrogen flux.

Elevated primary productivity associated with the putative trophic interactions is consistent with the rising pH trend inferred from the CCA trajectories (Fig. 3.4) and diatom-based pH inference models (chapter 2) for Touchwood Lake and L18. The effect of elevated primary productivity on pH is often observed in thermally stratified lakes as a clinograde pH profile that corresponds directly with the O_2 profile, and inversely with the $\sum CO_2$ profile (e.g. Wetzel 1983). This profile reflects enhanced photosynthetic fixation of $CO_{2(aq)}$ and HCO_3^-, resulting in the depletion of the H_2CO_3 (carbonic acid) pool through equilibrium processes. Provided that the rate of assimilatory depletion of $\sum CO_2$ exceeds the rate of $CO_{2(g)}$ dissolution, the net result of this equilibrium shift is an increase in pH. While this process does not constitute a permanent gain in alkalinity, the elevated pH can persist for extended periods provided that the water column remains stratified and the rate of carbon fixation remains relatively high. Touchwood Lake remains vertically stratified for much of the open water period. The stratified water column in Touchwood Lake exhibits a clinograde pH profile that is often characterised by a pH and O_2 maximum slightly below the water surface (Alberta Environment, unpublished data), indicating that the rate of photosynthetic CO_2 fixation can indeed outstrip the rate of $CO_{2(g)}$ dissolution, and that photosynthesis has an appreciable effect on pH in Touchwood Lake. While similar processes have probably induced the rising pH trend in L18, profile data for L18 and the other study lakes are usually collected close to or during fall overturn, when vertical stratification is weak or nonexistent. Evidence for the productivity-pH linkage therefore rests on the Touchwood Lake data.

Although the putative trophic linkage between the collapse of sportfish populations in Touchwood Lake and L18 and the proliferation of *S. minutulus* implies an increase in primary productivity, the available surface water quality data do not support this trend. Instead, these data indicate a slight increase in surface water transparency (Secchi depth), and a slight decline in chlorophyll *a* (Alberta Environment, unpublished data). This is consistent with the CCA trajectory for both lakes, which also suggests that total phosphorus and, by extension, productivity, has remained unchanged. As well, the onset of floristic changes in L18, particularly in relation to the chrysophyte cysts, likely predates any significant fishing pressure, and certainly predates the establishment of the resident cormorant colony. The floristic changes in L18 are also not strictly characterised by an increase in planktonic over benthic forms, but rather by a progression from one plankonic form to another, notably *Cyclotela bodanica* to *Aulacoseira subarctica* to *Stephanodiscus minutulus*. While it might be argued that this progression reflects a shift in grazing preference, this conclusion does not necessarily rest on the hypothesis of cascading trophic interactions.

Hypothesis two: Fire

The northern boreal plain is subject to a continual cycle of fire, the effects of which can be clearly seen in the catchments of some of the study lakes. Fires have been shown to enhance the export of nutrients from burnt catchments, causing increased primary productivity over a period of years to decades (Bayley *et al.* 1992, McEachern *et al.* 2000, Charette and Prepas 2003). The magnitude of the nutrient flux is contingent on the previous fire history, edaphic characteristics, catchment vegetation, and the intensity of the fire (Bayley *et al.* 1992). The response of planktonic communities to forest fire is quite variable (Enache and Prairie 2000, Paterson *et al.* 2002, Philibert *et al.* 2003), presumably in relation to the factors identified by Bayley *et al.* (1992).

The effect of two major fire events in 1981 and 1998 on the adjacent Birch Mountain lakes (L18 and L25) provides an illustration of the tremendous variability in ecosystem response to fire. In L25, the sediment □^{15}N was unaffected by the 1981 fire, but increased following the 1998 fire (Fig. 3.5). This is consistent with the floristic response to the two fires, which is more pronounced in the case of the second fire. *Synura petersenii* and *Mallomonas crassisquama* appear to respond to both fires, but increase far more significantly in abundance following the second fire event. While chrysophyte stomatocycts exhibit a similar response as *S. petersenii* and *M. crassisquama*, the composition of diatom assemblages remains largely unaltered. The sediment carbon and nitrogen inventory responds differently to fire in L18 than in L25. The sediments of L18 became enriched in ^{15}N following the 1981 fire, but were relatively unaffected by the 1998 fire (Fig. 3.5). Conversely, the sediment δ^{13}C becomes more negative following the 1998 fire, suggesting a shift in the source of organic matter, perhaps due to greater productivity. Although *S. petersenii* is absent from L18, the diatom community appears to respond strongly to both fires. *Aulacoseira subarctica*, a mesotraphentic species, becomes more abundant following the 1981 fire, and is most abundant just prior to the 1998 fire, after which *Stephanodiscus minutulus*, a hypereutraphentic species, becomes dominant. This apparent eutrophication suggests an increased export of nutrients from the L18 catchment following the 1998 fire. Although additional floristic changes occur in the L18 stratigraphic record prior to the 1981 fire, the historic record extends only to 1930. It should be noted, however, that subtle shifts in the sediment δ^{13}C occur at 15.0 cm and at 9.0 cm (ca. 1900) indicating changes in the sediment organic pool (Fig. 3.5). These shifts are concurrent with an increase in the abundance of chrysophyte stomatocycts at 15.0 cm, and the gradual decline of *Cyclotella bodanica*, an oligotraphentic species, beginning at 9.0 cm (ca. 1900). The implication is that repeated burning of the catchment has led to the gradual eutrophication of L18 throughout the 20th century. Conversely, using charcoal particles in sediments from Christina Lake (located north of Touchwood Lake) as a proxy indicator for forest fire, Philibert *et al.* (2003) showed that disturbance associate with fire is an episodic, rather than additive, process. The directional and intensifying changes in L18 therefore suggest that fire is at best only partially responsible for the observed floristic changes.

The floristic changes in L109, characterised most notably by an increase in the abundance of eutraphentic *Cyclotella pseudostelligera* and the scaled chrysophyte *Malomonas crassisquama* and a concomitant decrease in mesotraphentic *Aulacoseira subarctica*, suggest eutrophication. This is not reflected in the diatom concentration, which was apparently greatest ca. 1950, an episode that is not accompanied by any significant floristic changes. Unlike the lakes 107, L18, L25, and L39, the L109 catchment was not subject to any major catchment disturbances during the period of record. A relatively small fire (537 ha) occurred in the southern portion of the catchment in 1995, but burned only a very small fraction of the total catchment area. As well, a second, much larger, fire burned an extensive area (14,258 ha) of an adjacent catchment in 1998. While the floristic shifts in L109 may reflect an enhanced deposition of pyrogenic nutrients associated with these fires (Goldman *et al.* 1990, Spencer and Hauer 1991, Spencer *et al.* 2003), both fires occur after the advent of these floristic shifts. For these events to be causally linked would require a significant level of sediment mixing that is not indicated in the ^{210}Pb stratigraphy (Fig. 3.2). Unlike L109, the sudden appearance of *Mallomonas crassisquama* in the L107 sediment biostratigraphy is concurrent with a large fire in the catchment in 1979, strongly suggesting a correlation between the two.

Hypothesis three: Atmospheric deposition

Nutrient limitation is often predicted from the ratio of nitrogen to phosphorus in surface waters, and is expressed either as TN:TP or as DIN:TP, although the latter may provide a more robust indication of nutrient limitation as it better reflects bio-available nitrogen (Morris and Lewis 1988). Nitrogen limitation is more likely at TN:TP ratios of less than 14 (Downing and McCauley 1992) or DIN:TP ratios of less than 1 (Morris and Lewis 1988), while phosphorus limitation typically occurs at TN:TP ratios greater than 19 (Sakamoto 1966) or DIN:TP ratios greater than 4 (Morris and Lewis 1988). The Birch Mountain lakes (L18, L23, and L25) and L39 have the lowest TN:TP and DIN:TP ratios of the study lakes (Table 3.1). L23 and L39 have relatively high TN:TP ratios, which suggests that the majority of nitrogen in these lakes is organically bound, but not necessarily bioavailable, as indicated by the low DIN:TP ratio. The organic nitrogen fraction is probably derived from allochthonous sources, as both lakes also have relatively high DOC concentrations. All four lakes have DIN:TP ratios that would indicate nitrogen limitation, or co-limitation of nitrogen and phosphorus (Table 3.1), and may therefore be more susceptible to enhanced rates of nitrogen deposition. Of the four lakes, only L18 and L25 have undergone significant floristic changes. The composition of the diatom flora in L25 has changed only slightly over the past century, characterised by a modest increase in *Cyclotella pseudostelligera* and *Asterionella formosa*. Both species respond positively to nitrogen fertilisation (McKnight *et al.* 1990, Yang *et al.* 1996, Gregory_Eaves *et al.* 2004), although the temporal scale of the floristic change is not consistent with nitrogen deposition from bitumen extraction. However, the scaled chrysophytes *Mallomonas crassisquama* and *Synura petersenii* have increased dramatically during the past ten years. *Mallomonas crassisquama* is common and widely distributed, and is relatively abundant in three of the eight study lakes (L25, L109, and L107). It has broad ecological tolerances and is often considered to be of limited importance as an indicator species (Siver 1991), although *M. crassisquama* responds strongly to fertilisation at a high N:P ratio (Zeeb *et al.* 1994). Conversely, *Synura petersenii* appears to prefer oligotrophic conditions, and exhibits an opposite response to N fertilisation than *M. crassisquama* (Zeeb *et al.* 1994). *Synura petersenii* is frequently more abundant below the thermocline (Paterson *et al.* 2004), suggesting that it may be adapted to low light conditions. It can also form under-ice blooms (Watson *et al.* 2001), which may explain the co-occurrence of *M. crassisquama* and *Synura petersenii*, especially given the apparently divergent autecology of these two species.

In L18, the diatom concentration has been increasing steadily since ca.1900 and has increased dramatically in surface sediments, with a concomitant change in the structure of diatom assemblages, characterised most notably by the gradual disappearance of Cyclotella bodanica, the rise and decline of *Aulacoseira subarctica*, followed finally by a recent (ca. 2000) spike in *Stephanodiscus minutulus* (Fig. 3.3). This progression, which culminates in the dominance of hypereutraphentic *S. minutulus*, is consistent with a process of gradual eutrophication (e.g. Van Dam *et al.* 1994, Reavie *et al.* 1995, Moser *et al.* 2004). However, the timescale of this process extends beyond commercial-scale oil sands exploitation, indicating that nitrogen deposition is not the primary cause.

The near synchrony of the dramatic floristic changes in L107 and L109 provides the most compelling indication of atmospheric nutrient deposition. The increase in L109 of *C. pseudostelligera* at 4.5 cm (ca. 1990), and the increase in L107 of *M. crassisquama* at 4.5 cm (ca. 1985) follow nearly two decades of large-scale commercial bitumen extraction. The lag in ecosystem response to the nitrogen deposition associated with the bitumen extraction may reflect the attainment of a state of nitrogen saturation in the

L107 and L109 catchments. While the TN:TP and DIN:TP ratios do not indicate nitrogen limitation in either lake, these measurements are fairly recent and may reflect years of nitrogen fertilisation. As well, while none of the study lakes show any significant geochemical changes, the reported range of □^{15}N from vehicle emissions (-7 to +12‰, Heaton 1990), the primary source of nitrogen emissions in the region, is so broad as to provide no definitive source signature. The role of nitrogen deposition in the region therefore remains an open question.

Hypothesis four: Climate change

Mean air temperature in northern Alberta has increased significantly over the past century (Zhang *et al.* 2000). Since the 1960s the rate of increase at Fort McMurray and Fort Chippewyan has been greater than previously recorded, with minimum, mean, and maximum air temperatures increasing by nearly 0.5 °C per decade (Chaikowsky 2000). Climate warming has also extended the frost-free period in the region by 40-60 days (Shen *et al.* 2005). These observations significantly exceed values predicted by the Canadian Climate Centre First Generation Coupled Global Climate Model (CGCM1; Flato *et al.* 2000, Chaikowsky 2000), and are consistent with warming rates that have been shown to cause significant ecological change in arctic and subarctic lakes (Ruhland *et al.* 2003, Smol *et al.* 2005). The rate of warming in northeastern Alberta exceeds the rate of change at many high-latitude sites in North America (Keyser *et al.* 2000), where climate warming has been putatively linked to extensive change in freshwater communities (Ruhland *et al.* 2003, Smol *et al.* 2005).

Climate warming is widely expected to increase the stability and duration of thermal stratification (McCormick 1990, DeStasio *et al.* 1996, Livingstone 2003, Jankowski *et al.* 2006). This change is marked by earlier ice melt, and the earlier onset of spring stratification (Schindler *et al.* 1990, Magnuson *et al.* 2000, Winder and Schindler 2004). The most compelling evidence that similar physical changes are occurring in northeastern Alberta lakes is the rising pH in L18 and Touchwood Lake, inferred from the diatom-based pH inference model compiled for lakes in the region (Hazewinkel, this volume), and from the CCA trajectories for these two lakes. As discussed, the pH trend is probably due to the depletion of the

H_2CO_3 (carbonic acid) pool through equilibrium processes associated with photosynthetic $CO_{2(aq)}$ and HCO_3^- fixation. These processes are evident in the clinograde pH and O_2 profiles for Touchwood Lake, which occur in the stratified water column throughout much the open water season. While the inferred pH trend may be caused in part by increasing rates of primary productivity, it is contingent on the isolation of the trophogenic zone from the rest of the water column by thermal stratification. The rising pH trend therefore provides a robust indication that the duration and stability of the thermocline in Touchwood Lake and L18 are increasing.

Increasing thermal stability also has implications for the ion mass balance of surface waters. Isolation of the hypolimnion by thermal stratification may enhance the importance of in-lake processes to the overall ion budget, allowing more time for the removal of sulphates by bacterial reduction, and for the mineralization and subsequent diffusion of calcium from sediments (Schindler 1997). The net effect of these processes is an increase in alkalinity. While it is difficult to establish the relative contribution of internal alkalinity generation and photosynthetic $CO_{2(aq)}$ and HCO_3^- fixation to the pH trend inferred from the Touchwood Lake and L18 diatom assemblages, it is likely that these mechanisms are concurrent.

While *Stephanodiscus minutulus*, an alkaliphilous species, has been increasing steadily in Touchwood Lake throughout the past century, its dominance of the L18 sediment assemblages has occurred only during the last 10-15 years (Fig. 3.3). Prior to this, changes in the composition of diatom assemblages do not appear to be mediated by water chemistry (Fig. 3.4), indicating that in L18, unlike in Touchwood lake, the diatom community responds to some factor other than pH. The stratigraphic changes in L18 are marked by an increase in smaller planktonic taxa, progressing from the relatively massive *Cyclotella bodanica* through *Aulacoseira subarctica* and finally *S. minutulus.* The diatom stratigraphy in L109 follows a similar progression, from *A. subarctica* to the smaller *C. pseudostelligera.* The stratigraphic progression in both lakes suggests the existence of a selective mechanism that favours small planktonic species. This may be a response to shifting grazing pressure caused by earlier ice-out and the earlier onset of stratification. Winder and Schindler (2004) demonstrated that a forward shift in the onset of phytoplankton blooms resulting from earlier stratification could cause a temporal uncoupling with the emergence of grazers. This uncoupling produces a progressive decline in grazer populations, primarily *Daphnia* spp., that are reliant on the spring algal bloom. Winder and Schindler (2004) also show a correlation between the decline of the spring phytoplankton bloom (clear water phase) and the density of the daphnia population, indicating that grazing by daphnia limits the duration of the bloom. A decline in the daphnia population associated with a forward shift in the onset of stratification could therefore lead to an increase in primary productivity. Given that daphnia tend to be selective in their grazing behaviour, this reduction in grazing intensity could be associated with the floristic shifts in L18 and L109.

Changes in thermal structure of lakes can also impose selective pressure on forms with different sinking characteristics (Reynolds 1984). Investigations of taxon-specific sinking velocities indicate that the smaller size of species like *C. pseudostelligera* or *S. minutulus* imparts greater effective buoyancy (Sommer 1984, Ptacnik *et al.* 2003). The increased dominance of *C. pseudostelligera* and *S. minutulus* is therefore consistent with a shift from a more turbulent water column, which favours less buoyant forms (e.g. *A. subarctica*), to a more stable, stratified water column that favours more buoyant forms (Diehl *et al.* 2002, Huisman and Sommeijer 2002). This implies a shift in L18 and L109 from an un-stratified or weakly stratified water column to shallower, more persistent stratification. Climate-mediated changes in the thermal structure of the study lakes may also affect the structure of diatom and chrysophyte communities by altering nutrient availability. Careful assessment of seasonal community dynamics of diatoms and chrysophytes suggests that these two species may respond to nutrients recycled from the hypolimnion during spring overturn (Bradbury and Dietrich-Rurup 1993, Bradbury 1998). If the spring mixing period is extended, for example as a result of earlier ice-out due either to reduced ice cover or to warmer spring temperatures, the rate of internal phosphorus loading may be enhanced. This is consistent with the observation that the dominance of sediment diatom assemblages by small centric diatoms is often associated with warmer spring temperatures (Battarbee *et al.* 2002, Sorvari *et al.* 2002, Rühland *et al.* 2003). The effect of an extended mixing period is of particular importance in deeper lakes, which may otherwise not mix completely prior to stratification.

The floristic changes in L25 differ substantially from those in adjacent L18, and are characterised by increases in the abundance of the scaled chrysophytes *Mallomonas crassisquama* and *Synura petersenii*, and by subtle increases in the abundance of *Cyclotella pseudostelligera* and *Asterionella formosa*. The autecology of *Synura petersenii* is difficult to constrain, although it has been linked to environmental change in other studies (Paterson *et al.* 2004). It appears to prefer oligotrophic conditions, and commonly forms blooms below the thermocline in stratified lakes (Fee *et al.* 1977, Zeeb *et al.* 1994), suggesting that the floristic trend in L25 is a response to enhanced thermal stability. This is consistent with the increase in the abundance of *M. crassisquama*, *C. pseudostelligera*, and *A. formosa*, all of which are relatively buoyant planktonic forms favoured by thermal stability (Reynolds 1984).

CONCLUSIONS

Our results demonstrate that lakes located throughout northeastern Alberta are undergoing significant ecological change. This change, which has occurred primarily during the past century, is directional, and appears to be intensifying, suggesting that its origin is largely anthropogenic. However, there are few similarities in the nature of the ecological change in the study lakes. This is true even of lakes located within adjacent catchments (L18 and L25), indicating that catchment and limnological characteristics play a significant role in controlling ecosystem response to environmental stress. The most significant ecological changes occur in Touchwood Lake, L18, L25, L107, and L109. While floristic changes in L109 may reflect the effects of forest fire, these effects are overprinted on a longer-term trend that is probably climate-related. The changes in Touchwood Lake and L18 reflect a rising pH trend that suggests stronger and more persistent thermal stratification due to climate warming. It is not clear whether the cause of the pH trend is increasing primary productivity or a $\sum CO_2$ deficit due to a reduction in vertical mixing, but the length and consistency of the trend is consistent with climate warming that has occurred since the little ice age (ca. 1850). Touchwood Lake and L109 may also be affected by a trophic shift associated with fishing pressure. Primary productivity in Touchwood Lake, in particular, has undoubtedly been affected by the devastation of the sportfish populations caused by overfishing. Whether L18 has been subject so similar pressure is less clear, because long-term records are lacking. Although the diatom community in L25 is relatively invariant, the scaled chrysophytes *Mallomonas crassisquama* and *Synura petersenii* have become substantially more abundant. This may be a response to fire, although there is a modest indication of long-term change that may be climate-related. The changes in L107 and L109 are nearly synchronous, suggesting fertilisation by atmospheric nitrogen deposition. However, there is no geochemical evidence of this, as elsewhere (Wolfe *et al.* 2003). While L107 also appears to respond to fire, L109 is unaffected by fire. The changes in both lakes are probably too sudden to be climate-related, although climate change may be a factor. By comparison, A86, L23, and L39 show relatively little evidence of change. This probably reflects the dominance of diatom assemblages in these lakes by benthic species that, because they live at the boundary of sediment and water, are generally poor indicators of surface water processes.

This is the first report of widespread environmental change in northeastern Alberta. What is particularly interesting is the diversity of response in the study systems to this environmental change. To properly elucidate the linkages of the observed floristic changes to broad-scale environmental stressors will require more thorough understanding of the seasonal dynamics of the phytoplankton communities. These seasonal patterns are important, as they permit examination of the proximal effects of broad-scale environmental change, and inference of their importance in a regional context. The response of aquatic communities to environmental change must also be considered in relation to the additive stresses of resource exploration and exploitation in the region. The effects on aquatic systems of continued expansion in the oil and gas industry, particularly with respect to bitumen extraction, will undoubtedly be more damaging in combination with the factors that we have explored. It is therefore all the more important that we develop a more complete understanding of the mechanisms driving the ecological transformations that are clearly occurring in the region. In so doing, we will be better situated to limit the industrial activity that will otherwise cause these transformations to accelerate.

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CHAPTER FOUR: General conclusions

There is no question that the ecology of lakes in northeastern Alberta is changing. Although the paleoecological record that we present is relatively brief (>500 years), of the lakes that are undergoing significant floristic change (L25, L18, L109, L107, and Touchwood Lake), this change exceeds natural variability, and is accelerating. Of the lakes that have undergone little or no floristic change (L23, L39, and A86), the sediment microfossil assemblages generally comprise species that, because of their association with specific microhabitats, are less sensitive to environmental change (e.g. benthic or epiphytic species). The chronology and specific nature of the observed ecological changes are variable, reflecting the importance of local environmental characteristics in mediating environmental stressors on a broader scale. However, the changes are consistent with those observed in the paleoecological record throughout the boreal, subarctic, and arctic ecoregions. We evaluate several potential causes of the observed changes relative to known environmental stressors.

Given the increasing intensity of atmospheric emissions of SO_2 and NO_x in the oil sands region, there is very real possibility that lakes in the region will be affected by acid deposition. We use diatom-based pH inference models, developed specifically for acid sensitive lakes in northeastern Alberta, to estimate pH from diatom microfossil assemblages dating from approximately 100 to 500 years before present (Chapter 2). The pH values inferred from the microfossil assemblages give no indication of recent acidification. With the notable exceptions of Touchwood Lake and L18, pH in the study lakes has remained relatively unchanged throughout the period of record. Touchwood Lake and L18, on the other hand, appear to have become more alkaline. The reason for the apparent change is unclear. It is possible that the change is an artefact of the inference model, as the diatom species (*Stephodiscus minutulus*) that dominates surface assemblages in both lakes is rare in the training set of the inference model. It is equally possible that the change is due to an increase in the flux of base cations to the two lakes caused by increased deposition of aerosols mobilised by widespread deforestation, or by enhanced geochemical weathering. Enhanced catchment weathering constitutes a potential source of alkalinity in L18 due to enhanced weathering following the fires that occurred in the latter half of the last century, although the absence of a similar change in adjacent L25, which has been subject to similar catchment disturbances, casts doubt on this interpretation. We therefore explore alternate causes of the floristic changes in L18 in a second paper (Chapter 3).

In addition to acid deposition, lakes in northeastern Alberta are subject to several significant anthropogenic stressors that we examine in relation to the observed ecological changes. Climate warming has been implicated in creeping ecological change in lakes throughout the boreal, subarctic, and arctic ecoregions. In northern Alberta, climate warming is eroding the southern boundary of the zone of discontinuous permafrost (in which the study lakes are located), and has caused a dramatic increase in the total number of frost-free days. Many of the observed changes in the structure of microfossil assemblages occur on a time scale that is consistent with climate warming, and are floristically similar to changes observed elsewhere, particularly with regard to the increased abundance of small centric diatoms (Rühland *et al.* 2003, Harris *et al.* 2006). The onset of some of the floristic changes also coincides with major forest fires, which are expected to become more frequent and more severe under climate warming. The catastrophic changes caused by forest fire clearly have an effect on the mobilisation of carbon and nutrients from the catchment, however the specific effect relative to algal community composition appears to differ from lake to lake.

Although emissions of SO_2 and NO_x have not yet caused widespread acidification of surface waters in northeastern Alberta, given that many of these lakes and ponds are nitrogen limited, nitrogen deposition may potentially be causing eutrophication. However, while some of the observed floristic changes indicate increasing productivity, there is a lack of nitrophilous taxa. As well, geochemical proxies (C and N atomic mass and stable isotope measurements) provide no indication of changes in nitrogen biogeochemistry. Finally, fishing pressure may have caused the floristic changes observed in Touchwood Lake and L18. These are the only two study lakes that are subject to pressure from a sport fishery, and the floristic changes in both lakes are remarkably similar. Touchwood Lake, in particular, has experienced complete collapse of two sportfish populations, and extirpation of a third. This acute ecosystem disruption has undoubtedly affected other trophic levels, although whether it has altered the diatom community structure remains an open question.

The variability in the response of the study lakes to these environmental stressors substantially complicates interpretation of the observed ecological changes. Even in adjacent catchments, which presumably are subject to similar stressors, the floristic response differs substantially. This variability underscores the importance of proximal processes in interpreting the effects of environmental stressors. Further investigation of the observed changes must be undertaken on a finer spatial and temporal scale, for example by deploying sediment traps at varying depths in the water column. This will permit interpretation of ecological change relative to distinct limnological processes, an approach that is of particular importance to the examination of climate-related effects. Touchwood Lake also presents a unique opportunity to observe the effects of trophic reorganisation on diatom communities, for example by a more intensive study of grazing dynamics. Such research will permit environmental managers and regulators to mitigate further environmental change by identifying the cause and specific mode of action.

This study was commissioned primarily to aid in the establishment of critical acid loads for lakes in the region. The pH reconstructions, inferred from the microfossil assemblages in the study lakes, have three important implications for critical load calculations. First, because none of the study lakes appear to have become acidified as a result of atmospheric deposition, it is reasonable to use existing measurements of surface water alkalinity in mass balance calculations. It is also reasonable to assume that the alkalinity of most of the study lakes has remained relatively constant over the past 250 years. The notable exceptions are Touchwood Lake and L18, which may have become more alkaline, as indicated by the floristic changes. Finally, biological acid neutralization may a far more important source of acid neutralizing capacity than is currently believed. Biologically-mediated sulphate and nitrate reduction, which occur both in the catchment and in the lake, are not accounted for in the existing mass-balance critical load models. This is a major shortcoming of current critical load calculations. The importance of biological alkalinity generation may be assessed using paleolimnological techniques, for example by examination of stratigraphic changes in the concentration of reduced sulphur or iron. The advantage of the paleolimnological approach is that it does not require the selection of an arbitrary threshold, such at the pH 6 threshold used in current critical load calculations. Instead, this approach considers as the critical threshold the onset of ecological change. As such, the paleolimnological approach to critical loads is more ecologically rigorous than the mass balance approach, and should be considered whenever appropriate.

Further Research

The research presented in this thesis was conducted at a timescale of approximately one to three hundred years, at a resolution that varies from annual to decadal. This approach was sufficient to extract very clear ecological trends from several of the study lakes. Relative to acidification, interpretation of these trends is uambiguous, indicating that none of the study lakes have yet become acidified in any ecologically meaningful way. Similar research is presently being extended to other acid sensitive lakes in the region, to provide a more spatially extensive evaluation of lake acidification. Provided that this research can produce evidence of recent acidification, it will also be possible to adopt catchment-specific benchmarks (ANC_{lim}) to supercede the current 75 μeq/L ANC_{lim} used in the calculation of critical loads. This will provide a more ecologically meaningful assessment of critical loads than can be achieved by numerical models (Henrikson and Posch 2001). In addition to this work, and given the considerable uncertainty associated with the existing dispersion and deposition estimates and the potential for the long-range transport of acidifying pollutants, additional research effort should be extended to the highly acid sensitive lakes in northwestern Saskatchewan. As well, the influence of biological acid neutralisation, both assimilatory and dissimilatory, on critical loads should be examined. Research into nitrogen assimilation is currently being conducted relative to the assimilation of nitrogen by bryophytes, but rates of sulphate reduction in the catchment and water column have yet to be constrained. These factors may be of particular importance to the dynamic modelling efforts that are also currently underway.

