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Biomonitoring Using Diatoms and Paleolimnology in the Western Great Lakes National Parks

Natural Resource Technical Report NPS/GLKN/NRTR—2011/447

ON THE COVER
Background: Lake Harvey, Isle Royale National Park, Michigan. Inset (r-l): coring at Lake Ahmik (Isle Royale), sediment core cross-section, an entire vertical core sample, and diatoms from Great Lakes Network parks. Photos by Joan Elias and Mark Edlund.

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Natural Resource Technical Report NPS/GLKN/NRTR—2011/447

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Abbreviations Used in This Report

aff and/or *cf*	(Latin *affinis* / *conferre*) – having affinity with, like, similar to
APIS	Apostle Islands National Lakeshore
BSi	biogenic silica
Ca	calcium
CA	correspondence analysis
CCA	canonical correspondence analysis
Chl *a*	chlorophyll *a*
Cl	chloride
DCA	detrended correspondence analysis
DOC	dissolved organic carbon
EC25	specific conductance normalized to 25°C
EMAP	Environmental Monitoring and Assessment Program
GLKN	Great Lakes Network
GPS	global positioning system
GRPO	Grand Portage National Monument
HCl	hydrochloric acid
INDU	Indiana Dunes National Lakeshore
ISRO	Isle Royale National Park
K	potassium
Mg	magnesium
MISS	Mississippi National River and Recreation Area
N	normality, gram equivalents per liter of solution
NA	numerical aperture
NAWQA	National Water Quality Assessment
Pb	lead
pCi/g	measure of radioactivity by sample weight, picoCurie (pCi) per gram
PCA	principal components analysis
PIRO	Pictured Rocks National Lakeshore
QA/QC	quality assurance/quality control
SACN	St. Croix National Scenic Riverway
SiO_2	silicon dioxide, "silica"
SLBE	Sleeping Bear Dunes National Lakeshore
TMDL	Total Maximum Daily Load
TN	total nitrogen
TP	total phosphorus
µS/cm	measure of specific conductivity within a solution, microSiemens (µS) per cm
USEPA	United States Environmental Protection Agency
UTM	universal transverse meridian
VOYA	Voyageurs National Park
WA	weighted averaging
WQ	water quality

Abstract

A biomonitoring approach was developed for the Great Lakes Network (GLKN) parks to analyze diatom communities in lake, river, and lagoon sediments in an inventory and monitoring framework. We used combined analysis of sediment cores in the GLKN park lakes with repeated sampling of modern sedimented diatom communities and water quality monitoring to determine historical biological and water quality change, modern biological change, and the potential drivers of change. Thirteen sediment cores from GLKN lakes were analyzed for changes in geochemistry and diatom communities from ca. 1800 A.D. through the 2000s A.D. Surface sediments were collected from more than 60 lakes in the GLKN parks in conjunction with water quality monitoring to document the modern diatom assemblages and determine the abiotic gradients (conductivity, pH, and total phosphorus) that independently control diatom abundance and distribution in the GLKN parks. Weighted averaging models were developed that use sediment diatom assemblages to quantitatively estimate pH, total phosphorus, and conductivity. Models were applied to sediment cores to determine the background or reference condition of lakes and assess the extent and timing of change in each lake. Biological change was estimated over two time periods in the sediment cores using the squared chord distance between pre-Euro-American settlement and modern diatom communities and between diatom communities deposited at the time of each park's formation and modern diatom communities. Last, surface sediment diatom communities in two parks were resampled in 2008 and 2009 to determine the amount of diatom community change since 2005.

Results show that most of the GLKN park lakes that had long sediment cores analyzed did not show significant change in diatom-inferred water quality parameters during the last 200 years. In contrast, most lakes showed periods of biological change based on diatom microfossil analysis. Lakes that showed significant changes in diatom-inferred water quality were primarily located in SLBE and included changes in conductivity (Manitou, Florence, Shell, Bass), and pH (Manitou, Bass). The timing of the water quality shifts at SLBE was consistent with the development of farming in the region and may be related to hydrological changes associated with land clearance. The first biological shifts recorded in cores from GLKN lakes took place from the 1870s through the 1930s coincident with Euro-American settlement in the region and in most lakes the shifts represented the largest diatom community change in the last 200 years. Concomitant with biological shifts in the GLKN lakes were geochemical shifts, notably increased sedimentation rates and inorganic content of many cores. These changes were likely a result of enhanced erosion due to land clearance, changes in runoff, and potentially changes in lake levels.

In most lakes we also resolved a secondary biological shift in the sediment cores that took place as early as the 1950s and as late at the 2000s, with many lakes showing change from the 1970s to 1980s. The biological changes cannot be easily ascribed to known land use changes, although some lakes exhibited their secondary shifts concurrent with park formation (e.g., Grand Sable Lake at PIRO). Regardless, in no case did the GLKN lakes return to a reference (pre-Euro-American) biological community while under NPS management and protection. Alternatively, the secondary shifts in diatom communities may be related to climate change. Because these lakes are spread across a wide geographic region, and are in relatively pristine and protected areas, climate may be driving observed ecological changes in the lakes. Climate-linked mechanisms of recent ecological change included 1) shorter duration of ice cover, which leads to

earlier warming of surface water, earlier stratification, and longer growing seasons, and 2) increased frequency or intensity of summer storms, which may lead to increased availability of nutrients when lake waters mix more frequently. Changes in abundance of *Aulacoseira*, *Fragilaria crotonensis*, small fragilarioid species, and the planktonic cyclotelloid species adhered to these models of limnological and ecological response to climate warming and were similar to biological changes seen in many lake sediment records from arctic, alpine, and temperate boreal lakes.

The repeat sampling of surface sediment diatom assemblages was also tested as a biomonitoring approach in GLKN lakes. Floristic change was calculated between repeat surface samples from PIRO (collected 2008) and SLBE (collected in 2009) lakes by comparing to surface samples collected in 2005 from the same lakes. Many of the lakes showed very large and unexpected floristic changes between 2005 and 2008/2009. Although these changes may represent unprecedented recent change in the GLKN lakes, we also suggest that lake-specific sampling approaches should be implemented to ensure that 3-5 years of sedimented diatom communities are collected during future repeat surface sediment sampling.

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Introduction

In the water-rich Great Lakes Network (GLKN) park units, climate change, environmental contaminants, exotics, and land and resource uses including shoreline and urban development, recreation, water level management, logging, and agriculture have raised concerns about the state of the parks' resources and how to best manage them in a future certain to bring change. The Great Lakes Inventory and Monitoring Network has been charged with designing and implementing long-term ecological monitoring programs to periodically assess critical resources, evaluate the integrity of park ecosystems, and understand ecosystem processes.

An underutilized resource for environmental monitoring programs has been the sediment record of lakes and rivers. Depositional zones in lakes and rivers usually accumulate sediments in conformable patterns and act to spatially and temporally integrate samples that can be analyzed for biological and chemical proxies of environmental change. Because of conformable accumulation patterns, the sediment record can be sampled on multiple temporal scales to address specific monitoring goals. For example, the near-surface sediment record provides an integrated sample that can be used to characterize recent environmental activity in a lake. Repeat sampling of near surface sediments on intra-, inter-, and multiannual scales provides a timeline of ecological activity that can be used in a monitoring program (Stoermer et al. 1996).

However, it is the long-term sediment record that has proven to be a most valuable tool for understanding ecological change. With any environmental monitoring program a basic understanding of natural fluctuations within the monitored system is important. Reliable long-term water quality or biological data sets, on the order of 30 to 50 years, are generally not available for most regions of the country. Use of paleolimnology offers an opportunity to reconstruct missing long-term data sets. We can estimate past conditions and natural variability, identify changes, and determine rates of change and recovery through the use of paleolimnological techniques and quantitative environmental reconstruction. This type of information allows managers and researchers to put present environmental stresses and change into perspective with the natural variability of the system. Paleolimnology can also be used to determine response to and recovery from short-term disturbances. Background information on natural variations is particularly important in areas of low impact, such as wilderness areas. Such information makes it possible to identify early signs of unusual disturbance and allows for early action toward remediation or restoration.

Among the organisms used for biological monitoring of aquatic systems (lakes, rivers, wetlands, and estuaries), diatoms are one of the most powerful indicators of environmental conditions. Diatoms represent one of the common groups of microscopic algae and are found in most marine, freshwater, and even temporary aquatic habitats. Diatoms are characterized by having a two-part cell wall, which fits together like a Petri dish or pillbox, and is made of biologically produced glass, or biogenic silica (BSi). Most species can be positively identified based on the shape and ornamentation of their cell walls, which are specially prepared and mounted on microscope slides for analysis using light microscopes. However, because diatoms have not been studied in many parts of the world, it is still common to encounter specimens that cannot be positively identified. In that case, researchers routinely assign a provisional name or identification to the specimen(s) until they can be formally described as new species in the scientific literature.