The ecological trends that were extracted from the study lakes have several potential causes, as discussed in Chapter Three of this thesis. While the research presented in this thesis was conducted at a sufficiently fine resolution to extract these trends, further research will be required to distinguish between their causes. The possible influence of fire on these trends may be more clearly established by the examination of the stratigraphic distribution of charcoal particles in lake sediments, and by combining this approach with additional paleolimnological analyses on a longer timesacle (e.g. Philibert *et al.* 2003). Similarly, the influence of cascading trophic interactions on diatom assemblages may be established by the examination of the stratigraphic distribution of zooplankton remains. The influence of climate over biostratigraphic change poses a particular challenge, as the potential modes of action are diverse, and usually indirect. The most productive approach may be in the examination of the spatial and seasonal dynamics of the seston, using sediment traps (e.g. Bradbury 1998). This will permit the extraction of relationships between physical and chemical variables, especially those related to thermal stratification, and floristic changes. From these relationships, it may be possible to predict the potential susceptibility and response of other lakes in the region to climate change, and to identify appropriate ecological markers. It may also be possible to better characterize the extent of the issue as it relates to aquatic systems in the boreal forest, and provide impetus for the establishment of more appropriate climate policy.

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APPENDIX 1

TAXONOMIC DATA AND AUTHORITIES FOR THE EIGHT STUDY LAKES

	Otasan (L23) (1,250,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	11	2	9	3	2	9	9	6	4	3	1	1	1	7	1
Stomatocysts	24	20	16	21	16	21	17	16	19	16	13	39	12	16	9
Mallomonas crassisquama (Asmund) Fott															
Mallomonas heterospina Lund															
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman			2	5	16	15	17	5	4	1	4	15	14	11	11
Achnanthes altaica (Poretzky) Cleve-Euler				7	5	1	2	4	3		1		1	3	
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot															1
Achnanthes bioretii Germain															
Achnanthes calcar Cleve						1						1	6		
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei															
Achnanthes conspicua Mayer															
Achnanthes curtissima Carter				2	2		3		7			3		3	
Achnanthes daoensis Lange-Bertalot															
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot				1	1				1		1	1		2	
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt						1	1	1		1	2	1	6	4	
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua	1			3	1	2		4	1		1			1	
Achnanthes fulla Carter							2	2							
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wutrich															
Achnanthes helvetica (Hustedt) Lange-Bertalot		1					1						2		
Achnanthes impexa Lange-Bertalot															
Achnanthes impexiformis Lange-Bertalot			1			1		1	2						
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot			1												
Achnanthes lanceolata (Brebisson) Grunow	6	7	5	2	3	4	2	4	4	3	7	5	10	5	5
Achnanthes lanceolata var. dubia Grunow															
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot											1				
Achnanthes laterostrata Hustedt	4	3			7		3	3	5	4	1	2	4	1	3
Achnanthes levanderi var. helvetica Hustedt		1	6	4	6	3	2	3		5	3	3	7	7	2
Achnanthes marginulata Grunow	4	1	2					3	2	3		5	2		7
Achnanthes minuscula Hustedt		1									3	1			
Achnanthes minutissima Kutzing	7	11	1	6	11	9	5	5	10	9		8	10	1	6
Achnanthes minutissima var. robusta Hustedt											2		2		
Achnanthes nitidiformis Lange-Bertalot		1	1										1		
Achnanthes oblongella Oestrup															
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii	1	2	1	2	4	2				1	2	3		1	1
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragalli Brun & Heribaud	5	2	2		2	6	2		1	1	4	3	3		
Achnanthes petersenii Hustedt															
Achnanthes pusilla (Grunow) De Toni	2														
Achnanthes ricula Hohn & Hellerman	4	1	2	5	10	7	8	6	4	4	1	3	4	3	3
Achnanthes rosenstockii Lange-Bertalot											6				
Achnanthes rossii Hustedt	1	1	1		2		3	1	2	1		1	4	5	2
Achnanthes saccula Carter	30	16	3	6	6	4	1		1			3	1	3	
Achnanthes sp. aff. aueri Krasske														1	
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	14	7	5	10	7	4	12	6	20	13	21	8	29	10	12
Achnanthes suchlandtii Hustedt	13	15	9	15	13	4	10	15	14	10	17	18	25	19	9
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing															
Amphora pediculus (Kutzing) Grunow															
Amphora thumensis															
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow															
Anomoeoneis serians var. acuta Hustedt															
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross															
Asterionella formosa Hassall	3	4.5	6	1	3	1	1.5	2	2	1.5	2	1.5	1.5	0.5	2
Aulacoseira ambigua (Grunow) Simonsen															
Aulacoseira distans (Ehrenberg) Simonsen															
Aulacoseira distans var. humilis (Cleve-Euler) Ross		20	6	16	16	11	15	9	22	7	12	4	8	7	1
Aulacoseira perglabra (Oestrup) Haworth															
Aulacoseira subarctica (O. Muller) Haworth	17	1	14	14	3	8	17	14	15	11	2	12	6	3	8
Aulacoseira valida (Grunow) Krammer															
Caloneis bacillaris (Gregory) Cleve															
Caloneis bacillum (Grunow) Cleve															
Caloneis silicula (Ehrenberg) Cleve								2							
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer															
Cocconeis placentula Ehrenberg var. placentula														1	
Cocconeis placentula var. lingata (Ehrenberg) Van Heurck															
Cocconeis pseudothumensis Reichardt					1	1			1					1	
Cyclotella bodanica var. aff. affinis Grunow															
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	5	4	2	8	1	7	2	2	5	1	2	2	4	3	3
Cyclotella delicatula Hustedt															
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing															
Cyclotella michiganiana Skvortzow															
Cyclotella ocellata Pantocsek															
Cyclotella pseudostelligera Hustedt															
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck															
Cyclotella woltereckii Hustedt															
Cymbella amphicephala Naegeli ex Kutzing															
Cymbella caespitosa (Kutzing) Brun															

	Otasan (L23) (1,250,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow															
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot															
Cymbella gaeumannii Meister															
Cymbella gracilis (Ehrenberg) Kutzing				1	4						1				
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst															
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer															
Cymbella naviculiformis (Auerswald) Cleve												2			
Cymbella perpusilla A. Cleve															
Cymbella proxima Reimer															
Cymbella reichardtii Krammer															
Cymbella reinhardtii Grunow															
Cymbella silesiaca Bleisch									2						
Cymbella sinuata Gregory															
Cymbella subaequalis Grunow															
Denticula kuetzingii Grunow															
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve			1												2
Diploneis marginestriata Hustedt			2			1			1			1			
Entomoneis ornata (Bailey) Reimer															
Epithemia argus (Ehrenberg) Kutzing															
Epithemia goeppertiana Hilse															
Epithemia smithii Carruthers															
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg															
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot		1	1					2			3	0.5			1
Eunotia curvata (Kutzing) Lagerstedt							1								
Eunotia incisa Gregory var. incisa										1					
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot														1	
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg															
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel															
Fragilaria arcus (Ehrenberg) Cleve var. arcus															
Fragilaria brevistriata Grunow	2	2	11						1	2	2		3		8
Fragilaria capucina var. gracilis (Oestrup) Hustedt															
Fragilaria constricta forma stricta Cleve															
Fragilaria construens (Ehrenberg) Grunow f. construens	1				1	2		1		2	5	2	5	5	14
Fragilaria construens var. binodis (Ehrenberg) Grunow	3		2	3				1	1	3			2	2	4
Fragilaria construens var. venter (Ehrenberg) Grunow	226	221	234	244	228	236	232	235	251	232	268	281	266	247	260
Fragilaria crotonensis Kitton							1								
Fragilaria exigua Grunow	5	13	8.5	7	9	13	9	12	14	18	14	15	19	8	15
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow						3	1								
Fragilaria parasitica (W. Smith) Grunow var. parasitica															
Fragilaria pinnata Ehrenberg	37	28	22	9	35	7	11	23	23	22	41	49	56	27	38
Fragilaria pseudoconstruens Marciniak															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna		0.5	0.5		1		2		2			1	1		
Frustulia rhomboides (Ehrenberg) De Toni															
Gomphonema acuminatum Ehrenberg															
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh															
Gomphonema augur Ehrenberg var. augur															
Gomphonema clavatum Ehrenberg										2				2	1
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh															
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum															
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing				3			2	1		2					
Gomphonema subtile Ehrenberg															
Gomphonema truncatum Ehrenberg	1			3											
Gyrosigma acuminatum (Kutzing) Rabenhorst															
Hantzschia amphioxys (Ehrenberg) Grunow															
Navicula aboensis (Cleve) Hustedt			1	2		1		1		1	5		1		
Navicula absoluta Hustedt									2						
Navicula agrestis Hustedt						2			1	3	1		4		
Navicula arvensis Hustedt	2	4													9
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg									1						
Navicula bryophila Petersen															
Navicula capitata Ehrenberg var. capitata															
Navicula capitata var. lueneburgensis (Grunow) Patrick															
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt				1		2			2		1	5	2	3	
Navicula cocconeiformis Gregory ex Greville				2	3		1	1	1					2	
Navicula cryptocephala Kutzing	2	1		4	3	3	1			3	4	1		1	
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing															
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt															
Navicula explanata Hustedt	2						4		1						
Navicula farta Hustedt															
Navicula gerloffii Shimanski	5											2		2	
Navicula hambergii Hustedt	1	1													
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister															
Navicula jaernfeltii Hustedt	6	2	4	4	1	1	7	6	3	13	1	5	3	4	6
Navicula jentzschii Grunow															

	Otasan (L23) (1,259,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot	-1	3	16	3	6	9	6	9	7	7	12	3	8	7	5
Navicula laevissima Kutzing var. laevissima															
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt															
Navicula mediocris Krasske															
Navicula minima Grunow	6	14	9	8	12	5	6	5	1	9	3	5	13	9	2
Navicula minusculoides Hustedt			4			1			1	3			1		1
Navicula obsoleta Husedt					4		1					2		3	
Navicula oppugnata Hustedt							1	1							
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot		2		1		1	4	2	7	5		1	3	1	
Navicula protracta (Grunow) Cleve															
Navicula pseudoscutiformis Hustedt	4	2	1	2	1	2	3	1		4	5		6	4	3
Navicula pupula Kutzing var. pupula	1	0	1	0	0	0	0	1	1	0	0	0	2	1	0
Navicula pupula var. mutata (Krasske) Hustedt													1		
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot															
Navicula pusio Cleve															
Navicula radiosa Kutzing	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt	4	2	5	2	11	13	4	4		3	6	3	9	4	2
Navicula schoenfeldii Hustedt															
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt	15	15	22	16	9	9	11	11	19	19	17	16	25	18	22
Navicula seminulum Grunow	2	15	6	15	7	9	6	9	4	16	16	15	14	11	3
Navicula similis Krasske					2						2				3
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot															
Navicula subminuscula Manguin															
Navicula submolesta Hustedt		2		3		1	1				1	15		16	1
Navicula submuralis Hustedt	4	1	15	10	12	15	6	8	8	5	15		41		22
Navicula subrotundata Hustedt															
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske															
Navicula viridula (Kutzing) Ehreneberg	2				1										
Navicula vitiosa Schimanski	2	2		1	1		1	2	1	4	6	4	6	2	2
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer															
Neidium hitchcockii (Ehrenberg) Cleve															
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow															
Nitzschia dissipata (Kutzing) Grunow var. dissipata			1.5	0.5		1									
Nitzschia fasciculata (Grunow) Grunow															
Nitzschia fonticola Grunow				3											
Nitzschia frustulum (Kutzing) Grunow var. frustulum															
Nitzschia inconspicua Grunow															
Nitzschia pseudofonticola Hustedt															
Nitzschia recta Hantzsch															
Nitzschia rostellata Hustedt			4	1						1		1			
Nitzschia valdestriata Alcorn & Hustedt									1					2	
Pinnularia abaujensis var. linearis (Hustedt) Patrick															
Pinnularia borealis Ehrenberg															
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve															
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt						1	1								
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst	1														
Pinnularia interrupta W. Smith															
Pinnularia major (Kutzing) Rabenhorst															
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve															
Pinnularia rupestris Hantzsch															
Pinnularia subcapitata Gregory															
Pinnularia viridis (Nitzsch) Ehrenberg															
Pinnularia wisconsinensis Camburn & Charles															
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller															
Stauroneis anceps var. siberica Grunow								1	1						
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	1														
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt															
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow															
Stephanodiscus medius Hakansson															
Stephanodiscus minutulus (Kutzing) Cleve & Moller															
Stephanodiscus niagarae Ehrenberg															
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve															
Surirella didyma Kutzing															
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg															
Tabellaria flocculosa (Roth) Kutzing	14	10	11.5	3	6.5	4	3	6.5	3	4.5	7.5	9.5	7.5	6	7
Tabellaria flocculosa var. linearis Koppen				15.5	11.5	11.5	4.5	5	0.5	1.5			1.5	3	1
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.044	0.1067	0.1021	0.1018	0.1002	0.106	0.106	0.1052	0.101	0.1032	0.1087	0.2109	0.2072	0.2097	0.2062
Diatom concentration (x10^6 valves/g dry mass)	12061	25890	6162.3	19483	30564	5837.3	5765.2	8723.5	15053	18673	61120	32154	39123	4142.8	30795

	L109 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	117	173	58	74	149	134	280	899	132	163	34	42	46	239	128
Stomatocysts	124	149	145	183	175	150	135	167	114	153	109	96	131	258	104
Mallomonas crassisquama (Asmund) Fott	42	44	30	9	4	4	1	5			1	2		1	
Mallomonas heterospina Lund			1												
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman		3		2											
Achnanthes altaica (Poretzky) Cleve-Euler	1	4			1						1	2			
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot	1														
Achnanthes bioretii Germain		3	1			1	1	1			2	2			
Achnanthes calcar Cleve		2													
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei							1		2	1		2	1		
Achnanthes conspicua Mayer						1									
Achnanthes curtissima Carter		2	1			2	5	10	2		1	1	1	2	1
Achnanthes daoensis Lange-Bertalot	1		1		2				1						
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot		2				3							1		1
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt	1								2		3	3	1	2	
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua			2	2	5	4	3		4	5	1	4	2	4	9
Achnanthes fulia Carter	1			2				2			2	1		5	3
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wutrich			3	1											
Achnanthes helvetica (Hustedt) Lange-Bertalot		1									3	2		1	
Achnanthes impexa Lange-Bertalot		4	2	1	2	1									
Achnanthes impexiformis Lange-Bertalot	1			4											
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow	1	2	3	3	4	1	6	19	5	8	7	14	14	13	29
Achnanthes lanceolata var. dubia Grunow															
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot															
Achnanthes laterostrata Hustedt			1	4	3	1		2	4	1	2	3	1	2	1
Achnanthes levanderi var. helvetica Hustedt	3	2	6	3	4	9	5	4	3	2	7	10	1		2
Achnanthes marginulata Grunow															
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing	26	43	65	34	31	39	14	10	31	7	34	26	11	9	5
Achnanthes minutissima var. robusta Hustedt			1								1				
Achnanthes nitidiformis Lange-Bertalot							1								
Achnanthes oblongella Oestrup						3									
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii	2		2		2	3	1	2				2	3	4	3
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragalli Brun & Heribaud						1					2	3	2		
Achnanthes petersenii Hustedt			2				1			1	1	1			
Achnanthes pusilla (Grunow) De Toni				13	18	12	4	5	11	11	12	17	8	7	8
Achnanthes ricula Hohn & Hellerman		7		1	4		1			1					1
Achnanthes rosenstockii Lange-Bertalot															
Achnanthes rossii Hustedt		2	1		2		6		2		1	2	2	2	1
Achnanthes saccula Carter												4	4		
Achnanthes sp. aff. aueri Krasske		4					1						1		
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	1	3	5	4	2	6	1	3	2	2	8	11	3	5	7
Achnanthes suchlandtii Hustedt	2	1	1	3	1	4	2	4	1	3	6	4	4		5
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing		2	1		1			2	1	3	2	5	1	4	1
Amphora pediculus (Kutzing) Grunow					4	1				6	1			1	1
Amphora thumensis															
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow			1	1		1		1	1	2	1	1			
Anomoeoneis serians var. acuta Hustedt															
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross		2	1	1	3	2				1				2	
Asterionella formosa Hassall	6	2.5	5			0.5	0.5	0.5	1		0.5		0.5	2.5	0.5
Aulacoseira ambigua (Grunow) Simonsen															
Aulacoseira distans (Ehrenberg) Simonsen															
Aulacoseira distans var. humilis (Cleve-Euler) Ross	1	2	4	8	14	3	6	3	9	12	9	8	10	24	7
Aulacoseira perglabra (Oestrup) Haworth													8		
Aulacoseira subarctica (O. Muller) Haworth	20	27	27	66	34	59	111	85	88	60	82	67	110	76	45
Aulacoseira valida (Grunow) Krammer															
Caloneis bacillaris (Gregory) Cleve										2	1		1	1	
Caloneis bacillum (Grunow) Cleve									2		2				
Caloneis silicula (Ehrenberg) Cleve						1					5				
Caloneis undulata (Gregory) Krammer							1								
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer															
Cocconeis placentula Ehrenberg var. placentula															
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck				1											
Cocconeis pseudothumensis Reichardt					2	2	4	7	5	5	1	4	3	8	7
Cyclotella bodanica var. aff. affinis Grunow		1													
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	11	16	11	28	15	20	4	5	17	12	17	23	2		1
Cyclotella delicatula Hustedt	1														
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing								5	2	2	11	4	1	6	18
Cyclotella michiganiana Skvortzow	9	20	11	15	22	20	8	2	9	12	33	15		3	1
Cyclotella ocellata Pantocsek															
Cyclotella pseudostelligera Hustedt	240	165	73	115	66	32	15	20	12	4	8	18	5	1	
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck	7	30	31	17	16	14	5	4	22	25	11	4	4		
Cyclotella woltereckii Hustedt	31	26	12	21	17	14	11	1	6		2	3			
Cymbella amphicephala Naegeli ex Kutzing			2		1										
Cymbella caespitosa (Kutzing) Brun	1					1			2					1	

	LI09 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow		1	1		1				2		2		1		
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot		1				1			2	2	4	1			
Cymbella gaeumannii Meister															
Cymbella gracilis (Ehrenberg) Kutzing		5		3	3	1	1	3	1	3	4	1	1	1	
Cymbella hebridica (Grunow ex Cleve) Cleve											2				
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst															
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer		1			1		1								
Cymbella naviculiformis (Auerswald) Cleve														1	
Cymbella perpusilla A. Cleve														1	
Cymbella proxima Reimer										4			2	2	
Cymbella reichardtii Krammer								1	1		1				1
Cymbella reinhardtii Grunow				1	1	1				1					
Cymbella silesiaca Bleisch	2	3			4			1	8		1	3	6		
Cymbella sinuata Gregory				1				2	2	3					1
Cymbella subaequalis Grunow															
Denticula kuetzingii Grunow			1		1	1						1			
Denticula kuetzingii var. rumrichae Krammer	1								1				3		
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve				1						1		1			
Diploneis marginestriata Hustedt	5	2	2	1	4	5	1		5	3	2	3	3	4	2
Entomoneis ornata (Bailey) Reimer	1	2		4	1		1	1	2	2	1	3			
Epithemia argus (Ehrenberg) Kutzing							1	1		2		1			
Epithemia goeppertiana Hilse						1					1	1			
Epithemia smithii Carruthers												1		1	
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg			0.5	0.5									2	0.5	
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot	2	0.5	1	2.5	7	0.5		2	8		1		2	2.5	1.5
Eunotia curvata (Kutzing) Lagerstedt	1.5	2		2	4.5	2	1	0.5	2.5	4	6		1	2	0.5
Eunotia incisa Gregory var. incisa			3	1				0.5						0.5	
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot	4	0.5			5	2	2	3	3	8	2	1	1	2.5	0.5
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg													1.5		0.5
Eunotia rhomboidea Hustedt			3		1	2				0.5					
Eunotia rhyncocephala Hustedt var. rhyncocephala			1	1					0.5	1					
Eunotia serra var. tetraodon (Ehrenberg) Norpel		2													
Fragilaria arcus (Ehrenberg) Cleve var. arcus	1	0.5													
Fragilaria brevistriata Grunow		1				2	2	1	2	1	2	2	1	2	
Fragilaria capucina var. gracilis (Oestrup) Hustedt	0.5				1										
Fragilaria constricta forma stricta Cleve															
Fragilaria construens (Ehrenberg) Grunow f. construens		1			1	1	1	1	6	7	6	4	4	9	12
Fragilaria construens var. binodis (Ehrenberg) Grunow						2	1		5	3	3	5	2		2
Fragilaria construens var. venter (Ehrenberg) Grunow	17	18	45	51	29	88	59	60	77	49	66	90	68	102	79
Fragilaria crotonensis Kitton				2	1										
Fragilaria exigua Grunow	3	19	1	16	17	10	13	12	21	6	21	20	21	15	8
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica															
Fragilaria pinnata Ehrenberg	9	6	11	19	16	22	17	20	27	33	25	26	32	45	56
Fragilaria pseudoconstruens Marciniak															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna	2	2	3.5	3.5	0.5	0.5	0.5	1	3	1		4	2		
Frustulia rhomboides (Ehrenberg) De Toni	3	2	2	2	2	3.5	2	3	6			1		1	
Gomphonema acuminatum Ehrenberg	1			2	1	2			2		3	1	1		
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh		4	1	2	2	2	1	1					1		
Gomphonema augur Ehrenberg var. augur										2					
Gomphonema clavatum Ehrenberg					5										
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															1
Gomphonema minutum (C. Agardh) C. Agardh		4	4	8	9	13	7	1	6	5	15	1	5	8	5
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum															
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing	1	1	5					2							
Gomphonema subtile Ehrenberg									1.5	1					
Gomphonema truncatum Ehrenberg													2		
Gyrosigma acuminatum (Kutzing) Rabenhorst									1	3	2		7	1	2
Hantzschia amphioxys (Ehrenberg) Grunow		0.5		2											
Navicula aboensis (Cleve) Hustedt			1	1			2				2	3	1	7	3
Navicula absoluta Hustedt					1	2		3	2	1	4	2	1	5	2
Navicula agrestis Hustedt		2					3	1	1						
Navicula arvensis Hustedt	1		2												
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg								2	1						
Navicula bryophila Petersen				1											
Navicula capitata Ehrenberg var. capitata					2		2	1							
Navicula capitata var. lueneburgensis (Grunow) Patrick						6	1	2	3	7	4	2	9	3	1
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt	3	2	6	2	1	3	1	4	6	2	4	10	2	4	
Navicula cocconeiformis Gregory ex Greville	1		1	3	2	8	1		7	2	3	7	3	6	2
Navicula cryptocephala Kutzing	5	5		3	4	5	1	1	1	8	7	2	1	2	1
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing			1	1	2		2	11		1					
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt			2												
Navicula explanata Hustedt		4	1	3	4	2	1	1		2	4	4		5	
Navicula farta Hustedt							2	1	1	2					1
Navicula gerloffii Shimanski			3	2	1	2		1				1	1		
Navicula hambergii Hustedt															
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister														1	
Navicula jaernfeltii Hustedt			1	2	4	7	3	10	10	4	10	3	11	9	21
Navicula jentzschii Grunow															

	L109 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt			2	1			1			1			1	1	
Navicula kuelbsii Lange-Bertalot	2	4	4	2	2		6	2	2	3	3	5	2	4	2
Navicula laevissima Kutzing var. laevissima			1		1							1			
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt						1									
Navicula mediocris Krasske															
Navicula minima Grunow				3	3	2	4	4	4	1		4	1		
Navicula minusculoides Hustedt					1										
Navicula obsoleta Husedt		1	1		1	3	1	3	4	1	2		5	12	13
Navicula oppugnata Hustedt		3		2			2	3	5	1		1			1
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot						1					1			2	4
Navicula protracta (Grunow) Cleve															
Navicula pseudoscutiformis Hustedt						1	3	7	1	4	2	5	5	9	5
Navicula pupula Kutzing var. pupula	4	0	5	3	3	3	1	2	6	5	2	2	2	0	2
Navicula pupula var. mutata (Krasske) Hustedt															
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot			1									1		1	1
Navicula pusio Cleve									1						
Navicula radiosa Kutzing	0	2	0	0	1	1	1	1	4	0	1	1	1	1	1
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt		2			4						1		2		
Navicula schoenfeldii Hustedt															
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt	4	1			8	13	13	7	20	24	17	9	27	30	26
Navicula seminulum Grunow	3	2	4	1	2	1	4	2	3	7	2		7	5	1
Navicula similis Krasske		1		4	2										
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot		3							2						
Navicula subminuscula Manguin															
Navicula submolesta Hustedt	1	2	2	2	6	4	2	1	1		2	3	1	2	
Navicula submuralis Hustedt		3	8	10	18	13	19	20	11	8	11	11	6	12	27
Navicula subrotundata Hustedt															
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske															
Navicula viridula (Kutzing) Ehreneberg						1			1	1		1		1	
Navicula vitiosa Schimanski				1		10					3	1			
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer		1	1			1	1				1			5	
Neidium hitchcockii (Ehrenberg) Cleve				1	1						2				
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow									1						
Nitzschia dissipata (Kutzing) Grunow var. dissipata	0.5		0.5	1	1			1							
Nitzschia fasciculata (Grunow) Grunow				1							0.5				
Nitzschia fonticola Grunow	1		1.5		0.5	2.5	1		7	1	2	6	2		
Nitzschia frustulum (Kutzing) Grunow var. frustulum	0.5	0.5	2				0.5								
Nitzschia inconspicua Grunow	1			3	1						1				
Nitzschia pseudofonticola Hustedt						0.5						1			
Nitzschia recta Hantzsch			1												
Nitzschia rostellata Hustedt	0.5		1		0.5							1			
Nitzschia valdestriata Alcom & Hustedt															
Pinnularia abaujensis var. linearis (Hustedt) Patrick															
Pinnularia borealis Ehrenberg													1		
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve												1		1	
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt	1	1		1			1		1	2	3		1	3	1
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst		1								1				1	
Pinnularia interrupta W. Smith	1	1			1				1				1		
Pinnularia major (Kutzing) Rabenhorst															
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve						1			1	1		5	1		1
Pinnularia rupestris Hantzsch										5	2				
Pinnularia subcapitata Gregory															
Pinnularia viridis (Nitzsch) Ehrenberg				2	3	1		1	1	1		2			
Pinnularia wisconsinensis Cambum & Charles		2					1			1				1	
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller												1	1		
Stauroneis anceps var. siberica Grunow	1	3		3	3	2	3		2	2	1	1	1		1
Stauroneis phoenicenteron (Nitzsch) Ehrenberg			1		2	1		1	1	1			1		
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt															
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow								1							
Stephanodiscus medius Hakansson								2							
Stephanodiscus minutulus (Kutzing) Cleve & Moller															
Stephanodiscus niagarae Ehrenberg															
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve															
Surirella didyma Kutzing											1				
Surirella gemma Ehrenberg												1			
Surirella robusta Ehrenberg															
Tabellaria flocculosa (Roth) Kutzing	29	16.5	13.5	18	10.5	19	9.5	4.5	25.5	15	39	23	9.5	10.5	1.5
Tabellaria flocculosa var. linearis Koppen		2	2.5	5	4	3	0.5			2.5		1.5			
Tetracyclus glans (Ehrenberg) Mills					1										

Sample weight (g)	0.1187	0.1201	0.1066	0.112	0.1163	0.1051	0.1108	0.1184	0.1178	0.1153	0.1167	0.1202	0.117	0.1274	0.1813
Diatom concentration (x10^6 valves/g dry mass)	55.473	40.236	111.54	107.63	45.751	61.803	21.841	6.2382	59.68	38.395	237.11	177.32	143.44	27.85	30.922