Most diatoms live as individual cells; however, many genera are commonly found growing in filaments, band-shaped colonies, as tufts of cells attached to a substrate, or invested within a mucilage. Species that are free-floating within the water are called planktonic. Ironically, freshwater diatoms are heavier than water, thus planktonic species generally require some turbulence to stay suspended, which makes planktonic diatoms most abundant during periods of lake turnover in the spring and fall. Species that are attached to substrates are referred to as periphytic and can lie flat (adnate), adhere with a mucilage pad, produce and live at the end of mucilage stalks, or are motile on the surface of substrates. The periphytic diatoms can be broken down further based on their ecology and association with substrates. Benthic diatoms live on the bottom of lakes and rivers, epiphytic diatoms live on plants, epilithic species are associated with rocks and cobbles, epipelic species live on mud or fine grained sediments, and epipsammic diatoms live attached to sand grains. Tychoplanktonic species are often entrained into the plankton but can also live on substrates when they settle out of the water column.

Diatoms can be separated into several morphological groups that also correspond to their general ecological preferences. The morphological groups do not explicitly adhere to recognized phylogenetic or evolutionary groups, but offer a relatively simple breakdown of diatoms by shape, motility, and symmetry. The morphological groups are initially separated into species that are radially symmetric (symmetry about a point) or bilaterally symmetric (symmetry about a line). The radially symmetric species are called the centric diatoms and the bilaterally symmetric species are called the pennate diatoms. The centric diatoms (e.g., *Aulacoseira*, *Stephanodiscus*, *Cyclotella*, *Discostella*) mostly live as individual cells that are shaped like a hatbox or as filaments constructed like barrels placed end to end. Centric diatoms are sometimes separated into smaller groups based on several groups of genera, e.g., the cyclotelloids (*Cyclotella*, *Discostella*, *Puncticulata*), the stephanodiscoids (*Stephanodiscus*, *Cyclostephanos*). The centrics do not have the ability to move and are most commonly found living free-floating in the plankton of lakes and larger rivers. Apart from the centric diatoms, the other common planktonic diatoms belong to a group of bilaterally symmetric diatoms that are called the araphids. The planktonic araphids are generally long, thin forms, or live as band shaped colonies. Other araphid groups live attached to plants, rocks, or sand and are often grouped together as benthic araphids. The araphid diatoms do not have the ability to move because they lack a structure called a raphe. The raphe is a thin groove that runs along the length of some diatoms and imparts motility. Mucilage strands are extruded from the cell through the raphe slit and stick to whatever substrate the diatom is on; by moving the mucilage strands along the raphe, the diatoms can actively move across a substrate. Diatoms that have a raphe are referred to as the "raphid" diatoms are generally bilaterally symmetric and live as individual cells that are often motile and associated with substrates. Modifications of the raphe system provide the final breakdown of diatom groups. Diatoms with a raphe on only one of their valves or cell halves are called the monoraphids (e.g., *Achnanthidium*, *Cocconeis*), diatoms with rudimentary raphe systems are called the eunotioid diatoms as the group is typified by the genus *Eunotia*; the eunotioids are most diverse in low pH systems. The naviculoid diatoms (e.g. *Navicula*, *Stauroneis*) are bilaterally symmetric on their long and transverse axes, where as the gomphocymbelloid diatoms (named for the genera *Gomphonema* and *Cymbella*) are curved or wedge-shaped and symmetric about only their long or transverse axis. The latter group commonly grows attached to substrates using mucilage stalks. Finally the keeled diatoms have their raphe systems modified into specialized wing or keel. The keeled diatoms are often associated with fine-grained sediments and can move very quickly. Keeled diatoms are sometimes separated into smaller groups based on several segregate genera: the nitzschioid (*Nitzschia*, *Hantzschia*), epithemioids (*Epithemia*), and surirelloids (*Surirella*, *Cymatopleura*, and *Campylodiscus*).