	L38 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	16	41	23	27	26	17	26	25	27	30	18	38	16	24	
Stomatocysts	87	131	101	85	84	96	76	89	112	118	74	136	82	98	
Mallomonas crassisquama (Asmund) Fott	2	1	2	1		1				3					
Mallomonas heterospina Lund															
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman															
Achnanthes altaica (Poretzky) Cleve-Euler	1					2				1					
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot															
Achnanthes bioretii Germain				1		2			1			2	1		
Achnanthes calcar Cleve															
Achnanthes carissima Lange-Bertalot								1							
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei															
Achnanthes conspicua Mayer															
Achnanthes curtissima Carter		4	2	1	2	2					2	2	4	2	
Achnanthes daoensis Lange-Bertalot								1				1			
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot															
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt	1	1	2	1					2	1		3	1		
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua	1				1				1	2		4			
Achnanthes fulia Carter	4	1												1	
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wutrich													3		
Achnanthes helvetica (Hustedt) Lange-Bertalot							1	2			3	1			
Achnanthes impexa Lange-Bertalot		1													
Achnanthes impexiformis Lange-Bertalot		1	1	1	1	4									
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow	2	2	2			3	3		2		4	1		3	
Achnanthes lanceolata var. dubia Grunow															
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot															
Achnanthes laterostrata Hustedt														1	
Achnanthes levanderi var. helvetica Hustedt		1	2	1	4		1	1	5	2	2			1	
Achnanthes marginulata Grunow			5	1	2	2			3	1	1				
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing	57	75	48	46	37	51	39	49	51	66	58	70	56	56	
Achnanthes minutissima var. robusta Hustedt															
Achnanthes nitidiformis Lange-Bertalot															
Achnanthes oblongella Oestrup															
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii	1	1										1			
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragalli Brun & Heribaud													1		
Achnanthes petersenii Hustedt		3	2	2	3	1	2		2	1	1	2	1	1	
Achnanthes pusilla (Grunow) De Toni	6	7	16	13	9	6	10	7	6	3	7	9	6	6	
Achnanthes ricula Hohn & Hellerman						2									
Achnanthes rosenstockii Lange-Bertalot															
Achnanthes rossii Hustedt		1		1	2					3	2		1	1	
Achnanthes saccula Carter											1				
Achnanthes sp. aff. aueri Krasske															
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	8	2	6	6	11	8	7	8	2	7	3	2	17	8	
Achnanthes suchlandtii Hustedt	1					1	1						3	1	
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing		2	1	1		1	1	1		2	1	1			
Amphora pediculus (Kutzing) Grunow															
Amphora thumensis															
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow						1	1	1		1	3	1	2	1	
Anomoeoneis serians var. acuta Hustedt	5	12	11	6	14	11	4	6	17	7	10	13	7	8	
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross	4				1					1	3	1			
Asterionella formosa Hassall		2		2											
Aulacoseira ambigua (Grunow) Simonsen	24	10	6	8	9	8	9	7	7	4		1	1	7	
Aulacoseira distans (Ehrenberg) Simonsen					1										
Aulacoseira distans var. humilis (Cleve-Euler) Ross	2	1													
Aulacoseira perglabra (Oestrup) Haworth															
Aulacoseira subarctica (O. Muller) Haworth	3	10	9	10	9	20	16	11	12	9	9	3	2	6	
Aulacoseira valida (Grunow) Krammer		2		2	1	2	3	1		3				6	
Caloneis bacillaris (Gregory) Cleve							2				2			3	
Caloneis bacillum (Grunow) Cleve			1												
Caloneis silicula (Ehrenberg) Cleve					1				1						
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer															
Cocconeis placentula Ehrenberg var. placentula															
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck															
Cocconeis pseudothumensis Reichardt									1			1	1		
Cyclotella bodanica var. aff. affinis Grunow														1	
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	2	2	1		1	1	3	1	1	2		1		1	
Cyclotella delicatula Hustedt															
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing		2			3								1	2	
Cyclotella michiganiana Skvortzow															
Cyclotella ocellata Pantocsek															
Cyclotella pseudostelligera Hustedt	3	14	15	5	14	7	10	11	2	7	2	2	6	3	
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck	9	8	4	10	5	11	6	9	6	5	1	10	8	18	
Cyclotella woltereckii Hustedt		1	5	1	1		2	3	2	3		2	4	3	
Cymbella amphicephala Naegeli ex Kutzing															
Cymbella caespitosa (Kutzing) Brun	2														

	L30 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow	3	8	8	3	9	3		2		4	5	8	5	4	
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot	3	1	2							1					
Cymbella gaeumannii Meister											1				
Cymbella gracilis (Ehrenberg) Kutzing	3	5	4	4	3	1	1	3	3	3	14	3	7	5	
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing										1		2			
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst												5			
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer												3	1		
Cymbella naviculiformis (Auerswald) Cleve		3		6	1	1	2	1	4	4	3	5	5	2	
Cymbella perpusilla A. Cleve											2				
Cymbella proxima Reimer															
Cymbella reichardtii Krammer															
Cymbella reinhardtii Grunow	1														
Cymbella silesiaca Bleisch		1	1				2			1	4			3	
Cymbella sinuata Gregory															
Cymbella subaequalis Grunow															
Denticula kuetzingii Grunow															
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve						1					1				
Diploneis marginestriata Hustedt												1			
Entomoneis ornata (Bailey) Reimer											1	1			
Epithemia argus (Ehrenberg) Kutzing															
Epithemia goeppertiana Hilse															
Epithemia smithii Carruthers															
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg															
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot			2	4	2		2	1	1	2		3	3	1	
Eunotia curvata (Kutzing) Lagerstedt			3.5	1		2	1	1	1	2	1	6	1	1	
Eunotia incisa Gregory var. incisa															
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot	0.5		1.5	1		2	2	2	5				1		
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg															
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel								1	1					1	
Fragilaria arcus (Ehrenberg) Cleve var. arcus														2	
Fragilaria brevistriata Grunow				1				1							
Fragilaria capucina var. gracilis (Oestrup) Hustedt	7	12	16.5	11	20	21	14	16	13	15	8	12	13	1	
Fragilaria constricta forma stricta Cleve							3	4	1						
Fragilaria construens (Ehrenberg) Grunow f. construens	2		2	1	1		6							8	
Fragilaria construens var. binodis (Ehrenberg) Grunow			1				1			1		2	1		
Fragilaria construens var. venter (Ehrenberg) Grunow	62	72	37	74	37	46	61	51	63	57	34	30	36	76	
Fragilaria crotonensis Kitton															
Fragilaria exigua Grunow	26	21	20	23	17	12	15	18	25	32	9	6	9	7	
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica															
Fragilaria pinnata Ehrenberg	3	2	13	5	4	11	14	7	12	5	11	8	1	3	
Fragilaria pseudoconstruens Marciniak															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna	12.5	6	8	5	13	12	18	12	26	11	20	16	1	5	
Frustulia rhomboides (Ehrenberg) De Toni		3		1		1	1			1	1	1			
Gomphonema acuminatum Ehrenberg											1				
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh								1							
Gomphonema augur Ehrenberg var. augur		1													
Gomphonema clavatum Ehrenberg															
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh		11	7	6	7	6	4	3	5	2	6	5	1	4	
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum															
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing															
Gomphonema subtile Ehrenberg															
Gomphonema truncatum Ehrenberg															
Gyrosigma acuminatum (Kutzing) Rabenhorst															
Hantzschia amphioxys (Ehrenberg) Grunow															
Navicula aboensis (Cleve) Hustedt															
Navicula absoluta Hustedt	6	15	12	10	14	11	1	5	8	11	1	3	4	2	
Navicula agrestis Hustedt	1	2													
Navicula arvensis Hustedt															
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg	1							1							
Navicula bryophila Petersen													2		
Navicula capitata Ehrenberg var. capitata															
Navicula capitata var. lueneburgensis (Grunow) Patrick															
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt		1	1				1								
Navicula cocconeiformis Gregory ex Greville					2							1			
Navicula cryptocephala Kutzing	3	8	6	5	5	5	8		1	7	5	10	11	13	
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing			1	1	3			1							
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt					4			6	2	9	7	5	4	15	
Navicula explanata Hustedt	8	3	5	5	4	2	1	4	6	5	2	7	9	8	
Navicula farta Hustedt															
Navicula gerloffii Shimanski			5				2		2	2		1		1	
Navicula hambergii Hustedt															
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister															
Navicula jaernfeltii Hustedt		1				1	1				2	1			
Navicula jentzschii Grunow															

	L39 (150,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot	17	40	29	29	31	37	24	35	31	37	33	22	30	25	
Navicula laevissima Kutzing var. laevissima			2			1		2		4	9	5	5	3	
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt			1	1	2	2	5	1	1		2			1	
Navicula mediocris Krasske		2	2	2			5	4	3		2	5	10	3	
Navicula minima Grunow	4	1		4	4	9	5	6	2	1	8	5	2	6	
Navicula minusculoides Hustedt	1							2	4	3		1			
Navicula obsoleta Husedt	2	17	3	1				2							
Navicula oppugnata Hustedt			3		2			2	1			2	1		
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot															
Navicula protracta (Grunow) Cleve															
Navicula pseudoscutiformis Hustedt	1	3	1		3	2			2	3	5	4			
Navicula pupula Kutzing var. pupula	10	16	14	12	19	22	14	25	11	14	5	9	9	18	
Navicula pupula var. mutata (Krasske) Hustedt															
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot															
Navicula pusio Cleve															
Navicula radiosa Kutzing	7	1	4	1	2	1	3	5	2	1	2	8	2		
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt															
Navicula schoenfeldii Hustedt															
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt	1	7	5		3						2	4		1	
Navicula seminulum Grunow	8	11	1	4	5	3	6	3	2	2	6	8	2	10	
Navicula similis Krasske															
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot	1	2	2		2			2			2				
Navicula subminuscula Manguin							2								
Navicula submolesta Hustedt	1	1		1	2	2			1	4	1	2	1		
Navicula submuralis Hustedt			2		1				1	1				4	
Navicula subrotundata Hustedt															
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske				1			4		2	1		4	1		
Navicula viridula (Kutzing) Ehreneberg			1												
Navicula vitiosa Schimanski	9	5	2	3	1	3	5	2	4	3	5	11	6	11	
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer	11	10	4	11	14	11	9	7	8	8	9	12	10	13	
Neidium hitchcockii (Ehrenberg) Cleve						1									
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow															
Nitzschia dissipata (Kutzing) Grunow var. dissipata		3.5	0.5			1.5			1						
Nitzschia fasciculata (Grunow) Grunow	1														
Nitzschia fonticola Grunow	63	74	74	69	65	59	47	33	55	50	72	88	56	50	
Nitzschia frustulum (Kutzing) Grunow var. frustulum	1														
Nitzschia inconspicua Grunow															
Nitzschia pseudofonticola Hustedt	5	4.5	7	4	6	3			1	1					
Nitzschia recta Hantzsch															
Nitzschia rostellata Hustedt	3.5	12.5	8	4	9	18.5	16	2	3					1	
Nitzschia valdestriata Alcom & Hustedt											1				
Pinnularia abaujensis var. linearis (Hustedt) Patrick					1	3		3	1		1	2		3	
Pinnularia borealis Ehrenberg															
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve	1				1										
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt	7	13	4	3	4	1	4	2	3	4	3	2	2	6	
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst		1													
Pinnularia interrupta W. Smith	14	17	18	21	20	15	1	5	10	15	9	27	17	34	
Pinnularia major (Kutzing) Rabenhorst			1	1	2		1	4		1		4			
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve		1			7	8	8	10	5	7	5	15	6	22	
Pinnularia rupestris Hantzsch								3	2						
Pinnularia subcapitata Gregory															
Pinnularia viridis (Nitzsch) Ehrenberg		1	4	1	4	1	4	3	1	2	2	8			
Pinnularia wisconsinensis Camburn & Charles					1	1									
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller			1		1										
Stauroneis anceps var. siberica Grunow	3	9	9	6	12	4	8	6	13	11	11	22	9	11	
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	12	2	6	4	7	3	2	2		1		1	2	1	
Stenopterobia delicatissima (Lewis) Van Heurck										2					
Stephanodiscus cf. alpinus Hustedt															
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow															
Stephanodiscus medius Hakansson															
Stephanodiscus minutulus (Kutzing) Cleve & Moller															
Stephanodiscus niagarae Ehrenberg															
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve	2					1	1		2						
Surirella didyma Kutzing		1	1						3		1		1		
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg					1										
Tabellaria flocculosa (Roth) Kutzing	6	14.5	9	14	7	18	6	8	10	8	9	6	4	8	
Tabellaria flocculosa var. linearis Koppen															
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.1175	0.1087	0.13	0.1041	0.1087	0.112	0.1178	0.1186	0.1236	0.1209	0.108	0.1315	0.1211	0.1383	
Diatom concentration (x10^6 valves/g dry mass)	399.57	219.71	275.05	274.95	292.69	432.77	241.35	237.44	233.97	216.6	377.78	178.03	344.34	256.93	

	Legend (1,250,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	122	38	64	40	39	70	65	87	66	64	39	34	24	76	92
Stomatocysts	54	27	37	36	34	37	30	36	31	29	33	28	35	35	28
Mallomonas crassisquama (Asmund) Fott	23	15	17	5	9	14	20	12	10	4	3	2	1		
Mallomonas heterospina Lund															
Synura petersenii Korshikov	50	22	48	21	16	12	13	13	21	6	14	1	2		
Achnanthes acares Hohn & Hellerman			3	1					9		10	3	4	2	3
Achnanthes altaica (Poretzky) Cleve-Euler								4	1	1	1	2	1		
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot	1		1	1		2		1	2		2				
Achnanthes bioretii Germain															
Achnanthes calcar Cleve	1		1				1							1	1
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve	1														
Achnanthes clevei Grunow var. clevei															
Achnanthes conspicua Mayer															
Achnanthes curtissima Carter									2		2		1		
Achnanthes daoensis Lange-Bertalot									2	1					
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot									1						
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt						1			3		1				
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua															
Achnanthes fulla Carter									2						
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wutrich		1	9	3	1			1			1				
Achnanthes helvetica (Hustedt) Lange-Bertalot				2				1						1	
Achnanthes impexa Lange-Bertalot	1														
Achnanthes impexiformis Lange-Bertalot															
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow	20	14	6	2	10	4		6	6	9	8	8	16	11	3
Achnanthes lanceolata var. dubia Grunow	3						9				1				1
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot		1													
Achnanthes laterostrata Hustedt	3	2	3	1	5	3		4	6	10	3	4	5	3	4
Achnanthes levanderi var. helvetica Hustedt		8	1	2	2	5	3	2	7	3	1		5		1
Achnanthes marginulata Grunow	2	4	6	7	4	10	2	5	5	3	4	3	2	2	3
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing								4	1		1	2			
Achnanthes minutissima var. robusta Hustedt							9								
Achnanthes nitidiformis Lange-Bertalot															
Achnanthes oblongella Oestrup						4									
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii	1	4	2	1		1		5	2	1	1	1	2	1	1
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragallii Brun & Heribaud	1	2					1	1							1
Achnanthes petersenii Hustedt															
Achnanthes pusilla (Grunow) De Toni								1							
Achnanthes ricula Hohn & Hellerman		2	2	1		4	4					1		2	2
Achnanthes rosenstockii Lange-Bertalot		1													
Achnanthes rossii Hustedt	3	1				1		2	2	1	2	1	4	1	1
Achnanthes saccula Carter			5	4	8	10	6	5		8	9	6	1	2	5
Achnanthes sp. aff. aueri Krasske				1			1			1					
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	25	8	12	4	3	4	5	4	6	11	2	6	11	1	1
Achnanthes suchlandtii Hustedt	9	10	5	17	6	18	14	5	6	9	7	13	11	2	10
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing				1											
Amphora pediculus (Kutzing) Grunow	2		3	1	1										
Amphora thumensis															
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow															
Anomoeoneis serians var. acuta Hustedt															
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross								1							
Asterionella formosa Hassall	27	24	24	25	19.5	36	27.5	18.5	23	22	19.5	21.5	14.5	8	3
Aulacoseira ambigua (Grunow) Simonsen															
Aulacoseira distans (Ehrenberg) Simonsen	42	12	15	20	14	16	7	21		17	17	25	12	8	9
Aulacoseira distans var. humilis (Cleve-Euler) Ross															
Aulacoseira perglabra (Oestrup) Haworth															
Aulacoseira subarctica (O. Muller) Haworth	143	73	93	58	103	41	95	80	145	119	73	91	110	78	80
Aulacoseira valida (Grunow) Krammer															
Caloneis bacillaris (Gregory) Cleve															
Caloneis bacillum (Grunow) Cleve															
Caloneis silicula (Ehrenberg) Cleve															
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer					1										
Cocconeis placentula Ehrenberg var. placentula												1			
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck															
Cocconeis pseudothumensis Reichardt															
Cyclotella bodanica var. aff. affinis Grunow															
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	10	3	2	5	8	4	2	5	6	6	6	5	9	9	15
Cyclotella delicatula Hustedt	4	2	1		1	5	4	3		2		3	2	4	5
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing															
Cyclotella michiganiana Skvortzow															
Cyclotella ocellata Pantocsek	6	2	1	2			1		1						
Cyclotella pseudostelligera Hustedt	58	39	47	28	37	45	31	33	35	31	46	32	11	7	2
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck															
Cyclotella woltereckii Hustedt		8	2	4	5	8	5	6	14	8	5	1	2	1	2
Cymbella amphicephala Naegeli ex Kutzing		1										2			
Cymbella caespitosa (Kutzing) Brun	1												1		1

	Legend (1,250,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow															
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot															
Cymbella gaeumannii Meister															
Cymbella gracilis (Ehrenberg) Kutzing	1												1		2
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst															
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer			1												
Cymbella naviculiformis (Auerswald) Cleve															
Cymbella perpusilla A. Cleve															
Cymbella proxima Reimer					1		1	1							
Cymbella reichardtii Krammer	3									1					1
Cymbella reinhardtii Grunow					1										
Cymbella silesiaca Bleisch					2										
Cymbella sinuata Gregory			1					2			3			1	3
Cymbella subaequalis Grunow															
Denticula kuetzingii Grunow															
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve							1								
Diploneis marginestriata Hustedt															
Entomoneis ornata (Bailey) Reimer															
Epithemia argus (Ehrenberg) Kutzing															
Epithemia goeppertiana Hilse															3
Epithemia smithii Carruthers															
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg												0.5			
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot		1													
Eunotia curvata (Kutzing) Lagerstedt						0.5									
Eunotia incisa Gregory var. incisa															
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot															
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg															
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel															
Fragilaria arcus (Ehrenberg) Cleve var. arcus			1					0.5		1		0.5		0.5	
Fragilaria brevistriata Grunow	1	6		2	5	1	3	2		2	2	6	1	2	2
Fragilaria capucina var. gracilis (Oestrup) Hustedt	12	2.5	2	1	10.5	4.5	7	2	2	8.5	5.5	5	0.5	1.5	
Fragilaria constricta forma stricta Cleve															
Fragilaria construens (Ehrenberg) Grunow f. construens	2	2				1	1	1	2	1		2	4	4	14
Fragilaria construens var. binodis (Ehrenberg) Grunow									1						
Fragilaria construens var. venter (Ehrenberg) Grunow	67	31	19	37	42	63	27	26	85	51	83	67	99	123	109
Fragilaria crotonensis Kitton	5	5	2	1	0.5			3	1			3.5	0.5	3	0.5
Fragilaria exigua Grunow									1						
Fragilaria nanana Lange-Bertalot	12	1	1		0.5	1.5	1	1	1.5	2	1.5	1.5	1	0.5	0.5
Fragilaria nitzschioides Grunow				0.5											
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica															
Fragilaria pinnata Ehrenberg	212	135	115	92	90	90	112	113	90	83	74	62	67	84	98
Fragilaria pseudoconstruens Marciniak								1							
Fragilaria tenera (W. Smith) Lange-Bertalot	5	1	1	1			1								
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna	7	4	10	1	2.5	1.5	1.5	1	0.5	1.5	1	2.5	2	2	7
Frustulia rhomboides (Ehrenberg) De Toni															
Gomphonema acuminatum Ehrenberg															
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															1
Gomphonema angustum Aghardh															
Gomphonema augur Ehrenberg var. augur															
Gomphonema clavatum Ehrenberg							1								
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh								3			1				
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum															
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing	1			1											
Gomphonema subtile Ehrenberg															
Gomphonema truncatum Ehrenberg				1		2	3	1							
Gyrosigma acuminatum (Kutzing) Rabenhorst															
Hantzschia amphioxys (Ehrenberg) Grunow										0.5			0.5		
Navicula aboensis (Cleve) Hustedt													2		
Navicula absoluta Hustedt	2		4	5	3		5		2		2	3		3	2
Navicula agrestis Hustedt															
Navicula arvensis Hustedt															
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg															
Navicula bryophila Petersen				1		1		1							
Navicula capitata Ehrenberg var. capitata															
Navicula capitata var. lueneburgensis (Grunow) Patrick															
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt											1			1	2
Navicula cocconeiformis Gregory ex Greville	2				2	1	1								
Navicula cryptocephala Kutzing			1	2	2		3		3	1	4	2	1	1	
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing															
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt	3	2				1				1	2				
Navicula explanata Hustedt															
Navicula farta Hustedt	2		1												
Navicula gerloffii Shimanski				1		2									
Navicula hambergii Hustedt	2			1			1								1
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister															
Navicula jaernfeltii Hustedt	5	2	1	1	2			1	3	1	1	3	5	4	1
Navicula jentzschii Grunow	1		1										1	1	

	Legend (1,250,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot	6	5	4	3	7	5	4		8	10	5	4	8	2	3
Navicula laevissima Kutzing var. laevissima			1												
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt															
Navicula mediocris Krasske															
Navicula minima Grunow	12	12	7	1	5	9	12	4	13	5	4	15	10	9	5
Navicula minusculoides Hustedt															
Navicula obsoleta Husedt															
Navicula oppugnata Hustedt				1	1	1									
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot	11	2	3	1	4	1	2			4	1	1	1	3	1
Navicula protracta (Grunow) Cleve			1					1							
Navicula pseudoscutiformis Hustedt	7	3	7	4	1	1	3	3	3	4	9	5	5	11	3
Navicula pupula Kutzing var. pupula	1	1		2				1		2				1	
Navicula pupula var. mutata (Krasske) Hustedt					2	2	2	3			1				
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot															
Navicula pusio Cleve															
Navicula radiosa Kutzing	1				1					1	1				
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt							1	4			4	1			
Navicula schoenfeldii Hustedt															
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt	23	8	8	9	5	12	16	7	8	5	16	5	7	1	4
Navicula seminulum Grunow	5	5	3	2	3	3	7	4	8	6	6	10	6	2	2
Navicula similis Krasske														3	
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot															
Navicula subminuscula Manguin															
Navicula submolesta Hustedt															
Navicula submuralis Hustedt									5				1	6	3
Navicula subrotundata Hustedt															
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske															
Navicula viridula (Kutzing) Ehreneberg															1
Navicula vitiosa Schimanski	9	2	1	6	8	2	9	2	7	3	8	8	6	8	4
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer															
Neidium hitchcockii (Ehrenberg) Cleve															
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith							1			0.5					
Nitzschia angustata (W. Smith) Grunow															
Nitzschia dissipata (Kutzing) Grunow var. dissipata							1	0.5	0.5						
Nitzschia fasciculata (Grunow) Grunow				1											
Nitzschia fonticola Grunow									3						
Nitzschia frustulum (Kutzing) Grunow var. frustulum					1	1.5							1	1	
Nitzschia inconspicua Grunow					3	3									
Nitzschia pseudofonticola Hustedt	1					1	1	1.5					2		
Nitzschia recta Hantzsch												0.5			
Nitzschia rostellata Hustedt	3	1	0.5	6	1.5	4	0.5	2.5		1	1	1	1		
Nitzschia valdestriata Alcorn & Hustedt															
Pinnularia abaujensis var. linearis (Hustedt) Patrick															
Pinnularia borealis Ehrenberg															
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve															
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt															
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst		1												1	
Pinnularia interrupta W. Smith									1						
Pinnularia major (Kutzing) Rabenhorst															
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve															
Pinnularia rupestris Hantzsch															
Pinnularia subcapitata Gregory															
Pinnularia viridis (Nitzsch) Ehrenberg	1														
Pinnularia wisconsinensis Camburn & Charles		1													
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller															
Stauroneis anceps var. siberica Grunow															
Stauroneis phoenicenteron (Nitzsch) Ehrenberg															
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt												1			
Stephanodiscus chantaicus Genkal and Kuzmina			1	1	1	1	2	2	1	1					
Stephanodiscus hantzschii Grunow							5								
Stephanodiscus medius Hakansson															
Stephanodiscus minutulus (Kutzing) Cleve & Moller	1		1			6		1		3					
Stephanodiscus niagarae Ehrenberg	18	5	7	8	18	9	8	8	11	9	13	13	6	11	30
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve															
Surirella didyma Kutzing															
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg															
Tabellaria flocculosa (Roth) Kutzing	37	12.5	21	8	12	13.5	8.5	13	17.5	11.5	14.5	7	11.5	14	16
Tabellaria flocculosa var. linearis Koppen	2		2.5	1.5	1	5	0.5		1.5	1	1		0.5	1	1
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.1013	0.1021	0.0999	0.1056	0.1071	0.1026	0.1089	0.1017	0.1027	0.1009	0.1085	0.2035	0.2059	0.2013	0.2005
Diatom concentration (x10^6 valves/g dry mass)	856.69	1523.9	924.75	1166	1397.6	821.5	848.52	615.26	1044.7	937.85	1441.6	833.75	1204.1	350.93	321.21

	Namur (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	60mm	70mm	80mm	90mm	100mm
Eucalyptus globulus pollen grains	9	25	28	23	30	16	48	46	67	63	63	119	179	362	316
Stomatocysts	3	8	8	4	8	8	2	11	15	7	7	26	22	29	29
Mallomonas crassisquama (Asmund) Fott															
Mallomonas heterospina Lund															
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman						8						1		2	
Achnanthes altaica (Poretzky) Cleve-Euler															
Achnanthes amoena Hustedt		1		6	2		1								
Achnanthes bahusiensis (Grunow) Lange-Bertalot										1					
Achnanthes bioretii Germain															
Achnanthes calcar Cleve		1	3				1							6	5
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei															
Achnanthes conspicua Mayer															
Achnanthes curtissima Carter	6	6	7	2	3	5	4		4	6	6		3	1	5
Achnanthes daoensis Lange-Bertalot					1										
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot		1			1		7	2	1	1		1	1		2
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt								1							
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua													2		1
Achnanthes fulla Carter			1					3	1	1	9	6	7	3	2
Achnanthes gracillima Hustedt							1								
Achnanthes grischuna Wutrich															2
Achnanthes helvetica (Hustedt) Lange-Bertalot	1	1				1		2				1			
Achnanthes impexa Lange-Bertalot															
Achnanthes impexiformis Lange-Bertalot															
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow		3	9	10	6	10	6	4	7	12	17	11	7	7	8
Achnanthes lanceolata var. dubia Grunow															
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot															
Achnanthes laterostrata Hustedt							1	2		3	3	1		1	1
Achnanthes levanderi var. helvetica Hustedt			1	3	1	2	2	1			2	1			1
Achnanthes marginulata Grunow									2	1	3		1		
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing		7	14	7	9	5	1			1			2	2	
Achnanthes minutissima var. robusta Hustedt															
Achnanthes nitidiformis Lange-Bertalot									1						
Achnanthes oblongella Oestrup															
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii	3	1	3	2	6		2	6	7	4	3	6	3	4	4
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot											1				
Achnanthes peragallii Brun & Heribaud					1	2	1			1			1		
Achnanthes petersenii Hustedt															
Achnanthes pusilla (Grunow) De Toni	1														
Achnanthes ricula Hohn & Hellerman			3	2	3	1	2						2		
Achnanthes rosenstockii Lange-Bertalot															
Achnanthes rossii Hustedt					1										
Achnanthes saccula Carter															
Achnanthes sp. aff. aueri Krasske								1							
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald								3				2			
Achnanthes suchlandtii Hustedt	1		2	1	2	2	1		3	1		3	1		
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing	1		1	1								2			
Amphora pediculus (Kutzing) Grunow	2	4	6	3	5	4	7	11	5	5	6	6	3	3	
Amphora thumensis															
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow															
Anomoeoneis serians var. acuta Hustedt															
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross															
Asterionella formosa Hassall				2	2	3	1	1			1	1			2
Aulacoseira ambigua (Grunow) Simonsen	17	30	26	35	31	16	26	11	9	19	12	2	5	5	9
Aulacoseira distans (Ehrenberg) Simonsen															
Aulacoseira distans var. humilis (Cleve-Euler) Ross		2													
Aulacoseira perglabra (Oestrup) Haworth															
Aulacoseira subarctica (O. Muller) Haworth	36	38	82	102	103	67	79	66	50	35	28	11	27	17	33
Aulacoseira valida (Grunow) Krammer	1		15												
Caloneis bacillaris (Gregory) Cleve															1
Caloneis bacillum (Grunow) Cleve	1	2			1	3	3		1			1			1
Caloneis silicula (Ehrenberg) Cleve															
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer				1	1										
Cocconeis neothumensis Krammer		1	1										2	2	
Cocconeis placentula Ehrenberg var. placentula	2		3		3		1	2	1						3
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck															
Cocconeis pseudothumensis Reichardt		4			1	3	2	2	6	1	5	1	9	11	7
Cyclotella bodanica var. aff. affinis Grunow															
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	3	6	9	9	8	9	15	27	28	25	33	49	94	118	99
Cyclotella delicatula Hustedt															
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing															
Cyclotella michiganiana Skvortzow															
Cyclotella ocellata Pantocsek															
Cyclotella pseudostelligera Hustedt															
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck															
Cyclotella woltereckii Hustedt															
Cymbella amphicephala Naegeli ex Kutzing										1					
Cymbella caespitosa (Kutzing) Brun															

	Namur (160 000 pollen grains/ml)			
	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	514	437	550	
Stomatocysts	10	2	13	
Mallomonas crassisquama (Asmund) Fott				
Mallomonas heterospina Lund				
Synura petersenii Korshikov				
Achnanthes acares Hohn & Hellerman			2	
Achnanthes altaica (Poretzky) Cleve-Euler				
Achnanthes amoena Hustedt				
Achnanthes bahusiensis (Grunow) Lange-Bertalot				
Achnanthes bioretii Germain				
Achnanthes calcar Cleve				
Achnanthes carissima Lange-Bertalot				
Achnanthes cf. lapponica Cleve				
Achnanthes clevei Grunow var. clevei				
Achnanthes conspicua Mayer				
Achnanthes curtissima Carter				
Achnanthes daoensis Lange-Bertalot				
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot		2		
Achnanthes depressa (Cleve) Hustedt				
Achnanthes detha Hohn & Hellerman				
Achnanthes didyma Hustedt				
Achnanthes distincta Messikommer				
Achnanthes exigua Grunow var. exigua				
Achnanthes fulla Carter		1	1	
Achnanthes gracillima Hustedt				
Achnanthes grischuna Wutrich				
Achnanthes helvetica (Hustedt) Lange-Bertalot				
Achnanthes impexa Lange-Bertalot				
Achnanthes impexiformis Lange-Bertalot				
Achnanthes joursacense Heribaud				
Achnanthes krasskei Kobayasi & Sawatari				
Achnanthes kryophila Petersen				
Achnanthes kuelbsii Lange-Bertalot				
Achnanthes lanceolata (Brebisson) Grunow	1	1	2	
Achnanthes lanceolata var. dubia Grunow				
Achnanthes lapidosa var. appalachlana (Camburn & Lowe) Lange-Bertalot				
Achnanthes laterostrata Hustedt				
Achnanthes levanderi var. helvetica Hustedt				
Achnanthes marginulata Grunow				
Achnanthes minuscula Hustedt				
Achnanthes minutissima Kutzing			1	
Achnanthes minutissima var. robusta Hustedt				
Achnanthes nitidiformis Lange-Bertalot				
Achnanthes oblongella Oestrup				
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii		2	3	
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot				
Achnanthes peragalli Brun & Heribaud				
Achnanthes petersenii Hustedt				
Achnanthes pusilla (Grunow) De Toni				
Achnanthes ricula Hohn & Hellerman				
Achnanthes rosenstockii Lange-Bertalot				
Achnanthes rossii Hustedt				
Achnanthes saccula Carter				
Achnanthes sp. aff. aueri Krasske				
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald				
Achnanthes suchlandtii Hustedt				
Amphipleura kriegerana (Krasske) Hustedt				
Amphipleura pellucida (Kutzing) Kutzing				
Amphora inariensis Krammer				
Amphora libyca Ehrenberg				
Amphora montana Krasske				
Amphora ovalis (Kutzing) Kutzing			1	
Amphora pediculus (Kutzing) Grunow	2			
Amphora thumensis				
Amphora veneta Kutzing				
Anomoeoneis brachysira (Brebisson) Grunow				
Anomoeoneis serians var. acuta Hustedt				
Anomoeoneis styriaca (Grunow) Hustedt				
Anomoeoneis vitrea (Grunow) Ross				
Asterionella formosa Hassall				
Aulacoseira ambigua (Grunow) Simonsen	3	3		
Aulacoseira distans (Ehrenberg) Simonsen				
Aulacoseira distans var. humilis (Cleve-Euler) Ross				
Aulacoseira perglabra (Oestrup) Haworth				
Aulacoseira subarctica (O. Muller) Haworth	20	15	17	
Aulacoseira valida (Grunow) Krammer				
Caloneis bacillaris (Gregory) Cleve				
Caloneis bacillum (Grunow) Cleve		2		
Caloneis silicula (Ehrenberg) Cleve				
Caloneis undulata (Gregory) Krammer				
Cocconeis disculus (Schumann) Cleve				
Cocconeis neodiminuta Krammer				
Cocconeis neothumensis Krammer		2		
Cocconeis placentula Ehrenberg var. placentula				
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck				
Cocconeis pseudothumensis Reichardt		2	2	
Cyclotella bodanica var. aff. affinis Grunow				
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	14	17	23	
Cyclotella delicatula Hustedt				
Cyclotella krammeri Hakansson				
Cyclotella meneghiniana Kutzing				
Cyclotella michiganiana Skvortzow				
Cyclotella ocellata Pantocsek				
Cyclotella pseudostelligera Hustedt				
Cyclotella radiosa (Grunow) Lemmermann				
Cyclotella rossii (Grunow) Hakansson				
Cyclotella stelligera (Cleve & Grunow) Van Heurck				
Cyclotella woltereckii Hustedt				
Cymbella amphicephala Naegeli ex Kutzing				
Cymbella caespitosa (Kutzing) Brun				

	Namur (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	60mm	70mm	80mm	90mm	100mm
Cymbella cesatii (Rabenhorst) Grunow															
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot															
Cymbella gaeumannii Meister															
Cymbella gracilis (Ehrenberg) Kutzing												1	1		
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst															
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer															
Cymbella naviculiformis (Auerswald) Cleve														1	
Cymbella perpusilla A. Cleve															
Cymbella proxima Reimer															
Cymbella reichardtii Krammer				1								3			
Cymbella reinhardtii Grunow															
Cymbella silesiaca Bleisch									1						
Cymbella sinuata Gregory	4	1		1	2		3	1	1		1	2	3	2	4
Cymbella subaequalis Grunow															
Denticula kuetzingii Grunow															
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve	3														
Diploneis marginestriata Hustedt		10	5		2	2	2	6	3	4	2	2	2	2	2
Entomoneis ornata (Bailey) Reimer	1														
Epithemia argus (Ehrenberg) Kutzing															
Epithemia goeppertiana Hilse															
Epithemia smithii Carruthers															
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg															
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot															
Eunotia curvata (Kutzing) Lagerstedt															
Eunotia incisa Gregory var. incisa															
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot															
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg															
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel															
Fragilaria arcus (Ehrenberg) Cleve var. arcus		2	2	1		2	1		2	3	1	1	1		1
Fragilaria brevistriata Grunow		3	2	1	2	1	2			2	2	2	2	3	
Fragilaria capucina var. gracilis (Oestrup) Hustedt			9	9	3	5	2	5	9	5	5		5		1
Fragilaria constricta forma stricta Cleve									1						
Fragilaria construens (Ehrenberg) Grunow f. construens	12	30	27	24	55	27	45	39	34	63	30	20	18	5	21
Fragilaria construens var. binodis (Ehrenberg) Grunow			2		3	1			4		2		1	1	1
Fragilaria construens var. venter (Ehrenberg) Grunow	36	67	96	97	153	104	113	129	31	103	115	90	60	51	47
Fragilaria crotonensis Kitton															
Fragilaria exigua Grunow															
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica								1	2						
Fragilaria pinnata Ehrenberg	15	25	40	38	44	40	41	43	78	67	88	64	78	64	57
Fragilaria pseudoconstruens Marciniak															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna	2	7	2	5	9	13	11	11	5	7	6		2		
Frustulia rhomboides (Ehrenberg) De Toni															
Gomphonema acuminatum Ehrenberg															
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh															
Gomphonema augur Ehrenberg var. augur															
Gomphonema clavatum Ehrenberg															
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh		3													
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum					5										
Gomphonema olivaceum var. fonticola Hustedt									2						
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing															
Gomphonema subtile Ehrenberg															
Gomphonema truncatum Ehrenberg															
Gyrosigma acuminatum (Kutzing) Rabenhorst				1				1	1	1	1	5	16	22	28
Hantzschia amphioxys (Ehrenberg) Grunow															
Navicula aboensis (Cleve) Hustedt			1	3	4	5	2	3	4	6	15	8	17	16	38
Navicula absoluta Hustedt		1	1						3		1	1	1		
Navicula agrestis Hustedt									1			1			
Navicula arvensis Hustedt															
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg					1						1				
Navicula bryophila Petersen							1								
Navicula capitata Ehrenberg var. capitata															
Navicula capitata var. lueneburgensis (Grunow) Patrick	2	1						1	1						1
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt		1													
Navicula cocconeiformis Gregory ex Greville			2			1	1	5	1	2	1	2	4	4	7
Navicula cryptocephala Kutzing	1			1		3	2		2						1
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing															
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt		1									2				1
Navicula explanata Hustedt		1		1	1	1	2		2		1				
Navicula farta Hustedt	2		1			1									
Navicula gerloffii Shimanski		1	1		3	2		2	2	1	2	1	1		
Navicula hambergii Hustedt															
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister															
Navicula jaernfeltii Hustedt	2	1	2	4	1	4	4	2	9	2	8	15	14	10	9
Navicula jentzschii Grunow		1						3	4	2	10	10	11	19	5

	Namur (160,000 pollen grains/ml)			
	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow				
Cymbella cuspidata Kutzing				
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot				
Cymbella gaeumannii Meister				
Cymbella gracilis (Ehrenberg) Kutzing				
Cymbella hebridica (Grunow ex Cleve) Cleve				
Cymbella heteropleura (Ehrenberg) Kutzing				
Cymbella microcephala Grunow				
Cymbella minuta Hilse ex Rabenhorst				
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer				
Cymbella naviculiformis (Auerswald) Cleve				
Cymbella perpusilla A. Cleve				
Cymbella proxima Reimer				
Cymbella reichardtii Krammer				
Cymbella reinhardtii Grunow				
Cymbella silesiaca Bleisch	2		1	
Cymbella sinuata Gregory				
Cymbella subaequalis Grunow		2		
Denticula kuetzingii Grunow				
Denticula kuetzingii var. rumrichae Krammer				
Diatoma anceps (Ehrenberg) Kirchner				
Diploneis elliptica (Kutzing) Cleve				
Diploneis marginestriata Hustedt	1			
Entomoneis ornata (Bailey) Reimer				
Epithemia argus (Ehrenberg) Kutzing				
Epithemia goeppertiana Hilse				
Epithemia smithii Carruthers				
Epithemia sorex Kutzing				
Epithemia turgida var. granulata (Ehrenberg) Brun				
Eunotia arcus Ehrenberg				
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.				
Eunotia circumborealis Norpel & Lange-Bertalot				
Eunotia curvata (Kutzing) Lagerstedt				
Eunotia incisa Gregory var. incisa				
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot				
Eunotia minor (Kutzing) Grunow				
Eunotia praerupta Ehrenberg				
Eunotia rhomboidea Hustedt				
Eunotia rhyncocephala Hustedt var. rhyncocephala				
Eunotia serra var. tetraodon (Ehrenberg) Norpel				
Fragilaria arcus (Ehrenberg) Cleve var. arcus	1			
Fragilaria brevistriata Grunow			2	
Fragilaria capucina var. gracilis (Oestrup) Hustedt				
Fragilaria constricta forma stricta Cleve				
Fragilaria construens (Ehrenberg) Grunow f. construens		11	1	
Fragilaria construens var. binodis (Ehrenberg) Grunow				
Fragilaria construens var. venter (Ehrenberg) Grunow	12	14	24	
Fragilaria crotonensis Kitton				
Fragilaria exigua Grunow			2	
Fragilaria nanana Lange-Bertalot				
Fragilaria nitzschioides Grunow				
Fragilaria parasitica (W. Smith) Grunow				
Fragilaria parasitica (W. Smith) Grunow var. parasitica		1		
Fragilaria pinnata Ehrenberg	14	11	3	
Fragilaria pseudoconstruens Marciniak				
Fragilaria tenera (W. Smith) Lange-Bertalot				
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna	1	1		
Frustulia rhomboides (Ehrenberg) De Toni				
Gomphonema acuminatum Ehrenberg				
Gomphonema angustatum (Kutzing) Rabenhorst				
Gomphonema angustatum var. sarcophagus (Gregory) Grunow				
Gomphonema angustum Aghardh				
Gomphonema augur Ehrenberg var. augur				
Gomphonema clavatum Ehrenberg				
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot				
Gomphonema minutum (C. Agardh) C. Agardh	1			
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum				
Gomphonema olivaceum var. fonticola Hustedt				
Gomphonema olivaceum var. minutissimum Hustedt				
Gomphonema parvulum Kutzing				
Gomphonema subtile Ehrenberg				
Gomphonema truncatum Ehrenberg				
Gyrosigma acuminatum (Kutzing) Rabenhorst	4	4		
Hantzschia amphioxys (Ehrenberg) Grunow				
Navicula aboensis (Cleve) Hustedt	1	2		
Navicula absoluta Hustedt				
Navicula agrestis Hustedt				
Navicula arvensis Hustedt				
Navicula atomus (Kutzing) Grunow				
Navicula bacillum Ehrenberg				
Navicula bryophila Petersen				
Navicula capitata Ehrenberg var. capitata				
Navicula capitata var. lueneburgensis (Grunow) Patrick				
Navicula capitatoradiata Germain				
Navicula clementis Grunow				
Navicula cocconeiformis f. elliptica Hustedt				
Navicula cocconeiformis Gregory ex Greville		2	2	
Navicula cryptocephala Kutzing				
Navicula cryptotenella Lange-Bertalot				
Navicula cuspidata Kutzing				
Navicula digitulus Hustedt				
Navicula disjuncta Hustedt				
Navicula explanata Hustedt	1			
Navicula farta Hustedt				
Navicula gerloffii Shimanski			1	
Navicula hambergii Hustedt				
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot				
Navicula jaagii Meister				
Navicula jaernfeltii Hustedt	3	1		
Navicula jentzschii Grunow				

	Namur (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	60mm	70mm	80mm	90mm	100mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot		2		2	1	1	1		1		4				
Navicula laevissima Kutzing var. laevissima															
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt															
Navicula mediocris Krasske															
Navicula minima Grunow	2	1	6	6	1	2	2	5	3	5	3		1	1	4
Navicula minusculoides Hustedt					3		1								
Navicula obsoleta Husedt												3			
Navicula oppugnata Hustedt			2				1								
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot		2	6	3	6	3	9	5	7	3	3	10	3	2	4
Navicula protracta (Grunow) Cleve															
Navicula pseudoscutiformis Hustedt	2		4	1		2	1		2		4	1	1		1
Navicula pupula Kutzing var. pupula			1	1	1				1						
Navicula pupula var. mutata (Krasske) Hustedt															
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot							1		1	1				1	
Navicula pusio Cleve															
Navicula radiosa Kutzing	1		1	2				2	1	1	1				
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt															
Navicula schoenfeldii Hustedt													2		
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt	2				1	1	3		6	9	3	10	2	11	
Navicula seminulum Grunow			4	4	6	4	12	2	3						1
Navicula similis Krasske															
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot															
Navicula subminuscula Manguin															
Navicula submolesta Hustedt															
Navicula submuralis Hustedt		1		3	2	2	3	3	5	1	1	1	4	1	
Navicula subrotundata Hustedt					3										1
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske			1												
Navicula viridula (Kutzing) Ehreneberg															
Navicula vitiosa Schimanski											1				
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer									1						
Neidium hitchcockii (Ehrenberg) Cleve															
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow															
Nitzschia dissipata (Kutzing) Grunow var. dissipata			1			1					1		1		
Nitzschia fasciculata (Grunow) Grunow															
Nitzschia fonticola Grunow			3	6	4				2	3					
Nitzschia frustulum (Kutzing) Grunow var. frustulum										1					
Nitzschia inconspicua Grunow	1	1		1	1		1			2		2	2		
Nitzschia pseudofonticola Hustedt		1													
Nitzschia recta Hantzsch															
Nitzschia rostellata Hustedt	1														
Nitzschia valdestriata Alcom & Hustedt															
Pinnularia abaujensis var. linearis (Hustedt) Patrick															
Pinnularia borealis Ehrenberg															1
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve															
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt															
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst															
Pinnularia interrupta W. Smith		1													
Pinnularia major (Kutzing) Rabenhorst									1						
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve					1										
Pinnularia rupestris Hantzsch															
Pinnularia subcapitata Gregory								1	5	1	1	1			
Pinnularia viridis (Nitzsch) Ehrenberg															
Pinnularia wisconsinensis Camburn & Charles															
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller															
Stauroneis anceps var. siberica Grunow	1	1													
Stauroneis phoenicenteron (Nitzsch) Ehrenberg															
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt															
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow															
Stephanodiscus medius Hakansson		2		1						2					
Stephanodiscus minutulus (Kutzing) Cleve & Moller	283	207	109	65	50	55	58	80	73	67	74	60	45	37	65
Stephanodiscus niagarae Ehrenberg	2		3	5	2	1	1	3	5	2		4	1		
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve					3										
Surirella didyma Kutzing															
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg	1							1							
Tabellaria flocculosa (Roth) Kutzing			1	3				1			1			1	1
Tabellaria flocculosa var. linearis Koppen	2	5	6	4	6	2	4	1	6	4	4	1	2	1	2
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.1113	0.1071	0.1112	0.1217	0.1161	0.1161	0.1178	0.1031	0.1088	0.1207	0.1203	0.117	0.1232	0.1057	0.117
Diatom concentration (x10^6 valves/g dry mass)	723.57	291.62	270.81	274.37	261.84	367.79	140.02	169.02	99.21	102.68	110.62	49.07	34.173	18.273	21.205

	Namur (160,000 pollen grains/ml)			
	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt				
Navicula kuelbsii Lange-Bertalot				
Navicula laevissima Kutzing var. laevissima				
Navicula leptostriata Joergensen				
Navicula levanderii Hustedt				
Navicula mediocris Krasske				
Navicula minima Grunow		1		
Navicula minusculoides Hustedt				
Navicula obsoleta Husedt				
Navicula oppugnata Hustedt				
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot				
Navicula protracta (Grunow) Cleve				
Navicula pseudoscutiformis Hustedt				
Navicula pupula Kutzing var. pupula				
Navicula pupula var. mutata (Krasske) Hustedt				
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot				
Navicula pusio Cleve				
Navicula radiosa Kutzing				
Navicula reinhardtii Grunow				
Navicula schmassmannii Hustedt				
Navicula schoenfeldii Hustedt				
Navicula scutelloides W. Smith				
Navicula seminuloides Hustedt		2		
Navicula seminulum Grunow				
Navicula similis Krasske				
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot				
Navicula subminuscula Manguin				
Navicula submolesta Hustedt				
Navicula submuralis Hustedt				
Navicula subrotundata Hustedt				
Navicula subtilissima Cleve				
Navicula tuscula Ehrenberg				
Navicula ventralis Krasske				
Navicula viridula (Kutzing) Ehreneberg				
Navicula vitiosa Schimanski				
Navicula vulpina Kutzing				
Neidium ampliatum (Ehrenberg) Krammer				
Neidium hitchcockii (Ehrenberg) Cleve				
Neidium holstii Krammer				
Nitzschia acicularis (Kutzing) W. Smith				
Nitzschia angustata (W. Smith) Grunow				
Nitzschia dissipata (Kutzing) Grunow var. dissipata				
Nitzschia fasciculata (Grunow) Grunow				
Nitzschia fonticola Grunow				
Nitzschia frustulum (Kutzing) Grunow var. frustulum				
Nitzschia inconspicua Grunow				
Nitzschia pseudofonticola Hustedt				
Nitzschia recta Hantzsch				
Nitzschia rostellata Hustedt				
Nitzschia valdestriata Alcorn & Hustedt				
Pinnularia abaujensis var. linearis (Hustedt) Patrick				
Pinnularia borealis Ehrenberg				
Pinnularia borealis var. rectangularis Carlson				
Pinnularia brandelii Cleve				
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt				
Pinnularia gibba var. linaris Hustedt				
Pinnularia hemiptera (Kutzing) Rabenhorst				
Pinnularia interrupta W. Smith	1	1		
Pinnularia major (Kutzing) Rabenhorst				
Pinnularia mesolepta (Ehrenberg) W. Smith				
Pinnularia microstauron (Ehrenberg) Cleve				
Pinnularia rupestris Hantzsch				
Pinnularia subcapitata Gregory			1	
Pinnularia viridis (Nitzsch) Ehrenberg				
Pinnularia wisconsinensis Camburn & Charles				
Rhoicosphenia curvata (Kutzing) Grunow				
Rhopalodia gibba (Ehrenberg) O. Muller				
Stauroneis anceps var. siberica Grunow		1		
Stauroneis phoenicenteron (Nitzsch) Ehrenberg				
Stenopterobia delicatissima (Lewis) Van Heurck				
Stephanodiscus cf. alpinus Hustedt				
Stephanodiscus chantaicus Genkal and Kuzmina				
Stephanodiscus hantzschii Grunow				
Stephanodiscus medius Hakansson				
Stephanodiscus minutulus (Kutzing) Cleve & Moller	19	26	10	
Stephanodiscus niagarae Ehrenberg				
Stephanodiscus parvus				
Surirella angusta Kutzing				
Surirella cf. lapponica Cleve				
Surirella didyma Kutzing				
Surirella gemma Ehrenberg				
Surirella robusta Ehrenberg				
Tabellaria flocculosa (Roth) Kutzing	1	2		
Tabellaria flocculosa var. linearis Koppen		1	1	
Tetracyclus glans (Ehrenberg) Mills				
Sample weight (g)	0.1072	0.1051	0.1192	
Diatom concentration (x10^6 valves/g dry mass)	2.9618	4.5288	2.4405	

	A-88 (150,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	35	47	25	21	36	19	55	23	8	13	54	33	28	37	48
Stomatocysts	72	66	50	39	23	20	35	24	20	22	37	44	41	50	35
Mallomonas crassisquama (Asmund) Fott		1							1	1					
Mallomonas heterospina Lund															
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman	27	29	31	10	19	2	16	5	9	21	6	26	4	4	11
Achnanthes altaica (Poretzky) Cleve-Euler				2	1										
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot															
Achnanthes bioretii Germain															
Achnanthes calcar Cleve															
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei															
Achnanthes conspicua Mayer															
Achnanthes curtissima Carter		8	5	3	3	12	16	10	12	4	22	13	17	11	9
Achnanthes daoensis Lange-Bertalot															
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot		1	3												
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt	2	1	1								1	7	1	3	2
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua															
Achnanthes fulla Carter															
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wutrich												1			
Achnanthes helvetica (Hustedt) Lange-Bertalot															
Achnanthes impexa Lange-Bertalot		2	1	1		1	2	2			1	2	1	4	1
Achnanthes impexiformis Lange-Bertalot															
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow															
Achnanthes lanceolata var. dubia Grunow															
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot															
Achnanthes laterostrata Hustedt															
Achnanthes levanderi var. helvetica Hustedt															
Achnanthes marginulata Grunow	1			1	1			1					1		
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing	43	43	43	34	30	22	17	19	12	17	29	22	1	7	4
Achnanthes minutissima var. robusta Hustedt															
Achnanthes nitidiformis Lange-Bertalot															
Achnanthes oblongella Oestrup															
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii															
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragalli Brun & Heribaud															
Achnanthes petersenii Hustedt										1	1				
Achnanthes pusilla (Grunow) De Toni											2	3		3	
Achnanthes ricula Hohn & Hellerman	15	11	15	1								1	1		
Achnanthes rosenstockii Lange-Bertalot															
Achnanthes rossii Hustedt	1		2					2				2	2		4
Achnanthes saccula Carter															
Achnanthes sp. aff. aueri Krasske															
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	4	3	2	6	3	5	1	2		2	7	2		5	1
Achnanthes suchlandtii Hustedt															
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing			1								1			1	
Amphora pediculus (Kutzing) Grunow															
Amphora thumensis															
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow	2	3	9	3	2	2	1	2		2	2				
Anomoeoneis serians var. acuta Hustedt			1												
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross															
Asterionella formosa Hassall															
Aulacoseira ambigua (Grunow) Simonsen															
Aulacoseira distans (Ehrenberg) Simonsen															
Aulacoseira distans var. humilis (Cleve-Euler) Ross															
Aulacoseira perglabra (Oestrup) Haworth															
Aulacoseira subarctica (O. Muller) Haworth		2	1												
Aulacoseira valida (Grunow) Krammer															
Caloneis bacillaris (Gregory) Cleve													1		
Caloneis bacillum (Grunow) Cleve	4	2		2		1			2			1	2		
Caloneis silicula (Ehrenberg) Cleve															
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer															
Cocconeis placentula Ehrenberg var. placentula															
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck															
Cocconeis pseudothumensis Reichardt															
Cyclotella bodanica var. aff. affinis Grunow															
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann															
Cyclotella delicatula Hustedt															
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing															
Cyclotella michiganiana Skvortzow															
Cyclotella ocellata Pantocsek															
Cyclotella pseudostelligera Hustedt															
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck															
Cyclotella woltereckii Hustedt															
Cymbella amphicephala Naegeli ex Kutzing															
Cymbella caespitosa (Kutzing) Brun															