Many state, federal, and foreign agencies use diatoms as water quality (WQ) monitoring tools. In the US, the federal Environmental Monitoring and Assessment Program (EMAP) and National Water Quality Assessment (NAWQA) programs (Hunsaker and Carpenter 1990, Dixit and Smol 1994) employ diatoms to assess biotic integrity of surface waters. The USEPA has maintained a sampling and monitoring program on the Great Lakes for more than 20 years to assess annual variability, response to ecological change, and long-term impacts. States, including Kentucky, Minnesota, Wisconsin, and Montana, actively use diatoms to assess stream quality and reference conditions of lakes, and as supporting evidence for developing nondegradation standards, site-specific management plans, and EPA-mandated Total Maximum Daily Loads (TMDLs) and nutrient criteria (Kentucky Department of Environmental Protection 2002, Heiskary et al. 2004). These programs have capitalized on several attributes of diatoms that make them powerful biological indicators, including:

- The sensitivity and tolerance of diatoms to environmental variables – including nutrients, organic pollutants, pesticides, heavy metals, salinity (and major ion chemistry), pH, alkalinity, light, temperature, substrate, and depth – are known to vary among diatom species (Battarbee et al. 2001). These species-specific responses can be used to infer environmental conditions and provide an early-warning on the cumulative impacts of environmental change at the base of aquatic foodwebs. Through innumerable lab (e.g., resource competition experiments) and field (correlative and experimental, e.g., bioassay) studies, the environmental requirements and responses of many diatom species are well established, so much so that diatom assemblages can be numerically transformed using well-established multivariate techniques, into quantitative estimates of environmental variables such as pH, TP, salinity, and DOC (Fritz et al. 1999).

- Diatoms occur in highly diverse assemblages in almost all aquatic habitats, and species are relatively easily distinguished unlike other algae and invertebrates that are often identified to the level of genus or family (at best). Taxonomic resolution is critical to linking the occurrence/abundance of organisms and their environmental requirements. The taxonomic diversity of diatom communities provides a high level of redundancy (confirmation by responses from multiple species) for robust tracking of environmental conditions.

- Diatom life histories are dominated by asexual reproduction with high rates of cell division – on the order of one division every one to four days. As such, diatoms rapidly respond to changes in environmental conditions with both species-level and community-level shifts.

- Cell walls of diatoms are composed of biogenic opaline silica and are readily preserved in most sedimentary deposits and environments. Furthermore, diatom samples are easily archived and preserved semi-indefinitely (freeze-dried bulk samples, processed samples, or samples mounted on microscope slides), allowing samples to be re-examined at future dates, if desirable.

- Diatoms have been used extensively to assess past and present environmental conditions in freshwaters. Literally dozens of papers are published each year in peer-reviewed journals describing analytical and numerical (statistical) methods, taxonomic refinements, environmental requirements, paleo-environmental reconstructions, and applications in water-quality issues and policy development (Stoermer and Smol 1999). Diatoms are currently being used in both state (e.g., Minnesota, Montana) and national (EMAP, NAQWA) assessments of water quality.

Like other groups of organisms that are used in biomonitoring, diatoms serve as water quality indicators by responding to environmental stressors with changes in community composition (presence and abundance of different species). In some cases, the stressors may be clearly identifiable because of the response of particularly diagnostic species or groups (e.g., small *Stephanodiscus* species that faithfully record phosphorus enrichment), or because of a clear correlation with known or measured environmental impacts (e.g., agricultural intensification within the watershed). In other cases, the stressor may be unknown and quite possibly unanticipated, but due to the diverse ecological tolerances of different diatom species, an impact will be recorded by a change in community composition. This is precisely the reason that biomonitoring is used as an adjunct to (not a replacement for) direct measurement of physicochemical variables – because one can never anticipate nor directly measure all future water quality impacts. Subsequent analysis may reveal what causes a diatom community to change, but community change itself serves as an early warning that something has happened. In this respect, the use of diatoms as bioindicators is no different from that of any other group of organisms (e.g., benthic invertebrates).

In lake environments, especially in the sediments, diatoms are commonly used as biological indicators of change (Stoermer and Smol 1999). Diatoms have a proven ability to track past environmental change based on paleolimnological analysis of sediment cores (e.g., Smol 1995). Deep-water sediments provide a highly integrated sample of diatom community structure for the lake as a whole (Wolin et al. 1988). Sedimentary processes collect and mix diatoms from all habitats within the lake (plankton, periphyton, epilithic, epipelic) and deposit them in a uniformly mixed assemblage across deeper regions. This means that only a single sample of surface sediment is needed to characterize the entire lake (Anderson 1990) – as compared to the numerous samples required to overcome spatial heterogeneity for other bioindicators (e.g., benthic invertebrates). Sampling and numerical and taxonomic analysis of these subfossil assemblages are virtually the same as those used to monitor present-day lake conditions with diatoms denoting that present-day monitoring can be linked directly with past lake conditions using similar methods, quality assurance/quality control (QA/QC), and interpretation. The ability to place present day conditions and future trends in the context of background conditions and natural variability sets diatom biomonitoring apart from almost any other bioindicator.