	A-68 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow			1												
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot			1	1											
Cymbella gaeumannii Meister				1	1	3					10	2	2		5
Cymbella gracilis (Ehrenberg) Kutzing	3	8	9	3	2	4	5	2		2	6	10	1	6	7
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst															
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer															
Cymbella naviculiformis (Auerswald) Cleve	1	1			1		1	2		1	4	4			3
Cymbella perpusilla A. Cleve												1			
Cymbella proxima Reimer															
Cymbella reichardtii Krammer															
Cymbella reinhardtii Grunow															
Cymbella silesiaca Bleisch			1								1				
Cymbella sinuata Gregory														1	
Cymbella subaequalis Grunow	1														
Denticula kuetzingii Grunow															
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve															
Diploneis marginestriata Hustedt			2	1								2		2	1
Entomoneis ornata (Bailey) Reimer															
Epithemia argus (Ehrenberg) Kutzing															
Epithemia goeppertiana Hilse															
Epithemia smithii Carruthers															
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg															
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot						2		3			1				
Eunotia curvata (Kutzing) Lagerstedt			1	1				1					1		
Eunotia incisa Gregory var. incisa															
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot	2														
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg															
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel															
Fragilaria arcus (Ehrenberg) Cleve var. arcus															
Fragilaria brevistriata Grunow															
Fragilaria capucina var. gracilis (Oestrup) Hustedt											2				
Fragilaria constricta forma stricta Cleve															
Fragilaria construens (Ehrenberg) Grunow f. construens			2												
Fragilaria construens var. binodis (Ehrenberg) Grunow	1														
Fragilaria construens var. venter (Ehrenberg) Grunow	163	143	149	168	156	196	213	209	236	218	179	205	251	221	229
Fragilaria crotonensis Kitton															
Fragilaria exigua Grunow															
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica															
Fragilaria pinnata Ehrenberg			1		2	1	1		1		7	20	30	11	23
Fragilaria pseudoconstruens Marciniak															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna															
Frustulia rhomboides (Ehrenberg) De Toni	2			1		1			1	1					
Gomphonema acuminatum Ehrenberg															
Gomphonema angustatum (Kutzing) Rabenhorst												2			
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh															
Gomphonema augur Ehrenberg var. augur															
Gomphonema clavatum Ehrenberg															
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh			1												
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum															
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt						1		1							
Gomphonema parvulum Kutzing								1							
Gomphonema subtile Ehrenberg															
Gomphonema truncatum Ehrenberg															
Gyrosigma acuminatum (Kutzing) Rabenhorst															
Hantzschia amphioxys (Ehrenberg) Grunow												1			
Navicula aboensis (Cleve) Hustedt															
Navicula absoluta Hustedt			2		6	6			1						1
Navicula agrestis Hustedt	21	39	28	23	24	24	24	22	26	20	20	6	3	9	3
Navicula arvensis Hustedt			1	5											
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg															
Navicula bryophila Petersen	1	4	10	8	8		3	5	4	2	3			2	
Navicula capitata Ehrenberg var. capitata															
Navicula capitata var. lueneburgensis (Grunow) Patrick															
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt															
Navicula cocconeiformis Gregory ex Greville		1													
Navicula cryptocephala Kutzing	10	17	10	9	14	11	10	12	6	13	30	11	13	19	13
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing															
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt												3		7	
Navicula explanata Hustedt														1	
Navicula farta Hustedt															
Navicula gerloffii Shimanski			1	2	1	1	2					4			
Navicula hambergii Hustedt															
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister															
Navicula jaernfeltii Hustedt															
Navicula jentzschii Grunow															

	A-66 (180,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot	22	39	23	23	13	28	13	17	22	13	32	33	11	32	22
Navicula laevissima Kutzing var. laevissima					5	4	4	3	2	5	12	13	2	9	7
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt															
Navicula mediocris Krasske					4			2	3	4	2			2	1
Navicula minima Grunow	11		6	6	4	5	1	7	5	8	26	30	18	20	2
Navicula minusculoides Hustedt	1			1						1					
Navicula obsoleta Husedt															
Navicula oppugnata Hustedt															
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot															
Navicula protracta (Grunow) Cleve												1			
Navicula pseudoscutiformis Hustedt		5	3	2	3	1	2	4		3	1		1	4	1
Navicula pupula Kutzing var. pupula	14	13	15	12	13	2	3	4	6	2	5	11	6	5	6
Navicula pupula var. mutata (Krasske) Hustedt					2		1								
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot															
Navicula pusio Cleve															
Navicula radiosa Kutzing	6	1													
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt	8	3	3		6	5	5	2	6	9	7		1	1	2
Navicula schoenfeldii Hustedt															
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt		4	17	10	8	22	9	24	11	17	20	19	13	9	12
Navicula seminulum Grunow	20	44	34	25	30	26	27	45	24	30	46	23	16	35	13
Navicula similis Krasske															
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot															
Navicula subminuscula Manguin															
Navicula submolesta Hustedt				1	1	1		2							
Navicula submuralis Hustedt			1												
Navicula subrotundata Hustedt							1								
Navicula subtilissima Cleve				11	21	15	16	16	21	19	13		2	9	
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske															
Navicula viridula (Kutzing) Ehreneberg															
Navicula vitiosa Schimanski	1		1		1								3	6	
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer	6	4	5	4	2	1	5	4	3	1	1	4	1	4	5
Neidium hitchcockii (Ehrenberg) Cleve											1				
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow															
Nitzschia dissipata (Kutzing) Grunow var. dissipata	8	4	2	2	1										
Nitzschia fasciculata (Grunow) Grunow	1														
Nitzschia fonticola Grunow	3			2	1	3			3	7	4	4	2	2	2
Nitzschia frustulum (Kutzing) Grunow var. frustulum															
Nitzschia inconspicua Grunow															
Nitzschia pseudofonticola Hustedt	2	4		1				1							2
Nitzschia recta Hantzsch		1													
Nitzschia rostellata Hustedt	3	4	5	2	6	3	1			1	1	2			
Nitzschia valdestriata Alcorn & Hustedt															
Pinnularia abaujensis var. linearis (Hustedt) Patrick		1	1												
Pinnularia borealis Ehrenberg															
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve															
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt					2	1						2			
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst															
Pinnularia interrupta W. Smith	10	16	12	15	15	14	10	7	3	6	27	15	5	13	16
Pinnularia major (Kutzing) Rabenhorst	1	1									1				
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve	4	2	1				1		3	2		2		4	3
Pinnularia rupestris Hantzsch															
Pinnularia subcapitata Gregory															
Pinnularia viridis (Nitzsch) Ehrenberg															
Pinnularia wisconsinensis Camburn & Charles															
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller															
Stauroneis anceps var. siberica Grunow	21	24	22	18	21	11	7	12	5	8	11	12	10	16	28
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	3	4	10	4			1	1	1	6	8	6	2	3	4
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt															
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow															
Stephanodiscus medius Hakansson															
Stephanodiscus minutulus (Kutzing) Cleve & Moller															
Stephanodiscus niagarae Ehrenberg															
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve															
Surirella didyma Kutzing															
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg															
Tabellaria flocculosa (Roth) Kutzing	1			1	1		1	3		1	1		1		
Tabellaria flocculosa var. linearis Koppen															1
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.1042	0.1014	0.1133	0.1127	0.1093	0.1141	0.1113	0.109	0.1902	0.1253	0.1163	0.1087	0.1034	0.1245	0.1018
Diatom concentration (x10^6 valves/g dry mass)	197.42	165.18	280.18	288	176.48	322.52	109.78	290.39	854.29	439.07	141.14	235.51	235.42	170.54	145.38

	L-107 (160 000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Eucalyptus globulus pollen grains	8	9	12	17	12	19	7	9	9	19	11	11	13	11	6
Stomatocysts	41	28	31	54	32	32	25	35	25	39	17	14	18	17	8
Mallomonas crassisquama (Asmund) Fott		6	8	9	7	6	4	2	2						
Mallomonas heterospina Lund															
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman	3	3	8	6	6	9	14	4	3	5	3	4	3	9	6
Achnanthes altaica (Poretzky) Cleve-Euler	2		2	4	2					1	2				
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot			1								1				2
Achnanthes bioretii Germain	1					2	1	1	1			1	1		1
Achnanthes calcar Cleve															
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei															
Achnanthes conspicua Mayer															
Achnanthes curtissima Carter	2	1	2	1			1	2	1	2	3	5	3		3
Achnanthes daoensis Lange-Bertalot															
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot								1							
Achnanthes depressa (Cleve) Hustedt							1								
Achnanthes detha Hohn & Hellerman	3			1	4	1	3	1		4		3	7		3
Achnanthes didyma Hustedt		1		1				3			1		1		2
Achnanthes distincta Messikommer															
Achnanthes exigua Grunow var. exigua	1														
Achnanthes fulla Carter							1								
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wulrich															
Achnanthes helvetica (Hustedt) Lange-Bertalot						1						1	2		
Achnanthes impexa Lange-Bertalot															
Achnanthes impexiformis Lange-Bertalot															
Achnanthes joursacense Heribaud															
Achnanthes krasskei Kobayasi & Sawatari															
Achnanthes kryophila Petersen															
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow															
Achnanthes lanceolata var. dubia Grunow															
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot															
Achnanthes laterostrata Hustedt								1							
Achnanthes levanderi var. helvetica Hustedt	3	4	7	4	10	10	10	9	3	8	6	2	4	6	12
Achnanthes marginulata Grunow		1	1	1	1	9	4	2	9	7	7	8	5	5	5
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing	58	46	45	52	40	50	57	50	54	44	53	47	47	34	42
Achnanthes minutissima var. robusta Hustedt															
Achnanthes nitidiformis Lange-Bertalot															
Achnanthes oblongella Oestrup															
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii				1											
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragalli Brun & Heribaud															
Achnanthes petersenii Hustedt															1
Achnanthes pusilla (Grunow) De Toni	8	9	14	7	3	9	7	16	9	12	6	10	11	8	5
Achnanthes ricula Hohn & Hellerman	7	3	5	4	3	3	4	3	1	5	4	5	1	1	1
Achnanthes rosenstockii Lange-Bertalot		6	7	6	2	3	1							2	1
Achnanthes rossii Hustedt	1		1	2			2				1				
Achnanthes saccula Carter															
Achnanthes sp. aff. aueri Krasske															
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald		3												4	2
Achnanthes suchlandtii Hustedt	1		4		4	2	2	4		1	1	1	3	1	1
Amphipleura kriegerana (Krasske) Hustedt	1		1			2			1						
Amphipleura pellucida (Kutzing) Kutzing							1			1					
Amphora inariensis Krammer															
Amphora libyca Ehrenberg															
Amphora montana Krasske								1							
Amphora ovalis (Kutzing) Kutzing	1		1	4			1		1	1	1	1			
Amphora pediculus (Kutzing) Grunow							1						1		1
Amphora thumensis															
Amphora veneta Kutzing												1			
Anomoeoneis brachysira (Brebisson) Grunow	5	9	5	3	1		4	2		1	1		2		
Anomoeoneis serians var. acuta Hustedt	1		1	6	4	11	6	12	6	9	7	6	10	7	10
Anomoeoneis styriaca (Grunow) Hustedt		2		1	4		2								
Anomoeoneis vitrea (Grunow) Ross	1														1
Asterionella formosa Hassall															
Aulacoseira ambigua (Grunow) Simonsen															
Aulacoseira distans (Ehrenberg) Simonsen	1	1	2	3	2	3	3		1	3	1	1			1
Aulacoseira distans var. humilis (Cleve-Euler) Ross															
Aulacoseira perglabra (Oestrup) Haworth															
Aulacoseira subarctica (O. Muller) Haworth															
Aulacoseira valida (Grunow) Krammer															
Caloneis bacillaris (Gregory) Cleve				3	1			1		2					
Caloneis bacillum (Grunow) Cleve		1	1		1			2			1				
Caloneis silicula (Ehrenberg) Cleve	1														
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve															
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer													1	1	1
Cocconeis placentula Ehrenberg var. placentula			2												
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck				1											
Cocconeis pseudothumensis Reichardt			1			1			1	1		1			
Cyclotella bodanica var. aff. affinis Grunow															
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	5	8	6	12	6	7	5	10	3	12	5	6	5	4	1
Cyclotella delicatula Hustedt															
Cyclotella krammeri Hakansson															
Cyclotella meneghiniana Kutzing															
Cyclotella michiganiana Skvortzow	6	14	9	22	7	10	11	9	5	7	3	5		1	4
Cyclotella ocellata Pantocsek	30	35	25	30	34	34	24	21	12	28	24	20	15	13	14
Cyclotella pseudostelligera Hustedt	24	35	26	28	43	43	46	37	32	15	16	17	19	15	27
Cyclotella radiosa (Grunow) Lemmermann															
Cyclotella rossii (Grunow) Hakansson	5	2		4	1	3		6	1	2	5	1	5	4	
Cyclotella stelligera (Cleve & Grunow) Van Heurck		4	2		1										
Cyclotella woltereckii Hustedt			9	6	10	11	11	6	5	2	3		1		
Cymbella amphicephala Naegeli ex Kutzing															
Cymbella caespitosa (Kutzing) Brun															

	L107 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Cymbella cesatii (Rabenhorst) Grunow				1								2	2		6
Cymbella cuspidata Kutzing															
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot	8	15	19	25	9	12	17	25	18	15	19	12	13	9	7
Cymbella gaeumannii Meister								1	2	1	8	11	4	3	2
Cymbella gracilis (Ehrenberg) Kutzing	2	3	6	2	5	4	4	4	5	5	6	2	9	3	2
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow	7	20	24	12	25	15	21	27	18	24	23	23	21	23	20
Cymbella minuta Hilse ex Rabenhorst															
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer										2			7		
Cymbella naviculiformis (Auerswald) Cleve	2	6	2	7	2	4	2	1			2	2	2	1	1
Cymbella perpusilla A. Cleve															
Cymbella proxima Reimer		1													
Cymbella reichardtii Krammer															
Cymbella reinhardtii Grunow								1							
Cymbella silesiaca Bleisch	4	3	3	3	2	8	6	3	2	2	3	4	4	2	
Cymbella sinuata Gregory															
Cymbella subaequalis Grunow															
Denticula kuetzingii Grunow											1				
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner															
Diploneis elliptica (Kutzing) Cleve			1									1		1	1
Diploneis marginestriata Hustedt	1					1	1	2	2	3		1			2
Entomoneis ornata (Bailey) Reimer															
Epithemia argus (Ehrenberg) Kutzing														1	
Epithemia goeppertiana Hilse															
Epithemia smithii Carruthers													1		
Epithemia sorex Kutzing															
Epithemia turgida var. granulata (Ehrenberg) Brun															
Eunotia arcus Ehrenberg															
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.															
Eunotia circumborealis Norpel & Lange-Bertalot					1				2						
Eunotia curvata (Kutzing) Lagerstedt										1					
Eunotia incisa Gregory var. incisa													2		
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot															
Eunotia minor (Kutzing) Grunow															
Eunotia praerupta Ehrenberg															
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel															
Fragilaria arcus (Ehrenberg) Cleve var. arcus															
Fragilaria brevistriata Grunow	1										1				
Fragilaria capucina var. gracilis (Oestrup) Hustedt							1								
Fragilaria constricta forma stricta Cleve															
Fragilaria construens (Ehrenberg) Grunow f. construens	20	17	25	37	32	19	8	12	7	10	12	20	18	30	23
Fragilaria construens var. binodis (Ehrenberg) Grunow				4				2					1		
Fragilaria construens var. venter (Ehrenberg) Grunow	116	127	108	113	87	82	71	58	74	80	115	97	50	87	83
Fragilaria crotonensis Kitton															
Fragilaria exigua Grunow															
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica															
Fragilaria pinnata Ehrenberg	23	16	19	15	15	11	17	15	2	14	21	26	17	27	36
Fragilaria pseudoconstruens Marciniak															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna	2	2	2							2	4	3	1	2	3
Frustulia rhomboides (Ehrenberg) De Toni						1									
Gomphonema acuminatum Ehrenberg															
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh															
Gomphonema augur Ehrenberg var. augur															
Gomphonema clavatum Ehrenberg															
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh	2	1	2	3		1			3		1		3	1	
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum															
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing															
Gomphonema subtile Ehrenberg													3		
Gomphonema truncatum Ehrenberg															
Gyrosigma acuminatum (Kutzing) Rabenhorst															
Hantzschia amphioxys (Ehrenberg) Grunow															
Navicula aboensis (Cleve) Hustedt	1		2												
Navicula absoluta Hustedt	1			2		3	2			3			5		2
Navicula agrestis Hustedt	1		2				1	1		1	3			3	1
Navicula arvensis Hustedt															
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg							1		1				1	1	1
Navicula bryophila Petersen										2	1	2	2	1	1
Navicula capitata Ehrenberg var. capitata						1									
Navicula capitata var. lueneburgensis (Grunow) Patrick					1	1	2			1				1	
Navicula capitatoradiata Germain															
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt			1			1		1							
Navicula cocconeiformis Gregory ex Greville								1	1	1					
Navicula cryptocephala Kutzing	14	19	10	15	14	20	12	11	21	22	12	14	21	16	13
Navicula cryptotenella Lange-Bertalot															
Navicula cuspidata Kutzing															
Navicula digitulus Hustedt															
Navicula disjuncta Hustedt	3	1	2	2			1	2	2	2	3		4	3	2
Navicula explanata Hustedt			1							1			1		
Navicula farta Hustedt															
Navicula gerloffii Shimanski	2	3	2	6	2	3	1	1			2	1			2
Navicula hambergii Hustedt															
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot															
Navicula jaagii Meister		1	1												
Navicula jaernfeltii Hustedt		1	1	1	1		1	4				1	8		2
Navicula jentzschii Grunow															

	L-107 (160,000 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	100mm	150mm	200mm	250mm	300mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot	40	33	37	27	37	31	48	46	33	39	38	36	25	26	42
Navicula laevissima Kutzing var. laevissima	3	1	3	7	3	1	2	1	1	5	1	3	3	1	7
Navicula leptostriata Joergensen										1					
Navicula levanderii Hustedt						1			1				1		
Navicula mediocris Krasske			2		6			1	1	3		1		1	5
Navicula minima Grunow	7	5	1	5	4	5	2	2	6	3	7	13	1	11	14
Navicula minusculoides Hustedt															
Navicula obsoleta Husedt	1											1			
Navicula oppugnata Hustedt															
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot									1						
Navicula protracta (Grunow) Cleve															
Navicula pseudoscutiformis Hustedt	3	4	1	2	3	1	2	3	4	1	1	7	2	6	8
Navicula pupula Kutzing var. pupula	3	10	3	4	5	2	1		3	1	1	2	1		4
Navicula pupula var. mutata (Krasske) Hustedt															
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot															
Navicula pusio Cleve															
Navicula radiosa Kutzing	7		5	9	7	9	4	5	5	8	4	4	5	11	6
Navicula reinhardtii Grunow															
Navicula schmassmannii Hustedt															
Navicula schoenfeldii Hustedt															
Navicula scutelloides W. Smith															
Navicula seminuloides Hustedt	7	5	6	1	4	4	5	2	10	3	7	3	3	5	6
Navicula seminulum Grunow	2	7	6	4	3	1	3	1	1	13	11	7	6	7	17
Navicula similis Krasske															
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot															
Navicula subminuscula Manguin	1						1								
Navicula submolesta Hustedt	7														
Navicula submuralis Hustedt	2				2	1	4	2	2	2	2	4	4		
Navicula subrotundata Hustedt															
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg															
Navicula ventralis Krasske					1	1	1	2	1			1	1		
Navicula viridula (Kutzing) Ehreneberg															
Navicula vitiosa Schimanski		1													
Navicula vulpina Kutzing	3			2	2	5	1		2	2		3	1	1	1
Neidium ampliatum (Ehrenberg) Krammer		3	2	1			2	2	1	2		1		2	1
Neidium hitchcockii (Ehrenberg) Cleve					1								1		
Neidium hoelstii Krammer			2												
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow													2		
Nitzschia dissipata (Kutzing) Grunow var. dissipata															
Nitzschia fasciculata (Grunow) Grunow															
Nitzschia fonticola Grunow	12	9	8	10	10	7	14	5	9	12	12	16	12	11	28
Nitzschia frustulum (Kutzing) Grunow var. frustulum		1				1									
Nitzschia inconspicua Grunow									1						
Nitzschia pseudofonticola Hustedt		1	1								1			1	
Nitzschia recta Hantzsch															
Nitzschia rostellata Hustedt	1	3	4	1		1		1	3	2	1	2	6	3	
Nitzschia valdestriata Alcom & Hustedt															
Pinnularia abaujensis var. linearis (Hustedt) Patrick															
Pinnularia borealis Ehrenberg															
Pinnularia borealis var. rectangularis Carlson															
Pinnularia brandelii Cleve															
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt	1	1		1		1	1			1					
Pinnularia gibba var. linaris Hustedt															
Pinnularia hemiptera (Kutzing) Rabenhorst														1	
Pinnularia interrupta W. Smith	2	1	1	1				1	2	3	4	3			
Pinnularia major (Kutzing) Rabenhorst			1												
Pinnularia mesolepta (Ehrenberg) W. Smith															
Pinnularia microstauron (Ehrenberg) Cleve			1			1	1		1	1	1	5		1	
Pinnularia rupestris Hantzsch		1									1				
Pinnularia subcapitata Gregory															
Pinnularia viridis (Nitzsch) Ehrenberg								1							
Pinnularia wisconsinensis Camburn & Charles														1	
Rhoicosphenia curvata (Kutzing) Grunow															
Rhopalodia gibba (Ehrenberg) O. Muller		1			1										1
Stauroneis anceps var. siberica Grunow	1		1		2			3	3	2	1				2
Stauroneis phoenicenteron (Nitzsch) Ehrenberg						3	2			3	1	1	1		
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt		1													
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow															
Stephanodiscus medius Hakansson															
Stephanodiscus minutulus (Kutzing) Cleve & Moller															
Stephanodiscus niagarae Ehrenberg															
Stephanodiscus parvus															
Surirella angusta Kutzing															
Surirella cf. lapponica Cleve															
Surirella didyma Kutzing				1	1										
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg															
Tabellaria flocculosa (Roth) Kutzing	3		2	2			2	1		2					
Tabellaria flocculosa var. linearis Koppen	2	3	2	3						1		1			
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.1242	0.1171	0.117	0.1175	0.1226	0.1145	0.1177	0.1287	0.1132	0.1175	0.1089	0.1122	0.1139	0.1099	0.1116
Diatom concentration (x10^6 valves/g dry mass)	787.44	781.86	581.2	434.14	519.85	358.17	947.69	628.51	628.19	340.43	652.73	624.86	456	554.55	1192.4

	Touchwood (671) (153 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	60mm	70mm	80mm	90mm	100mm
Eucalyptus globulus pollen grains	119	100	42	87	114	89	99	107	110	129	145	129	120	201	186
Stomatocysts															
Mallomonas crassisquama (Asmund) Fott															
Mallomonas heterospina Lund															
Synura petersenii Korshikov															
Achnanthes acares Hohn & Hellerman															
Achnanthes altaica (Poretzky) Cleve-Euler															
Achnanthes amoena Hustedt															
Achnanthes bahusiensis (Grunow) Lange-Bertalot															
Achnanthes bioretii Germain															
Achnanthes calcar Cleve															
Achnanthes carissima Lange-Bertalot															
Achnanthes cf. lapponica Cleve															
Achnanthes clevei Grunow var. clevei	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Achnanthes conspicua Mayer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes curtissima Carter	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
Achnanthes daoensis Lange-Bertalot															
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot	1	0	1	1	1	10	1	2	2	0	0	2	1	0	0
Achnanthes depressa (Cleve) Hustedt															
Achnanthes detha Hohn & Hellerman															
Achnanthes didyma Hustedt	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Achnanthes distincta Messikommer	0	0	0	0	0	4	0	0	2	0	0	0	0	0	0
Achnanthes exigua Grunow var. exigua	1	0	0	1	2	0	0	3	1	3	0	2	0	2	3
Achnanthes fulla Carter															
Achnanthes gracillima Hustedt															
Achnanthes grischuna Wutrich															
Achnanthes helvetica (Hustedt) Lange-Bertalot															
Achnanthes impexa Lange-Bertalot															
Achnanthes impexiformis Lange-Bertalot															
Achnanthes joursacense Heribaud	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes krasskei Kobayasi & Sawatari	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes kryophila Petersen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes kuelbsii Lange-Bertalot															
Achnanthes lanceolata (Brebisson) Grunow	0	0	0	0	0	0	0	0	2	2	0	2	0	3	0
Achnanthes lanceolata var. dubia Grunow	0	0	0	0	0	0	1	0	2	5	5	3	1	0	5
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot															
Achnanthes laterostrata Hustedt															
Achnanthes levanderi var. helvetica Hustedt															
Achnanthes marginulata Grunow															
Achnanthes minuscula Hustedt															
Achnanthes minutissima Kutzing	0	2	3	1	1	1	0	1	0	3	2	0	4	6	1
Achnanthes minutissima var. robusta Hustedt															
Achnanthes nitidiformis Lange-Bertalot															
Achnanthes oblongella Oestrup	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii															
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot															
Achnanthes peragalli Brun & Heribaud															
Achnanthes petersenii Hustedt															
Achnanthes pusilla (Grunow) De Toni															
Achnanthes ricula Hohn & Hellerman															
Achnanthes rosenstockii Lange-Bertalot															
Achnanthes rossii Hustedt															
Achnanthes saccula Carter															
Achnanthes sp. aff. aueri Krasske															
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Achnanthes suchlandtii Hustedt	0	0	0	0	0	0	0	0	0	1	7	0	1	3	2
Amphipleura kriegerana (Krasske) Hustedt															
Amphipleura pellucida (Kutzing) Kutzing															
Amphora inariensis Krammer	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0
Amphora libyca Ehrenberg	0	0	0	0	1	0	1	2	0	0	2	0	1	0	2
Amphora montana Krasske															
Amphora ovalis (Kutzing) Kutzing															
Amphora pediculus (Kutzing) Grunow	5	3	7	4	5	8	8	9	10	10	18	16	14	9	14
Amphora thumensis	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
Amphora veneta Kutzing															
Anomoeoneis brachysira (Brebisson) Grunow															
Anomoeoneis serians var. acuta Hustedt															
Anomoeoneis styriaca (Grunow) Hustedt															
Anomoeoneis vitrea (Grunow) Ross															
Asterionella formosa Hassall															
Aulacoseira ambigua (Grunow) Simonsen	0	3	0	3	7	5	10	6	4	7	8	16	20	12	9
Aulacoseira distans (Ehrenberg) Simonsen	0	0	0	0	0	10	0	3	1	9	3	0	32	10	0
Aulacoseira distans var. humilis (Cleve-Euler) Ross															
Aulacoseira perglabra (Oestrup) Haworth	0	0	0	0	0	21	0	1	6	22	0	1	23	6	2
Aulacoseira subarctica (O. Muller) Haworth															
Aulacoseira valida (Grunow) Krammer															
Caloneis bacillaris (Gregory) Cleve															
Caloneis bacillum (Grunow) Cleve	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Caloneis silicula (Ehrenberg) Cleve															
Caloneis undulata (Gregory) Krammer															
Cocconeis disculus (Schumann) Cleve	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cocconeis neodiminuta Krammer															
Cocconeis neothumensis Krammer															
Cocconeis placentula Ehrenberg var. placentula	0	0	0	2	1	0	0	2	0	1	2	2	0	1	1
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck															
Cocconeis pseudothumensis Reichardt															
Cyclotella bodanica var. aff. affinis Grunow															
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	1	6	0	7	3	4	6	3	2	3	4	7	4	4	8
Cyclotella delicatula Hustedt															
Cyclotella krammeri Hakansson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella meneghiniana Kutzing															
Cyclotella michiganiana Skvortzow															
Cyclotella ocellata Pantocsek	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Cyclotella pseudostelligera Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella radiosa (Grunow) Lemmermann	0	2	0	2	4	0	2	0	0	0	0	0	0	0	0
Cyclotella rossii (Grunow) Hakansson															
Cyclotella stelligera (Cleve & Grunow) Van Heurck															
Cyclotella woltereckii Hustedt															
Cymbella amphicephala Naegeli ex Kutzing															
Cymbella caespitosa (Kutzing) Brun	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

	Touchwood (671,153 pollen grains/ml)											
	120mm	140mm	160mm	180mm	200mm	220mm	240mm	260mm	280mm	300mm	320mm	340mm
Eucalyptus globulus pollen grains	198	327	465	218	448	400	182	299	396	209	515	392
Stomatocysts												
Mallomonas crassisquama (Asmund) Fott												
Mallomonas heterospina Lund												
Synura petersenii Korshikov												
Achnanthes acares Hohn & Hellerman												
Achnanthes altaica (Poretzky) Cleve-Euler												
Achnanthes amoena Hustedt												
Achnanthes bahusiensis (Grunow) Lange-Bertalot												
Achnanthes bioretii Germain												
Achnanthes calcar Cleve												
Achnanthes carissima Lange-Bertalot												
Achnanthes cf. lapponica Cleve												
Achnanthes clevei Grunow var. clevei	0	2	1	2	1	0	0	0	0	0	0	0
Achnanthes conspicua Mayer	0	0	0	0	0	2	0	0	0	0	0	0
Achnanthes curtissima Carter	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes daoensis Lange-Bertalot												
Achnanthes delicatula ssp. Hauckiana (Grunow) Lange-Bertalot	0	1	1	0	0	0	0	0	0	0	0	0
Achnanthes depressa (Cleve) Hustedt												
Achnanthes detha Hohn & Hellerman												
Achnanthes didyma Hustedt	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes distincta Messikommer	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes exigua Grunow var. exigua	6	1	3	1	3	0	1	2	1	1	1	3
Achnanthes fulla Carter												
Achnanthes gracillima Hustedt												
Achnanthes grischuna Wutrich												
Achnanthes helvetica (Hustedt) Lange-Bertalot												
Achnanthes impexa Lange-Bertalot												
Achnanthes impexiformis Lange-Bertalot												
Achnanthes joursacense Heribaud	0	0	0	0	0	0	0	0	0	1	2	0
Achnanthes krasskei Kobayasi & Sawatari	0	0	0	0	0	0	0	2	0	0	1	0
Achnanthes kryophila Petersen	0	0	0	0	1	0	0	1	0	0	0	0
Achnanthes kuelbsii Lange-Bertalot												
Achnanthes lanceolata (Brebisson) Grunow	1	0	0	0	0	2	0	1	0	0	0	0
Achnanthes lanceolata var. dubia Grunow	1	2	4	6	4	1	1	0	1	0	1	4
Achnanthes lapidosa var. appalachiana (Camburn & Lowe) Lange-Bertalot												
Achnanthes laterostrata Hustedt												
Achnanthes levanderi var. helvetica Hustedt												
Achnanthes marginulata Grunow												
Achnanthes minuscula Hustedt												
Achnanthes minutissima Kutzing	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes minutissima var. robusta Hustedt												
Achnanthes nitidiformis Lange-Bertalot												
Achnanthes oblongella Oestrup	0	1	0	0	1	0	0	0	0	0	0	0
Achnanthes oestrupii (Cleve-Euler) Hustedt var. oestrupii												
Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot												
Achnanthes peragalli Brun & Heribaud												
Achnanthes petersenii Hustedt												
Achnanthes pusilla (Grunow) De Toni												
Achnanthes ricula Hohn & Hellerman												
Achnanthes rosenstockii Lange-Bertalot												
Achnanthes rossii Hustedt												
Achnanthes saccula Carter												
Achnanthes sp. aff. aueri Krasske												
Achnanthes subatomoides (Hustedt) Lange-Bertalot and Archibald	2	0	0	0	0	0	0	1	0	0	1	0
Achnanthes suchlandtii Hustedt	8	0	2	2	2	3	0	0	0	0	0	0
Amphipleura kriegerana (Krasske) Hustedt												
Amphipleura pellucida (Kutzing) Kutzing												
Amphora inariensis Krammer	0	0	0	0	0	0	0	0	0	0	0	0
Amphora libyca Ehrenberg	0	0	1	0	0	1	0	0	0	0	0	0
Amphora montana Krasske												
Amphora ovalis (Kutzing) Kutzing												
Amphora pediculus (Kutzing) Grunow	11	11	11	9	14	2	6	4	12	4	3	4
Amphora thumensis	1	1	0	0	1	0	0	0	1	1	0	0
Amphora veneta Kutzing												
Anomoeoneis brachysira (Brebisson) Grunow												
Anomoeoneis serians var. acuta Hustedt												
Anomoeoneis styriaca (Grunow) Hustedt												
Anomoeoneis vitrea (Grunow) Ross												
Asterionella formosa Hassall												
Aulacoseira ambigua (Grunow) Simonsen	19	4	3	0	2	2	3	1	0	0	0	3
Aulacoseira distans (Ehrenberg) Simonsen	0	0	3	14	0	7	30	7	0	0	4	2
Aulacoseira distans var. humilis (Cleve-Euler) Ross												
Aulacoseira perglabra (Oestrup) Haworth	0	1	0	27	0	4	38	21	2	8	0	7
Aulacoseira subarctica (O. Muller) Haworth												
Aulacoseira valida (Grunow) Krammer												
Caloneis bacillaris (Gregory) Cleve												
Caloneis bacillum (Grunow) Cleve	1	0	1	1	0	0	1	0	0	0	0	0
Caloneis silicula (Ehrenberg) Cleve												
Caloneis undulata (Gregory) Krammer												
Cocconeis disculüs (Schumann) Cleve	0	0	0	0	2	0	0	1	2	1	0	0
Cocconeis neodiminuta Krammer												
Cocconeis neothumensis Krammer												
Cocconeis placentula Ehrenberg var. placentula	0	3	1	0	0	0	1	0	0	0	2	0
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck												
Cocconeis pseudothumensis Reichardt												
Cyclotella bodanica var. aff. affinis Grunow												
Cyclotella bodanica var. aff. lemanica (O. Muller) Bachmann	9	8	20	12	12	11	2	3	0	0	4	0
Cyclotella delicatula Hustedt												
Cyclotella krammeri Hakansson	0	0	1	0	0	0	0	0	0	0	0	0
Cyclotella meneghiniana Kutzing												
Cyclotella michiganiana Skvortzow												
Cyclotella ocellata Pantocsek	0	0	0	0	0	0	0	1	0	3	0	0
Cyclotella pseudostelligera Hustedt	0	0	0	0	0	1	0	0	0	0	0	0
Cyclotella radiosa (Grunow) Lemmermann	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella rossii (Grunow) Hakansson												
Cyclotella stelligera (Cleve & Grunow) Van Heurck												
Cyclotella woltereckii Hustedt												
Cymbella amphicephala Naegeli ex Kutzing												
Cymbella caespitosa (Kutzing) Brun	0	2	0	2	0	0	0	1	0	0	0	0

	Touchwood (671,153 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	60mm	70mm	80mm	90mm	100mm
Cymbella cesatii (Rabenhorst) Grunow															
Cymbella cuspidata Kutzing	0	0	0	2	1	1	0	0	0	0	0	0	0	0	1
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot															
Cymbella gaeumannii Meister															
Cymbella gracilis (Ehrenberg) Kutzing															
Cymbella hebridica (Grunow ex Cleve) Cleve															
Cymbella heteropleura (Ehrenberg) Kutzing															
Cymbella microcephala Grunow															
Cymbella minuta Hilse ex Rabenhorst	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer															
Cymbella naviculiformis (Auerswald) Cleve															
Cymbella perpusilla A. Cleve															
Cymbella proxima Reimer															
Cymbella reichardtii Krammer															
Cymbella reinhardtii Grunow															
Cymbella silesiaca Bleisch	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
Cymbella sinuata Gregory	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella subaequalis Grunow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denticula kuetzingii Grunow	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Denticula kuetzingii var. rumrichae Krammer															
Diatoma anceps (Ehrenberg) Kirchner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diploneis elliptica (Kutzing) Cleve	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Diploneis marginestriata Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Entomoneis ornata (Bailey) Reimer															
Epithemia argus (Ehrenberg) Kutzing															
Epithemia goeppertiana Hilse															
Epithemia smithii Carruthers															
Epithemia sorex Kutzing	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
Epithemia turgida var. granulata (Ehrenberg) Brun	0	0	0	0	0	2	1	0	0	1	1	0	0	0	0
Eunotia arcus Ehrenberg															
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia circumborealis Norpel & Lange-Bertalot															
Eunotia curvata (Kutzing) Lagerstedt															
Eunotia incisa Gregory var. incisa															
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot															
Eunotia minor (Kutzing) Grunow	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Eunotia praerupta Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia rhomboidea Hustedt															
Eunotia rhyncocephala Hustedt var. rhyncocephala															
Eunotia serra var. tetraodon (Ehrenberg) Norpel															
Fragilaria arcus (Ehrenberg) Cleve var. arcus															
Fragilaria brevistriata Grunow	6	16	14	11	15	60	42	25	69	57	38	30	53	43	31
Fragilaria capucina var. gracilis (Oestrup) Hustedt															
Fragilaria constricta forma stricta Cleve															
Fragilaria construens (Ehrenberg) Grunow f. construens															
Fragilaria construens var. binodis (Ehrenberg) Grunow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Fragilaria construens var. venter (Ehrenberg) Grunow	1	1	0	3	2	1	1	5	12	7	0	0	2	3	2
Fragilaria crotonensis Kitton	0	0	1	2	4	1	0	0	2	0	0	5	0	0	0
Fragilaria exigua Grunow	1	1	0	0	6	2	0	1	4	6	2	3	1	4	4
Fragilaria nanana Lange-Bertalot															
Fragilaria nitzschioides Grunow															
Fragilaria parasitica (W. Smith) Grunow															
Fragilaria parasitica (W. Smith) Grunow var. parasitica	0	0	0	0	1	0	2	0	0	0	0	0	0	0	1
Fragilaria pinnata Ehrenberg	16	24	16	43	48	67	77	63	63	113	97	89	82	93	95
Fragilaria pseudoconstruens Marciniak	1	5	3	2	13	6	14	17	18	7	15	10	21	13	11
Fragilaria tenera (W. Smith) Lange-Bertalot	3	4	2	4	2	1	1	0	2	0	2	0	0	1	1
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna															
Frustulia rhomboides (Ehrenberg) De Toni	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
Gomphonema acuminatum Ehrenberg															
Gomphonema angustatum (Kutzing) Rabenhorst															
Gomphonema angustatum var. sarcophagus (Gregory) Grunow															
Gomphonema angustum Aghardh															
Gomphonema augur Ehrenberg var. augur															
Gomphonema clavatum Ehrenberg															
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot															
Gomphonema minutum (C. Agardh) C. Agardh															
Gomphonema olivaceum (Horneman) Brebisson var. olivaceum	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
Gomphonema olivaceum var. fonticola Hustedt															
Gomphonema olivaceum var. minutissimum Hustedt															
Gomphonema parvulum Kutzing	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
Gomphonema subtile Ehrenberg															
Gomphonema truncatum Ehrenberg															
Gyrosigma acuminatum (Kutzing) Rabenhorst	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2
Hantzschia amphioxys (Ehrenberg) Grunow															
Navicula aboensis (Cleve) Hustedt															
Navicula absoluta Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula agrestis Hustedt															
Navicula arvensis Hustedt															
Navicula atomus (Kutzing) Grunow															
Navicula bacillum Ehrenberg															
Navicula bryophila Petersen															
Navicula capitata Ehrenberg var. capitata															
Navicula capitata var. lueneburgensis (Grunow) Patrick															
Navicula capitatoradiata Germain	0	1	1	3	0	0	1	0	0	1	0	1	1	0	0
Navicula clementis Grunow															
Navicula cocconeiformis f. elliptica Hustedt															
Navicula cocconeiformis Gregory ex Greville															
Navicula cryptocephala Kutzing															
Navicula cryptotenella Lange-Bertalot	0	0	0	0	0	0	0	0	0	0	4	1	1	1	3
Navicula cuspidata Kutzing															
Navicula digitulus Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula disjuncta Hustedt															
Navicula explanata Hustedt															
Navicula farta Hustedt															
Navicula gerloffii Shimanski															
Navicula hambergii Hustedt															
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1
Navicula jaagii Meister															
Navicula jaernfeltii Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula jentzschii Grunow															

	Touchwood (671,153 pollen grains/ml)											
	120mm	140mm	160mm	180mm	200mm	220mm	240mm	260mm	280mm	300mm	320mm	340mm
Cymbella cesatii (Rabenhorst) Grunow												
Cymbella cuspidata Kutzing	0	0	0	2	0	0	0	0	0	0	0	0
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot												
Cymbella gaeumannii Meister												
Cymbella gracilis (Ehrenberg) Kutzing												
Cymbella hebridica (Grunow ex Cleve) Cleve												
Cymbella heteropleura (Ehrenberg) Kutzing												
Cymbella microcephala Grunow												
Cymbella minuta Hilse ex Rabenhorst	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella minuta var. pseudogracilis (Cholnoky) Reimer												
Cymbella naviculiformis (Auerswald) Cleve												
Cymbella perpusilla A. Cleve												
Cymbella proxima Reimer												
Cymbella reichardtii Krammer												
Cymbella reinhardtii Grunow												
Cymbella silesiaca Bleisch	1	1	2	2	0	0	3	1	2	2	0	0
Cymbella sinuata Gregory	0	1	0	0	0	0	0	0	0	0	0	0
Cymbella subaequalis Grunow	0	0	0	0	0	0	0	1	0	0	0	0
Denticula kuetzingii Grunow	0	0	0	0	0	0	0	0	0	0	0	0
Denticula kuetzingii var. rumrichae Krammer												
Diatoma anceps (Ehrenberg) Kirchner	0	0	0	0	0	0	0	0	0	0	0	0
Diploneis elliptica (Kutzing) Cleve	0	0	0	0	0	0	0	0	0	0	0	0
Diploneis marginestriata Hustedt	0	0	0	0	0	0	0	0	0	0	0	0
Entomoneis ornata (Bailey) Reimer												
Epithemia argus (Ehrenberg) Kutzing												
Epithemia goeppertiana Hilse												
Epithemia smithii Carruthers												
Epithemia sorex Kutzing	0	0	0	0	0	0	0	0	0	0	0	0
Epithemia turgida var. granulata (Ehrenberg) Brun	0	0	0	0	0	0	0	0	0	0	0	1
Eunotia arcus Ehrenberg												
Eunotia bilunaris (Ehrenberg) Mills var. bilunaris s.l.	0	0	0	0	0	0	0	0	0	0	2	0
Eunotia circumborealis Norpel & Lange-Bertalot												
Eunotia curvata (Kutzing) Lagerstedt												
Eunotia incisa Gregory var. incisa												
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot												
Eunotia minor (Kutzing) Grunow	0	0	1	0	0	2	0	0	0	2	1	0
Eunotia praerupta Ehrenberg	1	0	0	0	0	1	1	0	0	0	0	0
Eunotia rhomboidea Hustedt												
Eunotia rhyncocephala Hustedt var. rhyncocephala												
Eunotia serra var. tetraodon (Ehrenberg) Norpel												
Fragilaria arcus (Ehrenberg) Cleve var. arcus												
Fragilaria brevistriata Grunow	47	9	41	104	42	33	99	44	18	60	56	48
Fragilaria capucina var. gracilis (Oestrup) Hustedt												
Fragilaria constricta forma stricta Cleve												
Fragilaria construens (Ehrenberg) Grunow f. construens												
Fragilaria construens var. binodis (Ehrenberg) Grunow	0	0	1	0	0	0	0	0	0	0	0	0
Fragilaria construens var. venter (Ehrenberg) Grunow	6	10	8	0	4	10	5	3	3	8	7	11
Fragilaria crotonensis Kitton	7	0	0	0	0	0	0	0	0	0	0	0
Fragilaria exigua Grunow	1	2	3	3	3	9	2	4	4	46	19	27
Fragilaria nanana Lange-Bertalot												
Fragilaria nitzschioides Grunow												
Fragilaria parasitica (W. Smith) Grunow												
Fragilaria parasitica (W. Smith) Grunow var. parasitica	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria pinnata Ehrenberg	62	82	47	63	57	36	61	27	24	28	27	37
Fragilaria pseudoconstruens Marciniak	16	25	8	3	9	9	3	5	5	3	13	13
Fragilaria tenera (W. Smith) Lange-Bertalot	4	0	6	1	0	0	0	0	0	0	0	0
Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna												
Frustulia rhomboides (Ehrenberg) De Toni	0	0	0	2	0	0	1	1	0	0	0	0
Gomphonema acuminatum Ehrenberg												
Gomphonema angustatum (Kutzing) Rabenhorst												
Gomphonema angustatum var. sarcophagus (Gregory) Grunow												
Gomphonema angustum Aghardh												
Gomphonema augur Ehrenberg var. augur												
Gomphonema clavatum Ehrenberg												
Gomphonema grovei var. lingulatum (Hustedt) Lange-Bertalot												
Gomphonema minutum (C. Agardh) C. Agardh												
Gomphonema olivaceum (Homeman) Brebisson var. olivaceum	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema olivaceum var. fonticola Hustedt												
Gomphonema olivaceum var. minutissimum Hustedt												
Gomphonema parvulum Kutzing	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema subtile Ehrenberg												
Gomphonema truncatum Ehrenberg												
Gyrosigma acuminatum (Kutzing) Rabenhorst	2	0	0	0	2	0	0	0	0	0	0	0
Hantzschia amphioxys (Ehrenberg) Grunow												
Navicula aboensis (Cleve) Hustedt												
Navicula absoluta Hustedt	0	0	0	0	0	0	0	0	0	0	0	0
Navicula agrestis Hustedt												
Navicula arvensis Hustedt												
Navicula atomus (Kutzing) Grunow												
Navicula bacillum Ehrenberg												
Navicula bryophila Petersen												
Navicula capitata Ehrenberg var. capitata												
Navicula capitata var. lueneburgensis (Grunow) Patrick												
Navicula capitatoradiata Germain	0	0	0	0	0	1	1	0	0	0	0	0
Navicula clementis Grunow												
Navicula cocconeiformis f. elliptica Hustedt												
Navicula cocconeiformis Gregory ex Greville												
Navicula cryptocephala Kutzing												
Navicula cryptotenella Lange-Bertalot	0	0	2	0	0	0	0	0	0	0	0	0
Navicula cuspidata Kutzing												
Navicula digitulus Hustedt	0	0	0	10	3	0	5	4	0	4	2	1
Navicula disjuncta Hustedt												
Navicula explanata Hustedt												
Navicula farta Hustedt												
Navicula gerloffii Shimanski												
Navicula hambergii Hustedt												
Navicula ignota var. acceptata (Hustedt) Lange-Bertalot	0	0	0	1	0	0	0	0	1	0	0	0
Navicula jaagii Meister												
Navicula jaernfeltii Hustedt	4	1	2	2	1	0	0	1	4	0	0	0
Navicula jentzschii Grunow												

	Touchwood (671,153 pollen grains/ml)														
	5mm	10mm	15mm	20mm	25mm	30mm	35mm	40mm	45mm	50mm	60mm	70mm	80mm	90mm	100mm
Navicula krasskei Hustedt															
Navicula kuelbsii Lange-Bertalot															
Navicula laevissima Kutzing var. laevissima															
Navicula leptostriata Joergensen															
Navicula levanderii Hustedt															
Navicula mediocris Krasske															
Navicula minima Grunow	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0
Navicula minusculoides Hustedt															
Navicula obsoleta Husedt															
Navicula oppugnata Hustedt															
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot															
Navicula protracta (Grunow) Cleve															
Navicula pseudoscutiformis Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Navicula pupula Kutzing var. pupula	1	0	0	0	0	3	1	0	0	1	0	0	0	0	1
Navicula pupula var. mutata (Krasske) Hustedt	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot															
Navicula pusio Cleve															
Navicula radiosa Kutzing	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
Navicula reinhardtii Grunow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula schmassmannii Hustedt	0	0	0	0	0	17	1	1	3	4	0	1	6	3	1
Navicula schoenfeldii Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula scutelloides W. Smith	0	3	3	1	5	5	3	4	4	1	1	6	7	5	12
Navicula seminuloides Hustedt	0	0	0	0	0	1	2	9	6	10	3	4	6	8	7
Navicula seminulum Grunow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula similis Krasske															
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot															
Navicula subminuscula Manguin															
Navicula submolesta Hustedt															
Navicula submuralis Hustedt	0	0	0	0	0	1	3	3	1	8	0	5	1	7	4
Navicula subrotundata Hustedt															
Navicula subtilissima Cleve															
Navicula tuscula Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula ventralis Krasske	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicule viridula (Kutzing) Ehreneberg															
Navicula vitiosa Schimanski															
Navicula vulpina Kutzing															
Neidium ampliatum (Ehrenberg) Krammer															
Neidium hitchcockii (Ehrenberg) Cleve															
Neidium holstii Krammer															
Nitzschia acicularis (Kutzing) W. Smith															
Nitzschia angustata (W. Smith) Grunow															
Nitzschia dissipata (Kutzing) Grunow var. dissipata															
Nitzschia fasciculata (Grunow) Grunow															
Nitzschia fonticola Grunow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia frustulum (Kutzing) Grunow var. frustulum															
Nitzschia inconspicua Grunow															
Nitzschia pseudofonticola Hustedt															
Nitzschia recta Hantzsch															
Nitzschia rostellata Hustedt															
Nitzschia valdestriata Alcom & Hustedt															
Pinnularia abaujensis var. linearis (Hustedt) Patrick															
Pinnularia borealis Ehrenberg															
Pinnularia borealis var. rectangularis Carlson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia brandelii Cleve															
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt															
Pinnularia gibba var. linaris Hustedt	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Pinnularia hemiptera (Kutzing) Rabenhorst															
Pinnularia interrupta W. Smith	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia major (Kutzing) Rabenhorst															
Pinnularia mesolepta (Ehrenberg) W. Smith	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Pinnularia microstauron (Ehrenberg) Cleve	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0
Pinnularia rupestris Hantzsch															
Pinnularia subcapitata Gregory	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0
Pinnularia viridis (Nitzsch) Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia wisconsinensis Camburn & Charles															
Rhoicosphenia curvata (Kutzing) Grunow	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
Rhopalodia gibba (Ehrenberg) O. Muller															
Stauroneis anceps var. siberica Grunow	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stenopterobia delicatissima (Lewis) Van Heurck															
Stephanodiscus cf. alpinus Hustedt															
Stephanodiscus chantaicus Genkal and Kuzmina															
Stephanodiscus hantzschii Grunow	4	16	10	25	14	11	22	15	6	9	12	10	2	10	8
Stephanodiscus medius Hakansson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanodiscus minutulus (Kutzing) Cleve & Moller	238	320	336	234	177	94	134	107	50	58	86	83	26	100	57
Stephanodiscus niagarae Ehrenberg	2	1	4	3	4	1	1	3	2	3	0	4	2	1	1
Stephanodiscus parvus															
Surirella angusta Kutzing	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Surirella cf. lapponica Cleve															
Surirella didyma Kutzing															
Surirella gemma Ehrenberg															
Surirella robusta Ehrenberg															
Tabellaria flocculosa (Roth) Kutzing	1	1	6	5	3	2	3	7	6	2	7	2	1	4	7
Tabellaria flocculosa var. linearis Koppen															
Tetracyclus glans (Ehrenberg) Mills															
Sample weight (g)	0.0149	0.0997	0.1084	0.1043	0.1004	0.1025	0.1051	0.1035	0.1029	0.0991	0.1044	0.1022	0.1066	0.1019	0.1029
Diatom concentration (x10^6 valves/g dry mass)	254.47	65.958	143.38	63.83	45.432	62.264	52.744	42.331	40.569	46.684	34.034	37.258	40.025	28.122	25.479

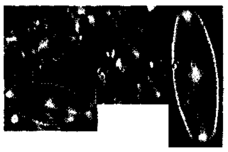
	Touchwood (671,153 pollen grains/ml)											
	120mm	140mm	160mm	180mm	200mm	220mm	240mm	260mm	280mm	300mm	320mm	340mm
Navicula krasskei Hustedt												
Navicula kuelbsii Lange-Bertalot												
Navicula laevissima Kutzing var. laevissima												
Navicula leptostriata Joergensen												
Navicula levanderii Hustedt												
Navicula mediocris Krasske												
Navicula minima Grunow	0	0	0	0	0	0	0	1	0	0	0	0
Navicula minusculoides Hustedt												
Navicula obsoleta Husedt												
Navicula oppugnata Hustedt												
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot												
Navicula protracta (Grunow) Cleve												
Navicula pseudoscutiformis Hustedt	1	0	0	0	0	1	1	1	0	2	4	0
Navicula pupula Kutzing var. pupula	0	0	0	1	0	0	0	2	0	0	0	0
Navicula pupula var. mutata (Krasske) Hustedt	1	0	0	0	0	0	1	0	0	1	0	0
Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot												
Navicula pusio Cleve												
Navicula radiosa Kutzing	0	0	0	0	0	0	0	0	0	0	0	0
Navicula reinhardtii Grunow	1	0	0	0	0	0	0	0	0	0	0	0
Navicula schmassmannii Hustedt	0	0	0	7	1	0	4	5	0	4	0	2
Navicula schoenfeldii Hustedt	0	0	0	0	0	0	0	0	0	0	0	1
Navicula scutelloides W. Smith	6	11	17	8	16	0	18	33	38	17	38	30
Navicula seminuloides Hustedt	4	4	5	7	5	1	2	5	3	1	0	2
Navicula seminulum Grunow	0	0	0	0	0	0	0	2	0	0	0	0
Navicula similis Krasske												
Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot												
Navicula subminuscula Manguin												
Navicula submolesta Hustedt												
Navicula submuralis Hustedt	1	1	4	2	5	3	0	3	3	1	4	1
Navicula subrotundata Hustedt												
Navicula subtilissima Cleve												
Navicula tuscula Ehrenberg	0	0	0	0	0	1	0	0	0	0	0	0
Navicula ventralis Krasske	0	1	0	0	0	0	0	0	0	0	0	0
Navicula viridula (Kutzing) Ehreneberg												
Navicula vitiosa Schimanski												
Navicula vulpina Kutzing												
Neidium ampliatum (Ehrenberg) Krammer												
Neidium hitchcockii (Ehrenberg) Cleve												
Neidium holstii Krammer												
Nitzschia acicularis (Kutzing) W. Smith												
Nitzschia angustata (W. Smith) Grunow												
Nitzschia dissipata (Kutzing) Grunow var. dissipata												
Nitzschia fasciculata (Grunow) Grunow												
Nitzschia fonticola Grunow	0	1	0	0	1	0	0	0	0	1	0	0
Nitzschia frustulum (Kutzing) Grunow var. frustulum												
Nitzschia inconspicua Grunow												
Nitzschia pseudofonticola Hustedt												
Nitzschia recta Hantzsch												
Nitzschia rostellata Hustedt												
Nitzschia valdestriata Alcom & Hustedt												
Pinnularia abaujensis var. linearis (Hustedt) Patrick												
Pinnularia borealis Ehrenberg												
Pinnularia borealis var. rectangularis Carlson	0	1	0	0	0	0	0	0	0	0	0	0
Pinnularia brandelii Cleve												
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt												
Pinnularia gibba var. linaris Hustedt	0	0	3	0	1	1	1	3	0	0	2	0
Pinnularia hemiptera (Kutzing) Rabenhorst												
Pinnularia interrupta W. Smith	0	1	0	0	0	10	0	0	0	0	0	0
Pinnularia major (Kutzing) Rabenhorst												
Pinnularia mesolepta (Ehrenberg) W. Smith	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia microstauron (Ehrenberg) Cleve	0	0	0	0	0	6	0	0	0	4	3	0
Pinnularia rupestris Hantzsch												
Pinnularia subcapitata Gregory	1	0	1	0	0	0	0	2	0	5	12	1
Pinnularia viridis (Nitzsch) Ehrenberg	0	0	0	0	0	1	0	1	0	0	0	0
Pinnularia wisconsinensis Cambum & Charles												
Rhoicosphenia curvata (Kutzing) Grunow	0	0	0	0	0	0	0	0	0	0	0	0
Rhopalodia gibba (Ehrenberg) O. Muller												
Stauroneis anceps var. siberica Grunow	0	0	1	1	0	0	1	0	0	0	1	0
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	1	0	0	0	0	0	0	0	0	0	0	0
Stenopterobia delicatissima (Lewis) Van Heurck												
Stephanodiscus cf. alpinus Hustedt												
Stephanodiscus chantaicus Genkal and Kuzmina												
Stephanodiscus hantzschii Grunow	17	6	4	1	0	3	0	1	0	0	0	0
Stephanodiscus medius Hakansson	0	0	0	0	0	0	0	0	0	0	0	2
Stephanodiscus minutulus (Kutzing) Cleve & Moller	49	21	17	2	7	2	1	2	0	0	1	0
Stephanodiscus niagarae Ehrenberg	6	7	5	1	2	0	0	0	0	0	0	0
Stephanodiscus parvus												
Surirella angusta Kutzing	0	0	0	0	0	0	0	0	0	0	0	0
Surirella cf. lapponica Cleve												
Surirella didyma Kutzing												
Surirella gemma Ehrenberg												
Surirella robusta Ehrenberg												
Tabellaria flocculosa (Roth) Kutzing	1	6	0	0	0	2	0	0	0	0	0	0
Tabellaria flocculosa var. linearis Koppen												
Tetracyclus glans (Ehrenberg) Mills												
Sample weight (g)	0.0999	0.1029	0.1033	0.1021	0.1034	0.1021	0.1036	0.1071	0.1026	0.0997	0.1038	0.1018
Diatom concentration (x10^6 valves/g dry mass)	24.186	10.842	7.6612	21.494	6.9771	6.5818	24.863	9.8929	4.8831	15.971	6.3154	8.0347