The purpose of this project is to develop diatom-based biomonitoring for the GLKN parks that combines a traditional water quality monitoring program with analysis of repeatedly sampled diatom communities preserved in the surface sediments of the GLKN lakes. To provide context to changes in the diatom communities between samplings, we consider change in both a historical and modern framework. The historical context is considered using geochemical and diatom analysis of one to four sediment cores from each park unit to estimate natural variability, reference conditions, and the timing and magnitude of changes in each lake for the last 200 years. The modern context uses the development of a calibration or training dataset of more than 60 surface sediment diatom communities and mean annual water quality measures from GLKN lakes to analyze the relationship between modern diatom species abundance and water quality and environmental parameters. Based on the species-environment relationship, models called transfer functions are developed to quantitatively estimate water quality parameters from diatom communities. As such, biological and water quality changes can be resolved using repeated sampling of surface sediment diatom communities in GLKN lakes. This project directly addresses the goals and science-based results criteria of the GLKN inventory and monitoring program. Project results will be used to determine the status and trends of selected bioindicators in park ecosystems, provide early warning and identification of potential causes of abnormal aquatic resources conditions and better understanding of the dynamic nature and condition of aquatic ecosystems, and serve as historical reference points or conditions for comparisons. Results can be used to measure progress towards performance goals of specific management decisions.

In this report, we summarize the development of the diatom biomonitoring program using integration of paleolimnological techniques with modern water quality and diatom community analysis in an inventory and monitoring framework; the outcome of this combined approach will facilitate future biomonitoring using diatoms. Results of this report and earlier protocols (Elias et al. 2008, Ramstack et al. 2008) provide a model for combining traditional physico-chemical monitoring with diatom-based biological monitoring of sediment assemblages. The model is linked to a management foundation by determining the natural variability or reference condition of national park lakes from reconstructing a detailed history of lake response to ecological changes in and around the lakes during the last 150 to 200 years. And because lake-sediment records integrate across both spatial and temporal scales, research results will be used as a biomonitoring strategy by revisiting lakes on regular intervals (three to five years) to quantify modern environmental conditions relative to historical conditions, detect early ecological change and recent trends, and evaluate success of management actions.

Methods

Water Quality Sampling and Site Selection

To understand the relationship between water quality and the distribution and abundance of diatoms in the GLKN parks for biomonitoring purposes, physical and water chemistry parameters were measured in each park unit in conjunction with surface sediment core collection for diatoms (Elias et al. 2008, Ramstack et al. 2008) (Figure 1). A set of 33 index lakes were selected for water quality and surface sediment diatom monitoring based on deletion or preference criteria outlined in Elias et al. (2008). Lakes were selected at each park that are spatially distributed throughout each park and span gradients of chemical and physical parameters, visitor use, and watershed area. Some lakes are of particular interest to a park. We selected the downstream lake of those lakes connected via stream or channel, as it serves as an integrator of its drainage system. In addition to the index lakes identified for long-term annual water quality monitoring (Elias et al. 2008), water quality and sediments from other lakes and depositional sites along rivers in the GLKN parks were sampled to better capture the range of lake/river types and biological communities.

Figure 1. Locations of the nine Great Lakes Inventory and Monitoring Network national park units.

In sum, 60 sites were sampled representing four bays and lagoons from Apostle Islands National Lakeshore (APIS; Figure 2), one lake from Indiana Dunes National Lakeshore (INDU; Figure 3), nine lakes from Isle Royale National Park (ISRO; Figure 4), three sites at Mississippi National River and Recreation Area (MISS; Figure 5), six lakes at Pictured Rocks National Lakeshore (PIRO; Figure 6), five sites at St. Croix National Riverway (SACN; Figure 7), nine lakes at Sleeping Bear Dunes National Lakeshore (SLBE; Figure 8), and 22 lakes at Voyageurs National Park (VOYA; Figure 9) (Table 1). Most PIRO and SLBE sites were sampled in 2005; VOYA, INDU, and MISS were sampled in 2006; and APIS, SACN, and ISRO in 2007 (Table 1). Little Trout Lake (VOYA) was sampled in two different years (2006 and 2007); both sets of water quality and sediment samples were included in the development of the diatom-environment calibration set. To examine biological change through time, four lakes at PIRO were resampled in October 2008 and eight lakes were resampled in April-June 2009 (see Repeat or Future Sampling, below).

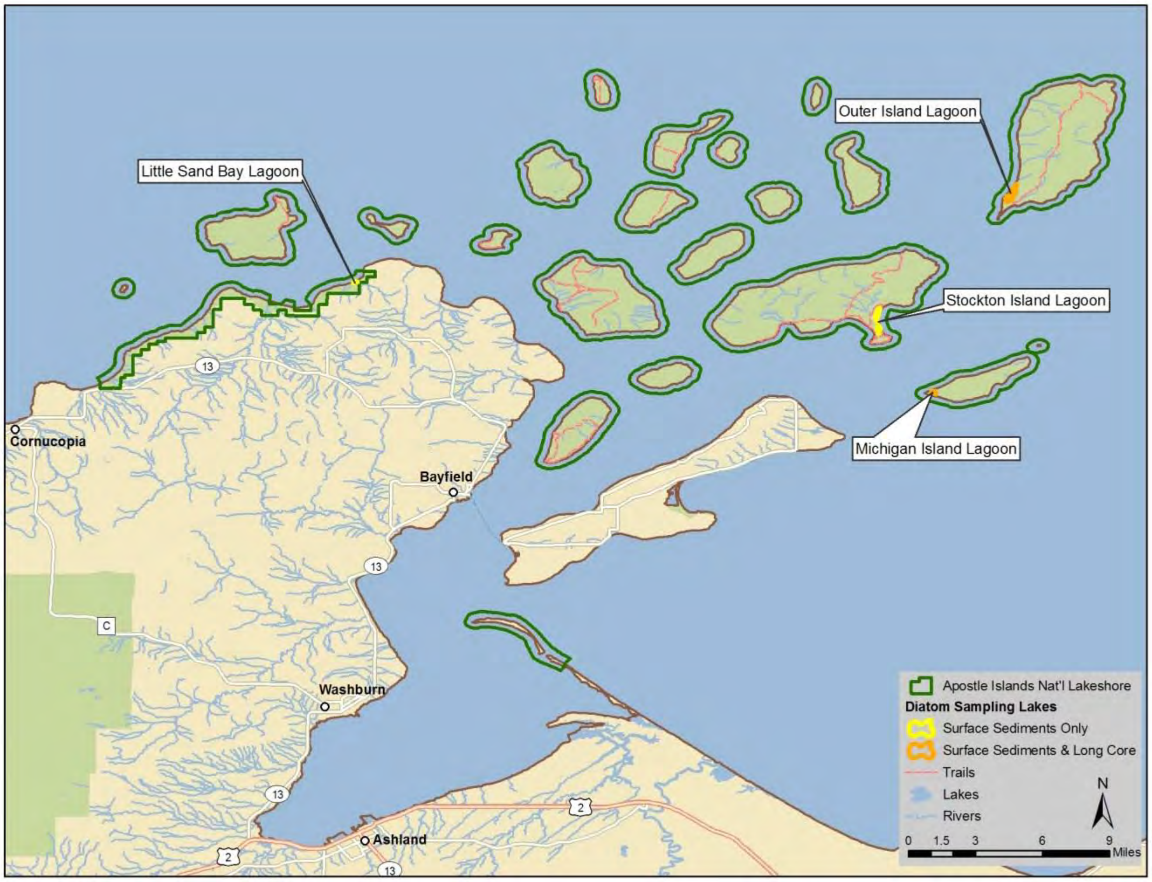


Figure 2. Apostle Islands National Lakeshore, Wisconsin, with sampling sites shown.

Figure 3. Indiana Dunes National Lakeshore, Indiana, with sampling site shown.