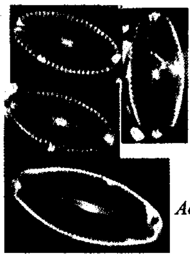
APPENDIX 2

DIATOM IMAGES

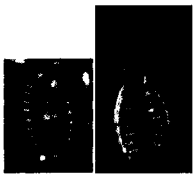
143


Achnanthes acares Hohn & Hellerman


Achnanthes altaica (Poretzky) Cleve-Euler

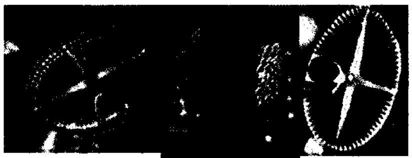



Achnanthes bioretii Germain


Achnanthes conspicua Mayer

Achnanthes clevei Grunow var. clevei

Achnanthes carissima Lange-Bertalot


Achnanthes calcar Cleve


Achnanthes bahusiensis (Grunow) Grunow

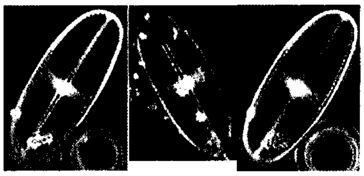
Achnanthes detha Hohn & Hellermann


Achnanthes delicatula ssp. hauckiana (Grunow) Lange-Bertalot

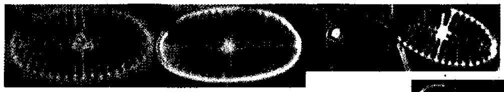
Achnanthes cf. daoensis Lange-Bertalot


Achnanthes kuelbsii Lange-Bertalot


Achnanthes curtissima Carter


Achnanthes helvetica (Hustedt) Lange-Bertalot

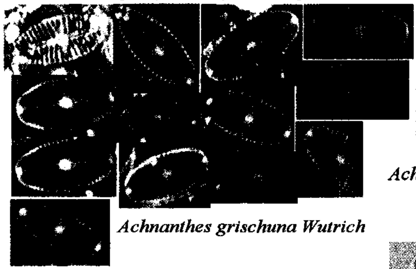
Achnanthes depressa (Cleve) Hustedt


Achnanthes fulla Carter

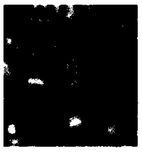

Ahnanthes exigua (Grunow) var. Exigua


Achnanthes daoensis Lange-Bertalot

Achnanthes gracillima Hustedt


Achnanthes grischuna Wutrich


Achnanthes impexiformis Lange-Bertalot


Achnanthes lanceolata var. Dubia (Grunow)

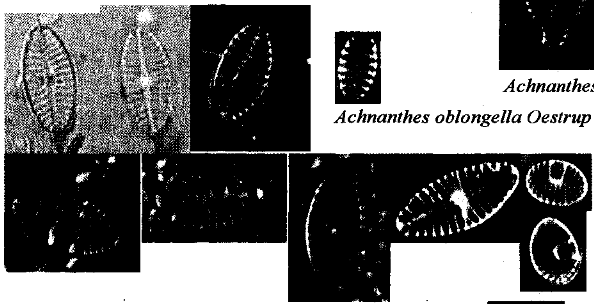

Achnanthes laterostrata Hustedt

Achnanthes oblongella Oestrup

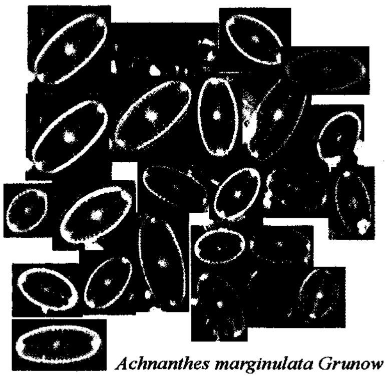
Achnanthes didyma Hustedt


Achnanthes cf. Peragalli Brun & Heribaud

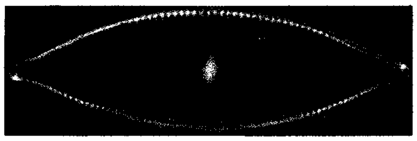

Achnanthes minutissima Kutzing var minutissima


Achnanthes lanceolata (Brebisson) Grunow


Achnanthes pusilla Grunow


Achnanthes marginulata Grunow

Achnanthes nitidiformis Lange-Bertalot

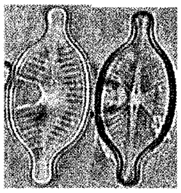

Achnanthes oestrupii var. pungens (Cleve-Euler) Lange-Bertalot


Achnnthes levanderi var. helvetica Hustedt


Achnanthes oestrupii (Cleve-Euler) Hustedt var oestrupii

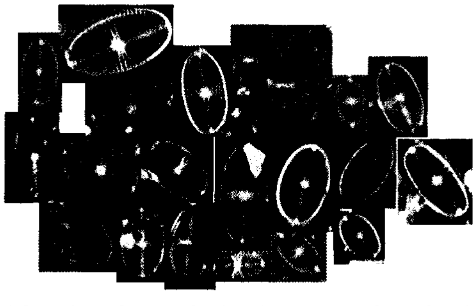
Achnanthes clevei Grunow var. clevei

Achnanthes minuscula Hustedt

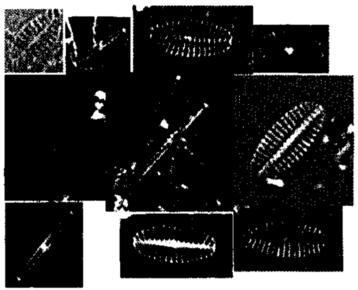

Achnanthes peragalli Brun & Heribaud


Achnanthes rosenstockii Lange-Bertalot

Achnanthes saccula Carter


Achnanthes subatomoides (Hust) Lange-Bertalot and Archibald


Achnanthes rossii Hustedt

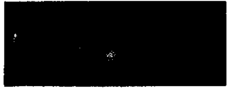

Achnanthes suchlandtii Hustedt


Achnanthes ricula Hohn & Hellerman

Achnanthes minutissima var. robusta Hustedt

Achnanthes sp. aff. aueri Krasske

Achnanthes impexa Lange-Bertalot

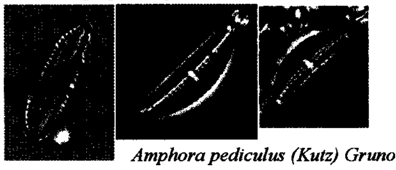


Amphora montana Krasske

Achnanthes petersenii Hustedt

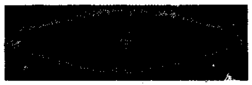
Amphipleura pellucida (Kutzing) Kutzing

Amphipleuraa kriegerana (Krasske) Hustedt

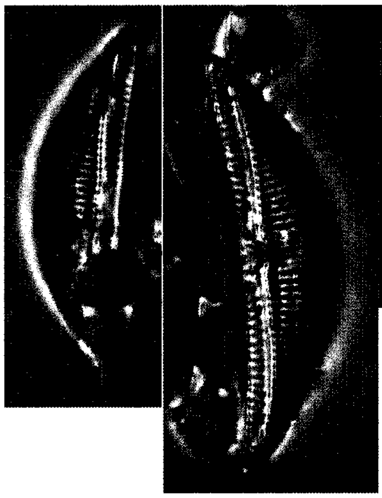


Amphora pediculus (Kutz) Grunow

Amphora veneta Kutzing



Anomoneis brachysira (Brebisson) Grunow



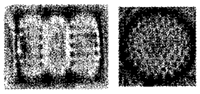
Amphora ovalis (Kutz) Kutz

Anomoneis vitrea (Grunow) Ross

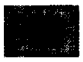
Anomoneis styriaca (Grunow) Hustedt

Anomoneis serians var. acuta Hustedt

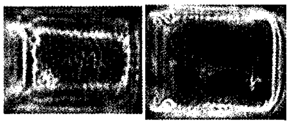
Asterionella formosa Hassall



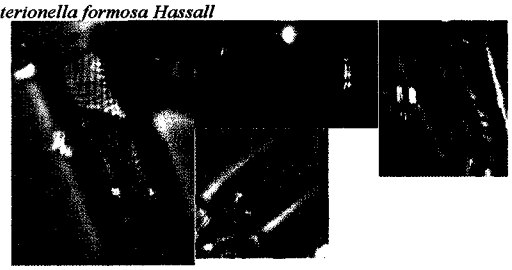
Aulacosira distans var. humilis (Cleve-Euler) Ross



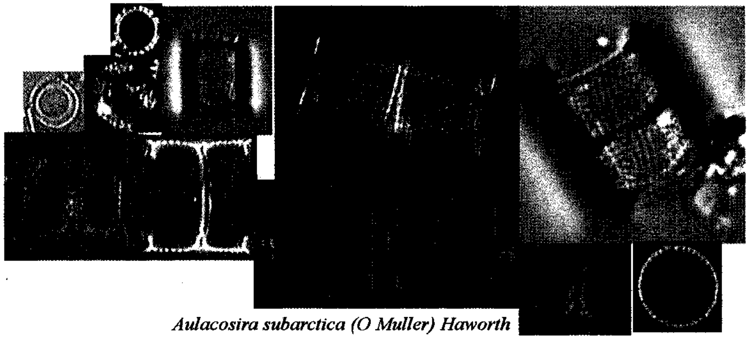
Aulacosira perglabra (Oestrup) Haworth



Aulacosira ambigua (Grunow) Simonsen



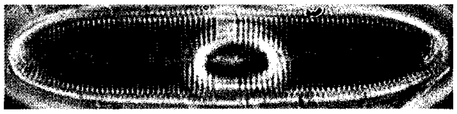
Aulacosira granulata (Ehr) Simonsen



Aulacosira subarctica (O Muller) Haworth

Caloneis bacillum (Grunow) Cleve

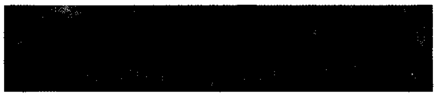
Caloneis undulata (Gregory) Krammer



Caloneis silicula (Ehrenberg) Cleve

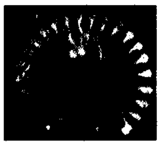
Cocconeis neodiminuta Krammer

Aulacosira valida (Grunow) Krammer

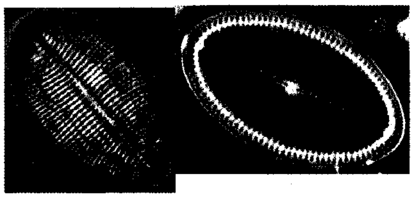


Caloneis bacillaris (Gregory) Cleve

Cocconeis pseudothumensis Reichardt

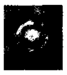


Cyclotella meneghiniana Kutzing



Coconeis placentula var. Placentula

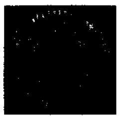
Cocconeis neothumensis Krammer



Cyclotella delicatula Hustedt

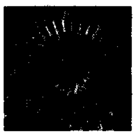
Cyclotella pseudostelligera Hustedt

Cyclotella ocellata Pantocsek



Cyclotella michiganiana

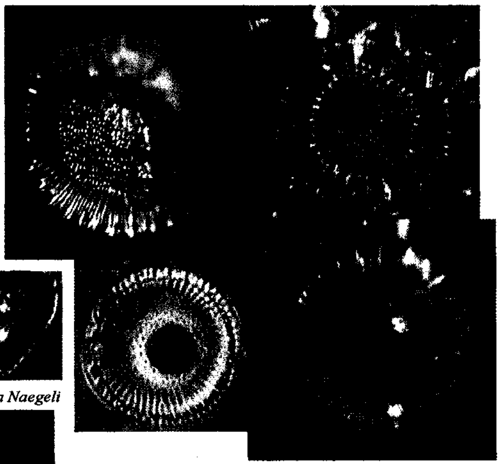
Cyclotela woltereckii Hustedt



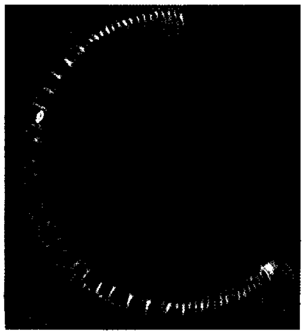
Cyclotella stelligera Cleve and Grunow

Cyclotella rossii (Grunow) Hakansson

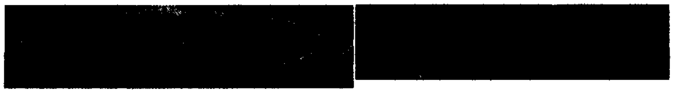
Cymbella amphicephala Naegeli



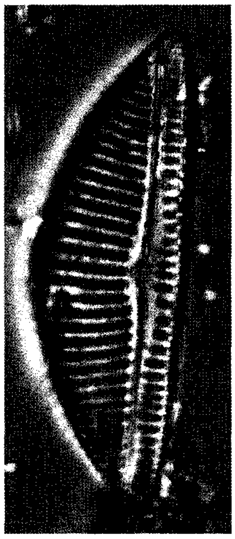
Cyclotella bodanica var aff lemanica



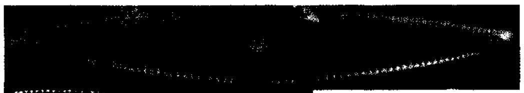
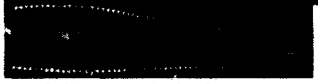
Cyclotella bodanica var. aff. affinis Grunow



Cymbella descripta (Hustedt) Krammer



Cymbella caespitosa (Kutz) Brun

Cymbella cesatii (Rabenhorst) Grunow

Cymbella minuta Hilse

Cymbella reichardtii Krammer

Eunotia praerupta Ehrenberg

Cymbella gaeumannii Meister

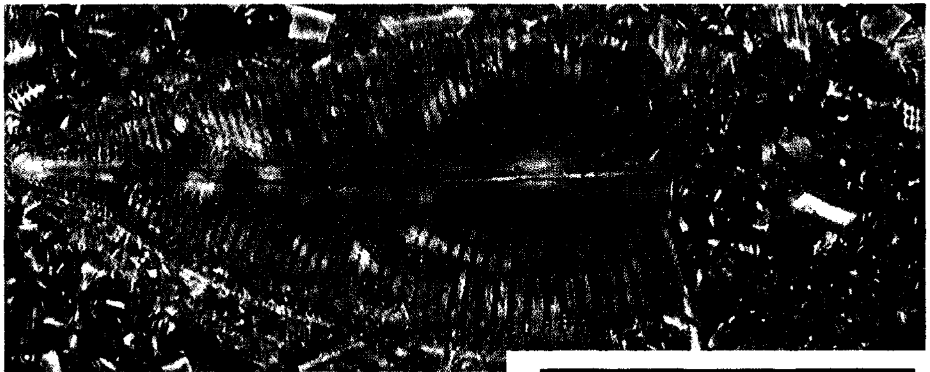

Cymbella gracilis (Ehrenberg) Kutzing

Cymbella hebridica (Grunow) Cleve

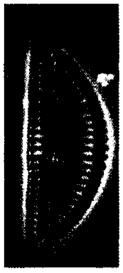
Cymbella minuta var. Pseudogracilis (Cholnoky) Reimer

Cymbella microcephala Grunow

Cymbella perpusilla A. Cleve

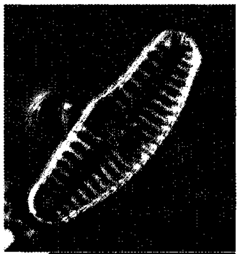


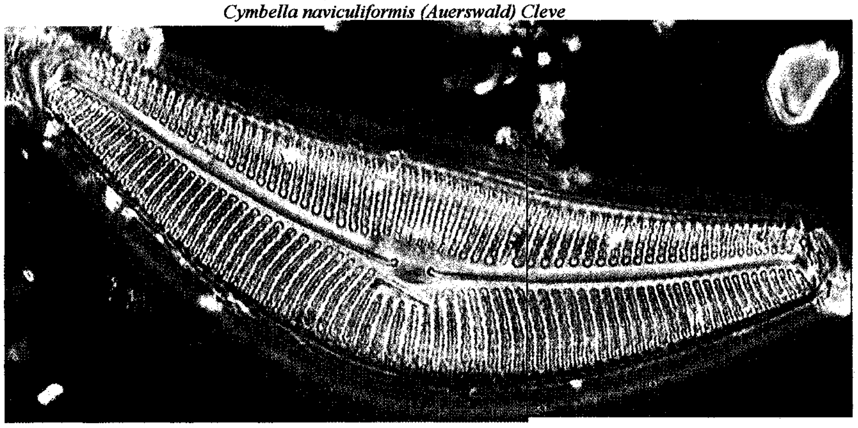
Cymbella heteropleura (Ehrenberg) Kutzing



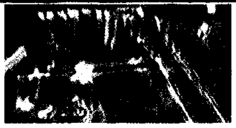
Cymbella silesiaca Bleisch


Cymbella naviculiformis (Auerswald) Cleve

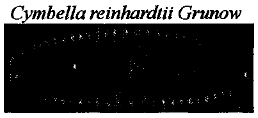




Cymbella proxima Reimer

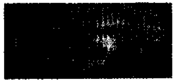


Cymbella reinhardtii Grunow

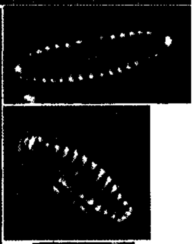


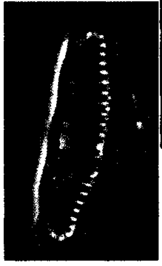
Cymbella subaequalis Grunow

Denticula kuetzingii Grunow

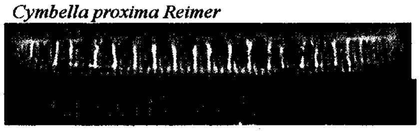


Diploneis marginestriata Hustedt

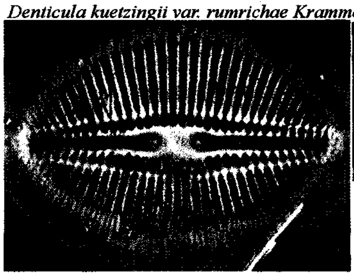





Cymbella sinuata Gregory



Denticula kuetzingii var. rumrichae Krammer



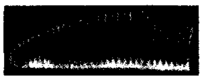
Entomoneis ornata (Bailey) Reimer

Epithemia goeppertiana Hilse

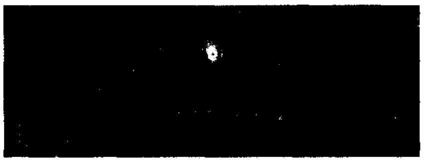
Eunotia cf. arcus Ehrenberg

Diploneis elliptica (Kutzing) Cleve

Epithemia argus (Ehrenberg) Kutzing



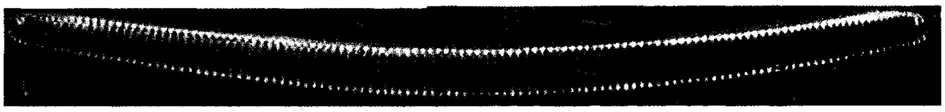
Eunotia incisa Gregory var. incisa



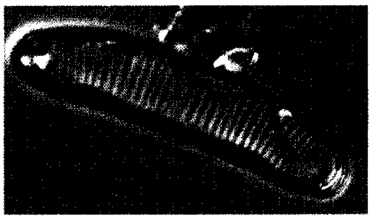
Epithemia smithii Carruthers

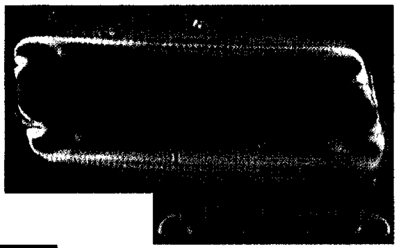
Eunotia intermedia (Krasske) Norpel & Lange-Bertalot

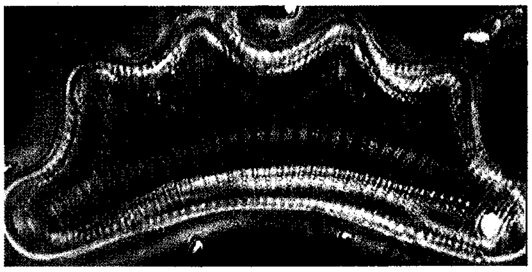
Eunotia circumborealis Norpel & Lange-Bertalot



Eunotia curvata (Kutzing) Lagerst

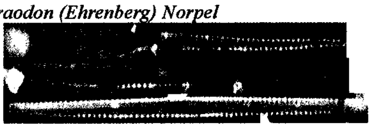

Eunotia praerupta Ehrenberg

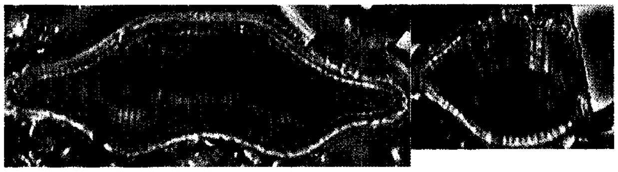

Eunotia rhomboidea Hustedt

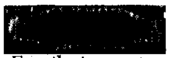

Eunotia serra var. tetraodon (Ehrenberg) Norpel


Fragilaria brevistriata Grunow

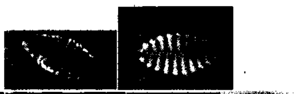

Fragilaria arcus (Ehrenberg) Cleve var. arcus


Fragilaria capucina var. Gracilis (Oestrup) Hustedt


Fragilaria constricta f. stricta Cleve

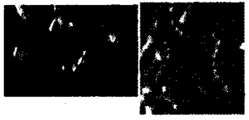

Fragilaria construens var. binodis


Eunotia rhyncocephala Hustedt var. rhyncocephala



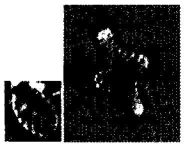
Fragilaria construens var. venter (Ehr.) Grun


Fragilaria exigua


Fragilaria construens (Ehr) Grun f. Construens


Fragilaria crotonensis Kitton

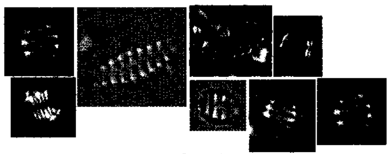

Fragilaria parasitica (W. Smith) Grunow var. Parasitica

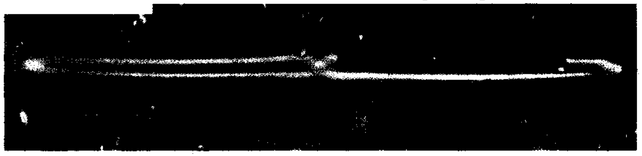

Fragilaria pseudoconstruens Marciniak

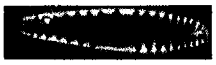

Fragilaria nitzschioides Grunow

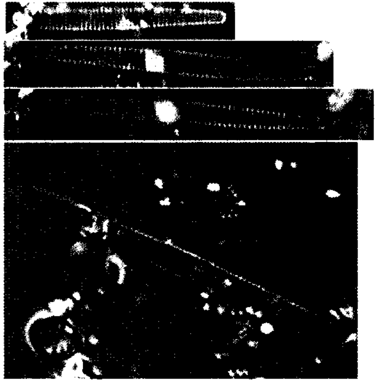

Fragillaria nanana Lange-Bertalot


Fragilaria tenera (W. Smith) Lange-Bertalot

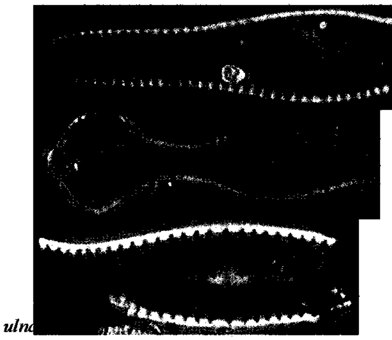

Fragilaria pinnata Ehrenberg


Frustulia rhomboides (Ehrenberg) De Toni

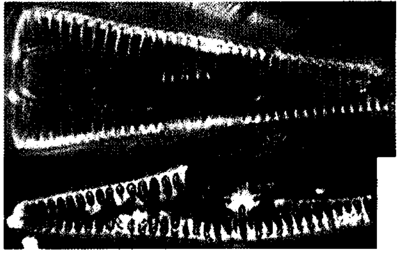

Gomphonema angustum Agardh

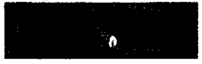

Fragilaria ulna (Nitzsch) Lange-Bertalot var. ulna


Gomphonema angustatum (Kutzing) Rabenhorst


Gomphonema acuminatum Ehrenberg


Gomphonema angustatum var. sarcophagus (Gregory) Grunow


Gomphonema clavatum Ehrenberg

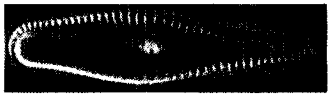

Gomphonema olivaceum var. minutissimum Hustedt

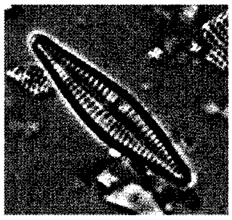

Gomphonema grovei var. lingulatum(Hustedt) Lange-Bertalot

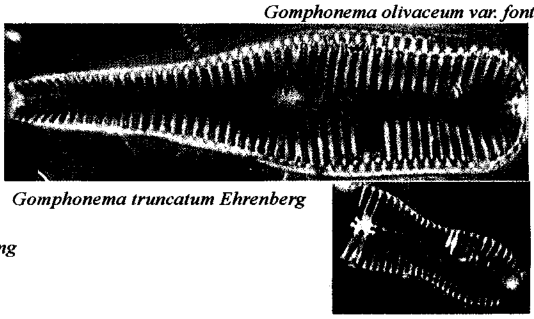

Gomphonema augur Ehrenberg var. augur

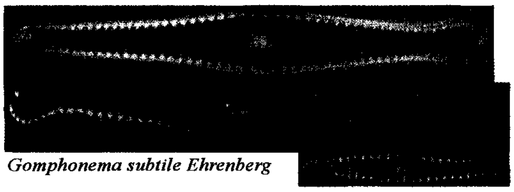

Gomphonema minutum (C. Agardh) C. Agardh


Gomphonema olivaceum var. fonticola Hustedt

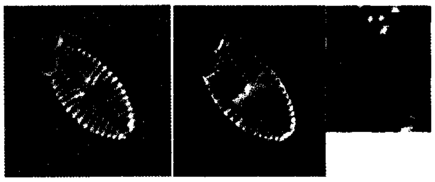

Gomphonema olivaceum (Hornemann) Brebisson var. Olivaceum


Gomphonema parvulumKutzing


Gomphonema truncatum Ehrenberg


Gomphonema subtile Ehrenberg

Gyrosigma acuminatum (Kutzing) Rabenhorst



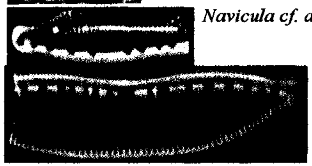
Navicula aboensis (Cleve) Hustedt

Navicula cf. agrestis Hustedt

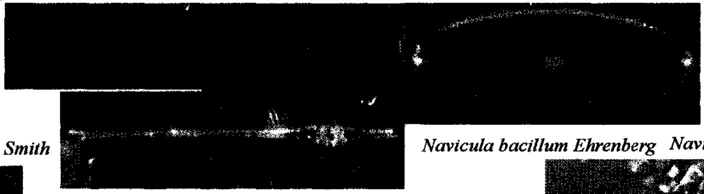
Navicula arvensis Hustedt

Navicula atomus (Kutz) Grunow

Navicula capitata Ehrenberg var capitata



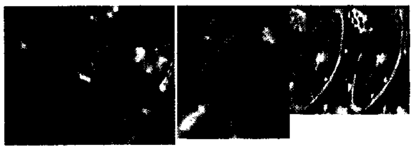
Hantzschia amphioxys (Ehrenberg) W. Smith