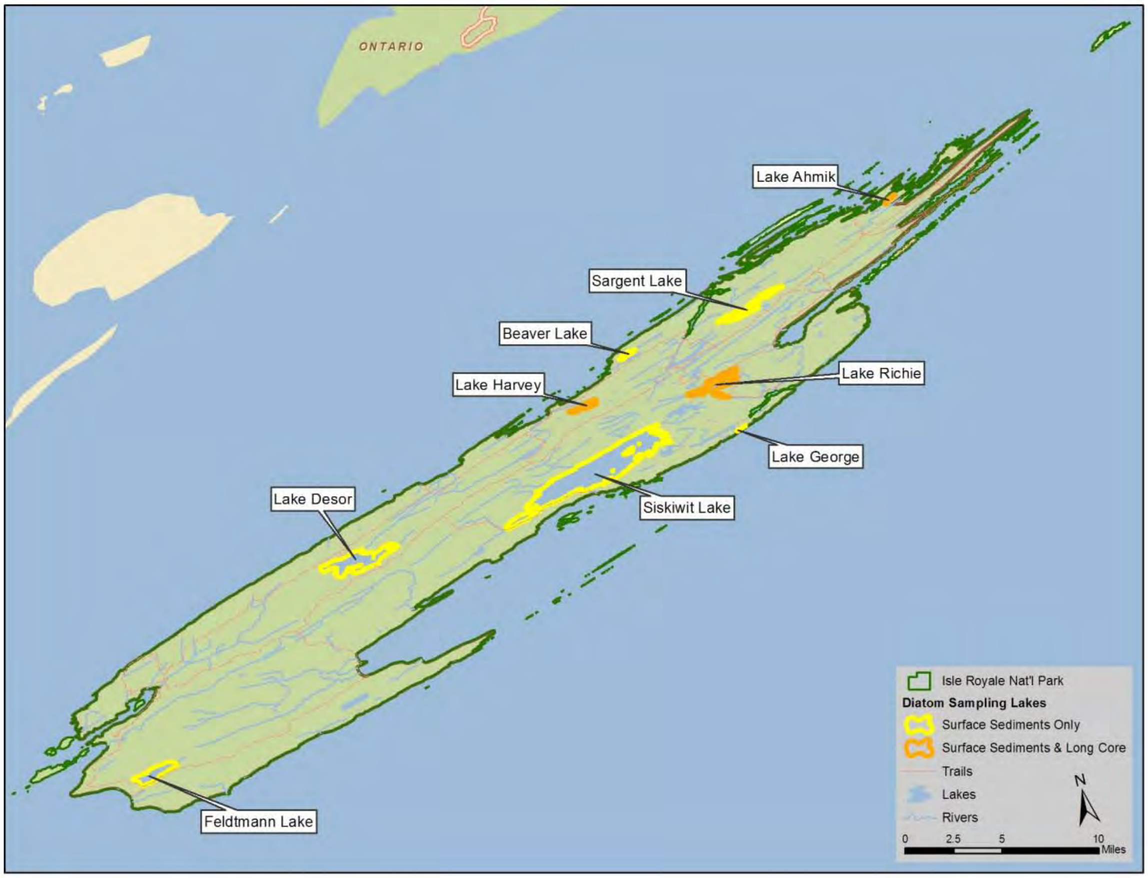


Figure 4. Isle Royale National Park, Michigan, with sampling sites shown.