Navicula bacillum Ehrenberg

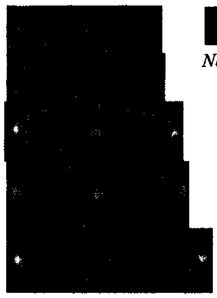
Navicula capitata var. lueneburgensis (Grunow) Patrick

Navicula bryophila Petersen

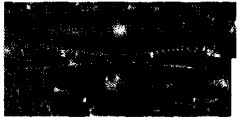


Navicula cocconeiformis fo. elliptica Hustedt

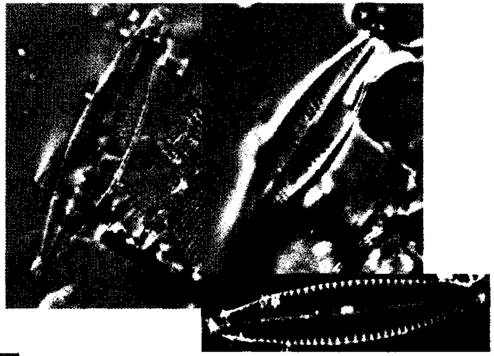
Navicula cocconeiformis Gregory ex Greville



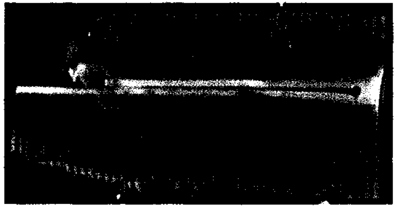
Navicula absoluta hustedt



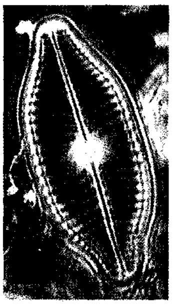
Navicula disjuncta Hustedt



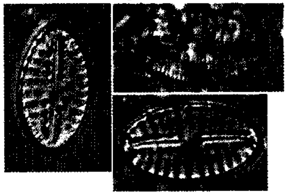
Navicula cf cryptocephala Kutz



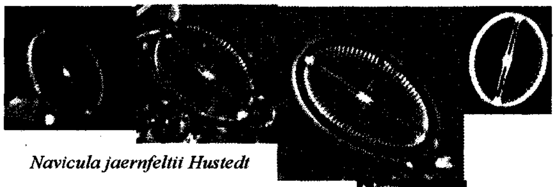
Navicula cuspidata Kutzing



Navicula explanata Hustedt

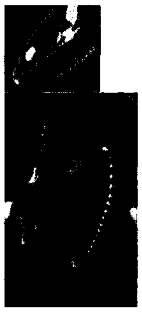


Navicula farta Hust

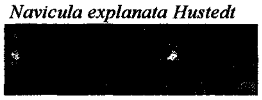


Navicula jaernfeltii Hustedt

Navicula gerloffii Schimanski



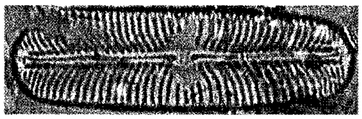
Navicula hambergii Hustedt



Navicula jaagii Meister

Navicula jentzschii Grunow

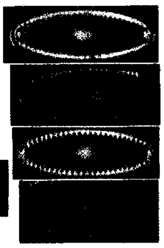
Navicula krasskei Hustedt



Navicula laevissima Kutzing var. laevissima

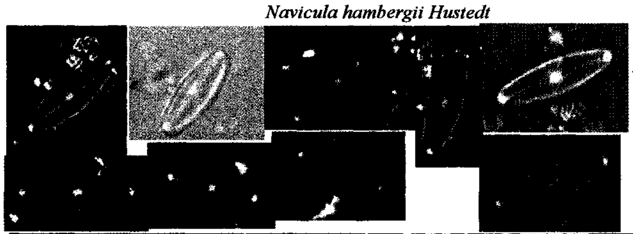
Navicula mediocris Krasske

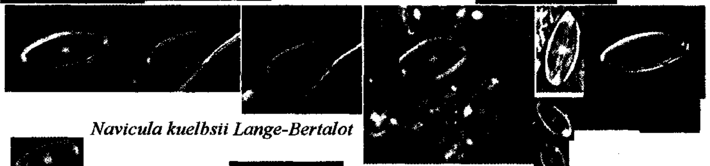
Navicula minusculoides Hustedt



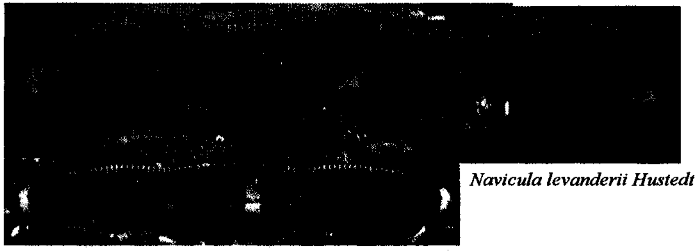
Navicula obsoleta Hustedt

Navicula leptostriata Joergensen

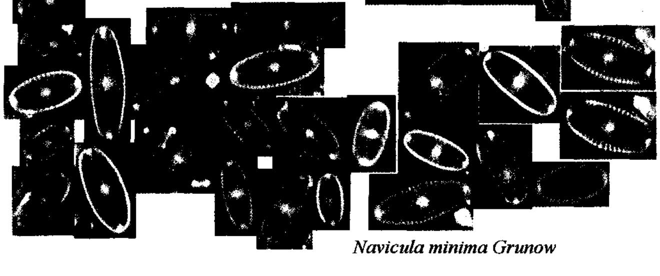




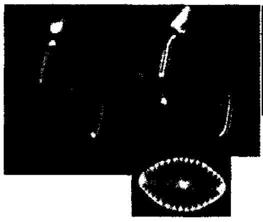
Navicula kuelbsii Lange-Bertalot



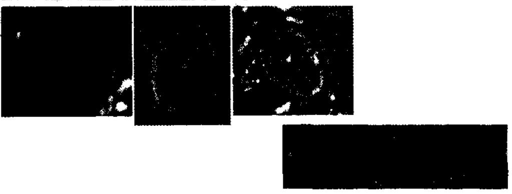
Navicula levanderii Hustedt



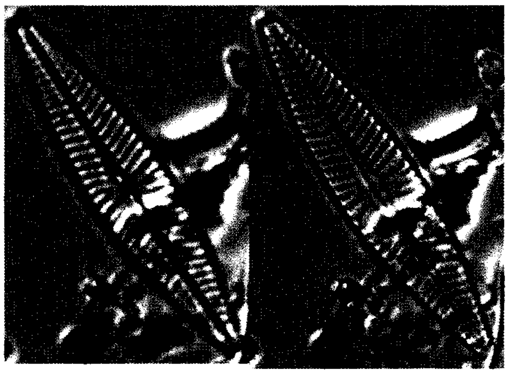
Navicula minima Grunow

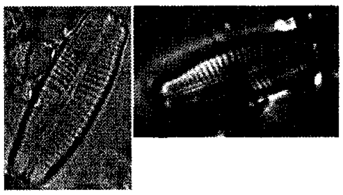


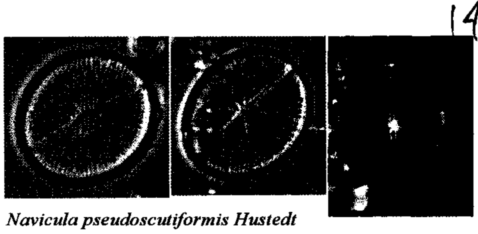
Navicula porifera var. opportunata (Hustedt) Lange-Bertalot

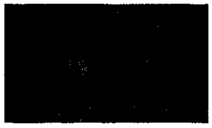


Navicula vitabunda Hustedt


Navicula oppugnata Hust

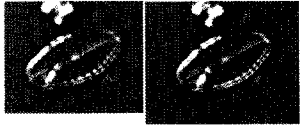

Navicula cf. protracta (Grunow) Cleve


Navicula pseudoscutiformis Hustedt

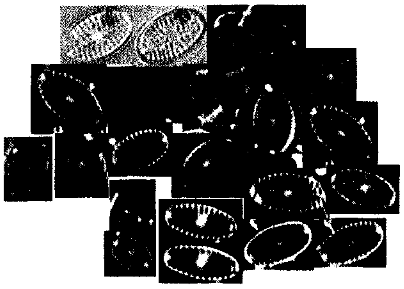

Navicula pusio Cleve


Navicula radiosa Kutzing


Navicula pupula Kutzing var. pupula


Navicula schoenfeldii Hustedt

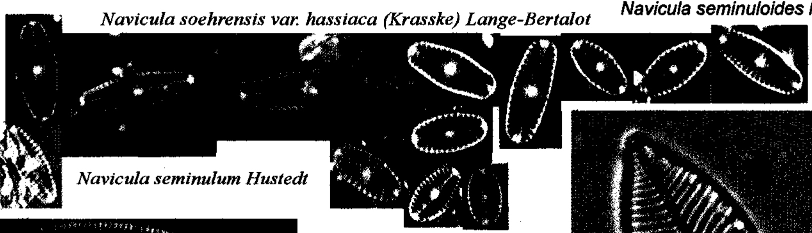

Navicula similis Krasske


Navicula seminuloides Hustedt

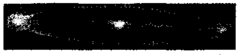

Navicula soehrensis var. hassiaca (Krasske) Lange-Bertalot

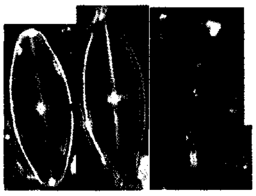

Navicula schmassmannii Hustedt

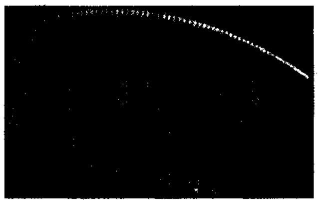

Navicula pupula var. nyassensis (O. Muller) Lange-Bertalot

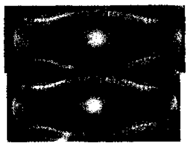

Navicula seminulum Hustedt

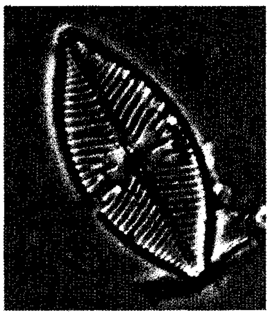

Navicula subminuscula Manguin

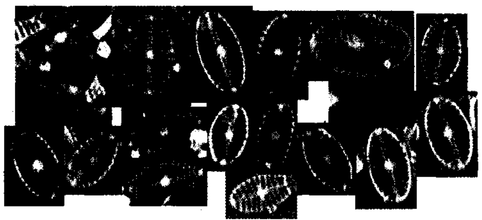

Navicula submolesta Hustedt


Navicula pupula var. mutata (Krasske) Hustedt


Navicula placenta Ehrenberg


Navicula ventralis Krasske


Navicula explanata Hustedt

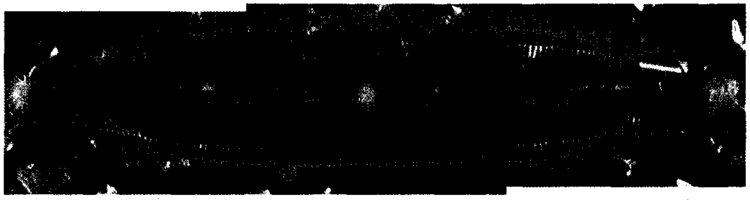

Navicula submuralis Hustedt


Navicula radiosa Kutzing

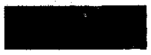

Navicula subrotundata Hustedt


Navicula viridula (Kutzing) Egrenberg var. viridula


Navicula vulpina Kutzing


Neidium ampliatum (Ehrenberg) Krammer

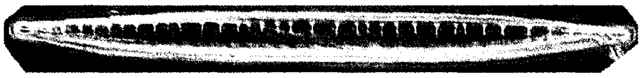

Neidium hitchcockii (Ehrenberg) Cleve


Navicula subtilissima Cleve


Navicula vitiosa Schimanski


Neidium holstii Krammer

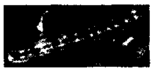
Nitzschia acicularis (Kutzing) W. Smith



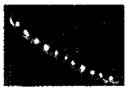
Nitzschia fasciculata (Grunow) Grunow

Nitzschia fonticola Grunow

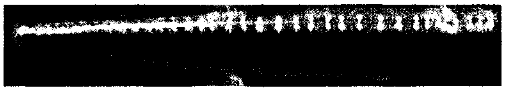
Nitzschia frustulum (Kutzing) Grunow var. frustulum



Nitzschia dissipata (Kutzing) Grunow var. dissipata



Nitzschia inconspicua Grunow



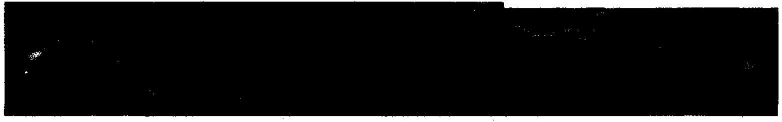
Nitzschia recta Hantzsch

Nitzschia cf. rostellata Hustedt

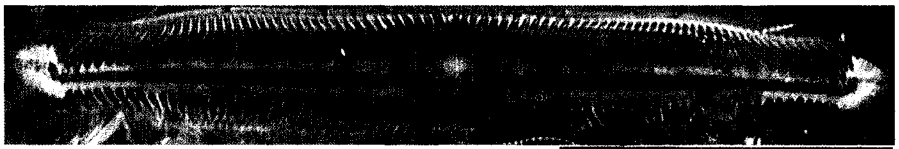
Nitzschia valdestriata Aleem & Hustedt

Pinnularia rupestris Hantzsch

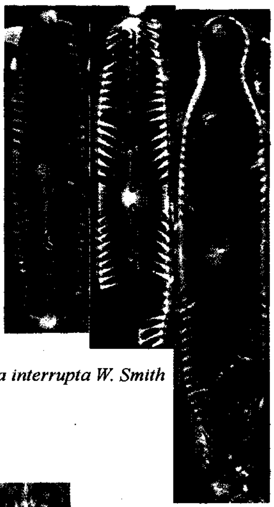
Pinnularia abaujensis var. linearis (Hustedt) Partick



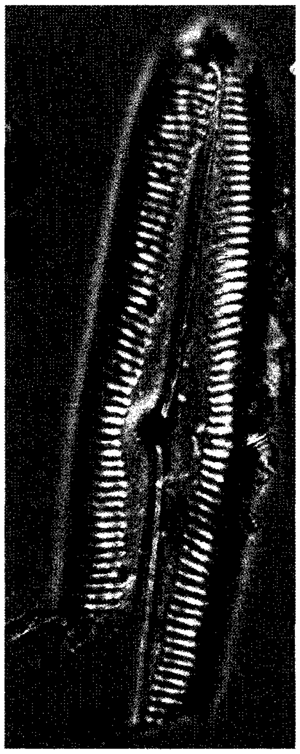
Pinnularia brandelii Cleve



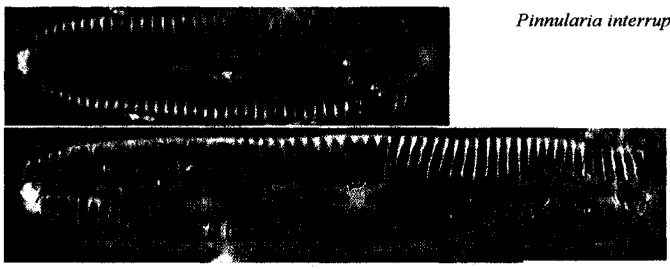
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt



Pinnularia interrupta W. Smith



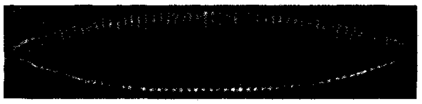
Pinnularia hemiptera (Kutz) Rabenh



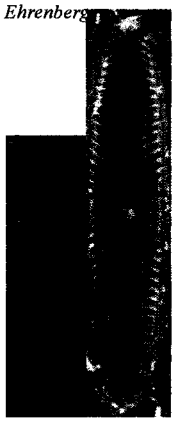
Pinnularia viridis (Nitzsch) Ehrenberg

Pinnularia subcapitata Gregory

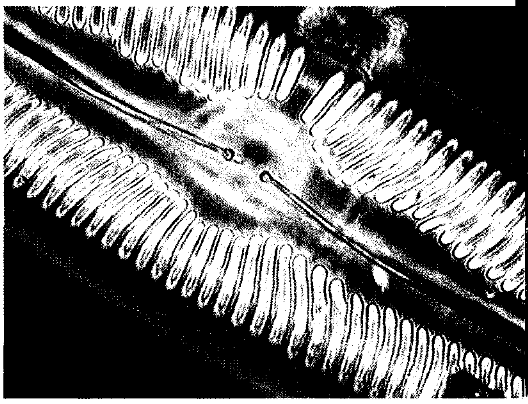
Pinnularia borealis Ehrenberg

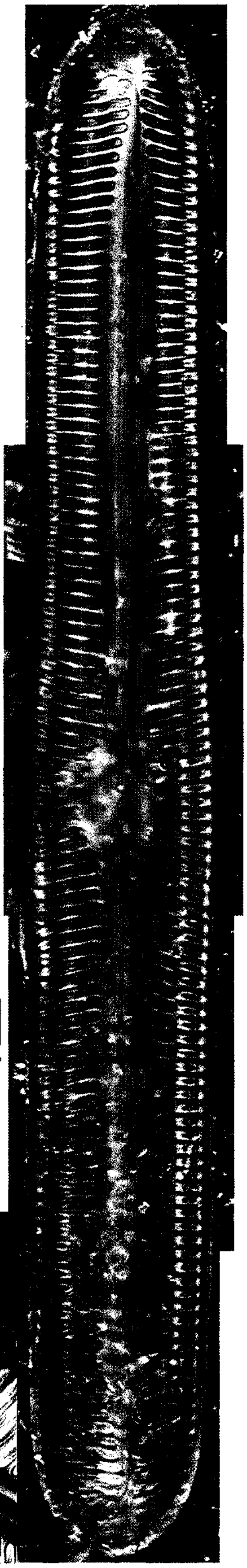


Nitzschia ansustata (W. Smith) Grunow

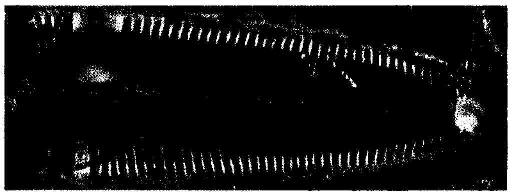


Pinnularia microstauron (Ehrenberg) Cleve

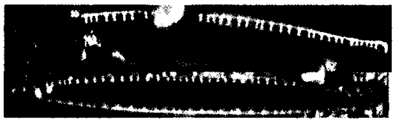




Pinnularia major (Kutzing) Rabenhorst



Pinnularia wisconsinensis Camburn & Charles

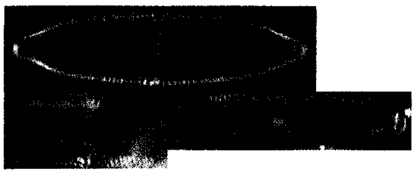


Nitzschia pseudofonticola Hustedt

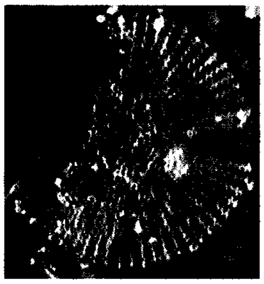
Rhopalodia gibba (Ehrenberg) O. Muller var. gibba

Stenopterobia delicatissima (Lewis) Van Heurck

Stephanodiscus chantaicus Genkal and Kuzmina



Stauroneis anceps var. siberica Grunow

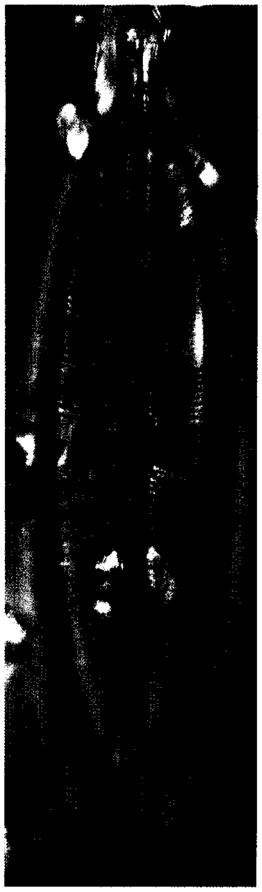


Stephanodiscus cf. alpinus

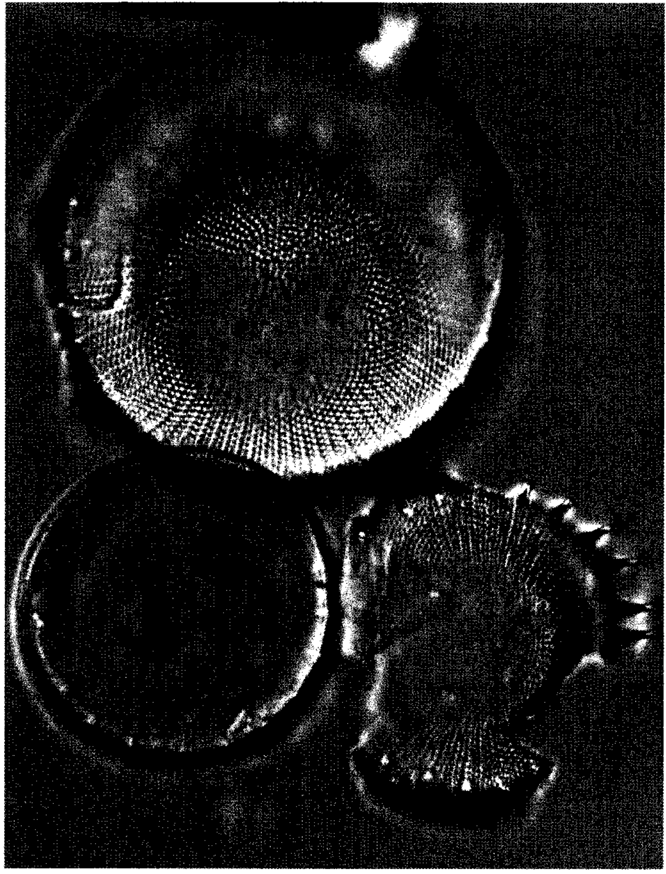
Stephanodiscus minutulus (Kutzing) Cleve & Moller

Stephanodiscus medius Hakansson

Stephanodiscus hantzschii Grunow



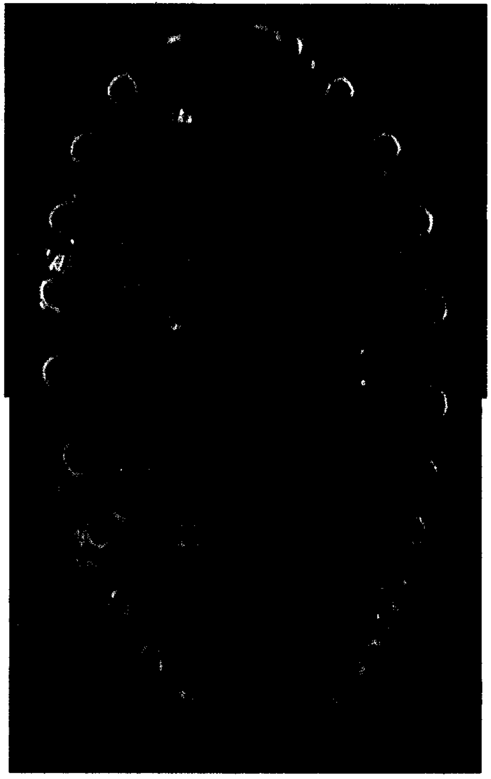
Stauroneis phoenicenteron (Nitzsch) Ehrenberg



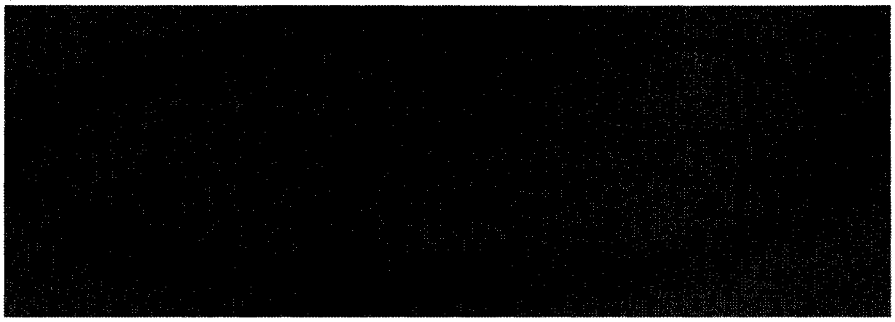
Stephanodiscus niagarae Ehr

Surirella cf lapponica Cleve

Surirella didyma Kutzing

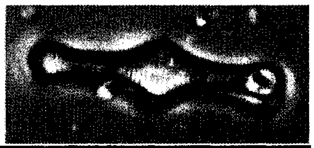


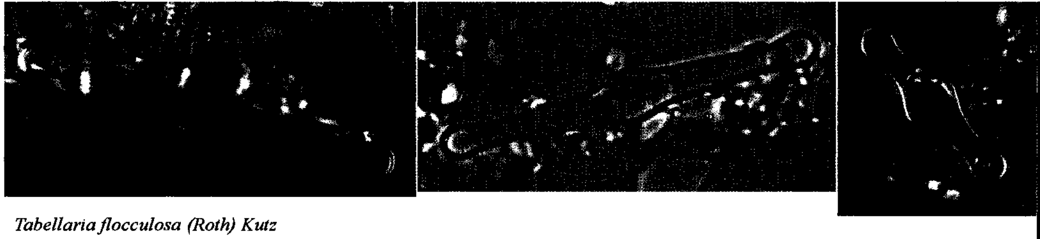
Surirella gemma Ehrenberg

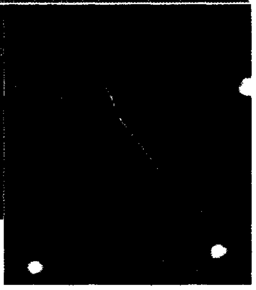


Surirella robusta Ehrenberg (600x)

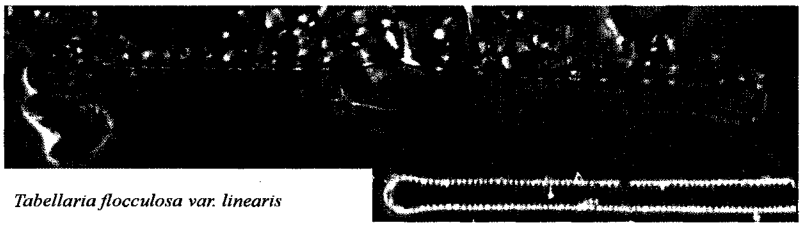
Mallomonas heterospina







Tabellaria flocculosa (Roth) Kutz



Tabellaria flocculosa var. linearis