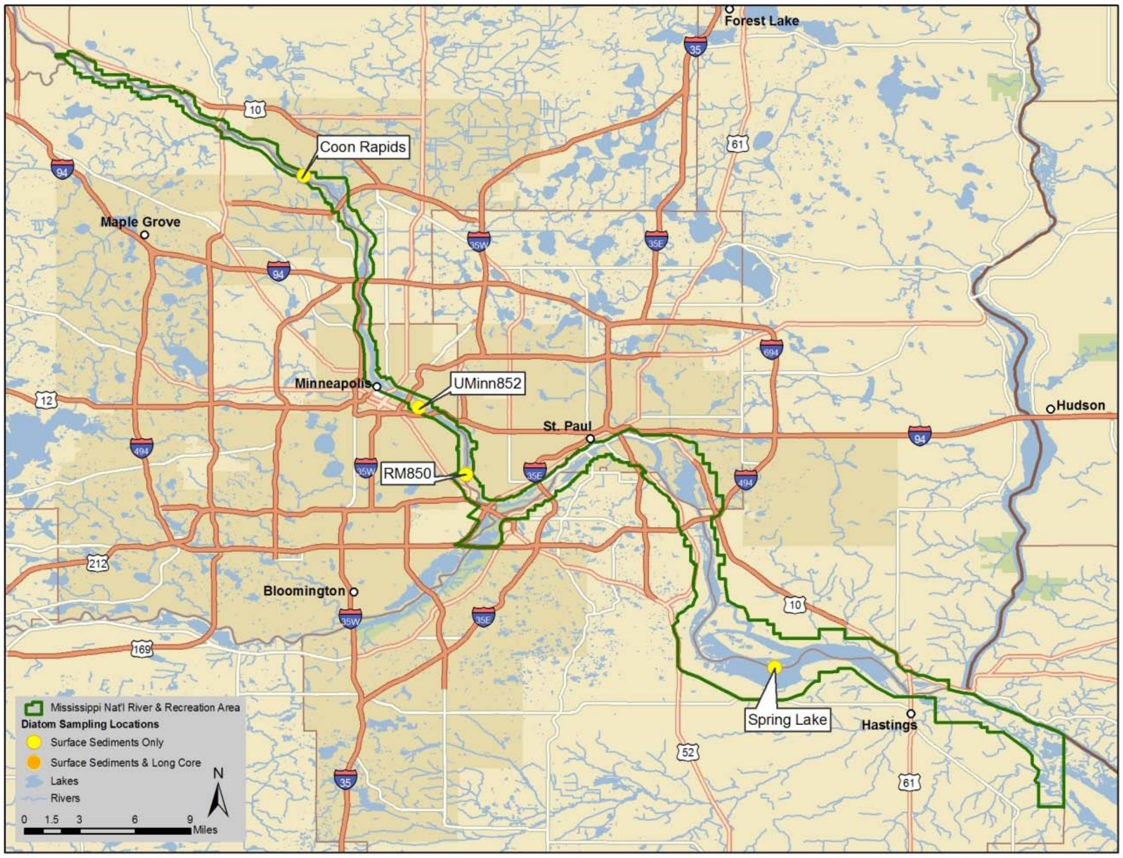


Figure 5. Mississippi National River and Recreation Area, Minnesota, with sampling sites shown.

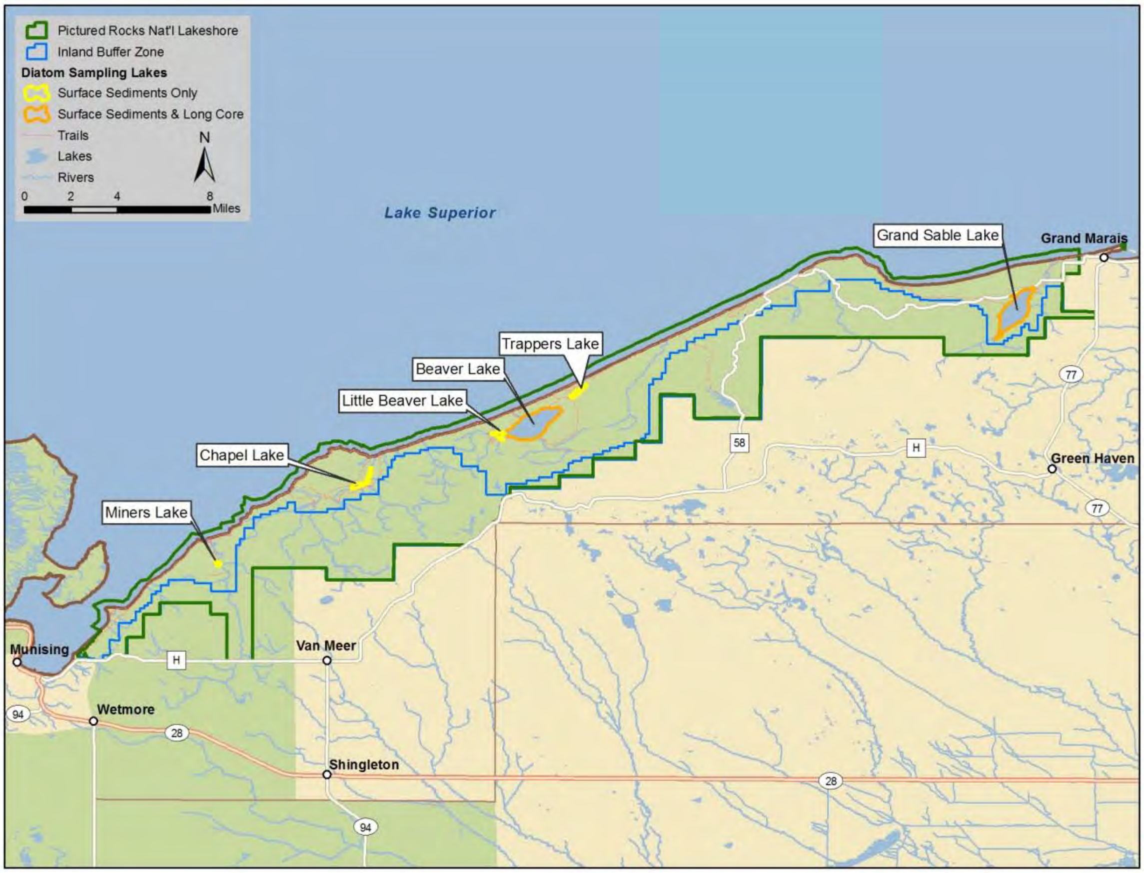


Figure 6. Pictured Rocks National Lakeshore, Michigan, with sampling sites shown.

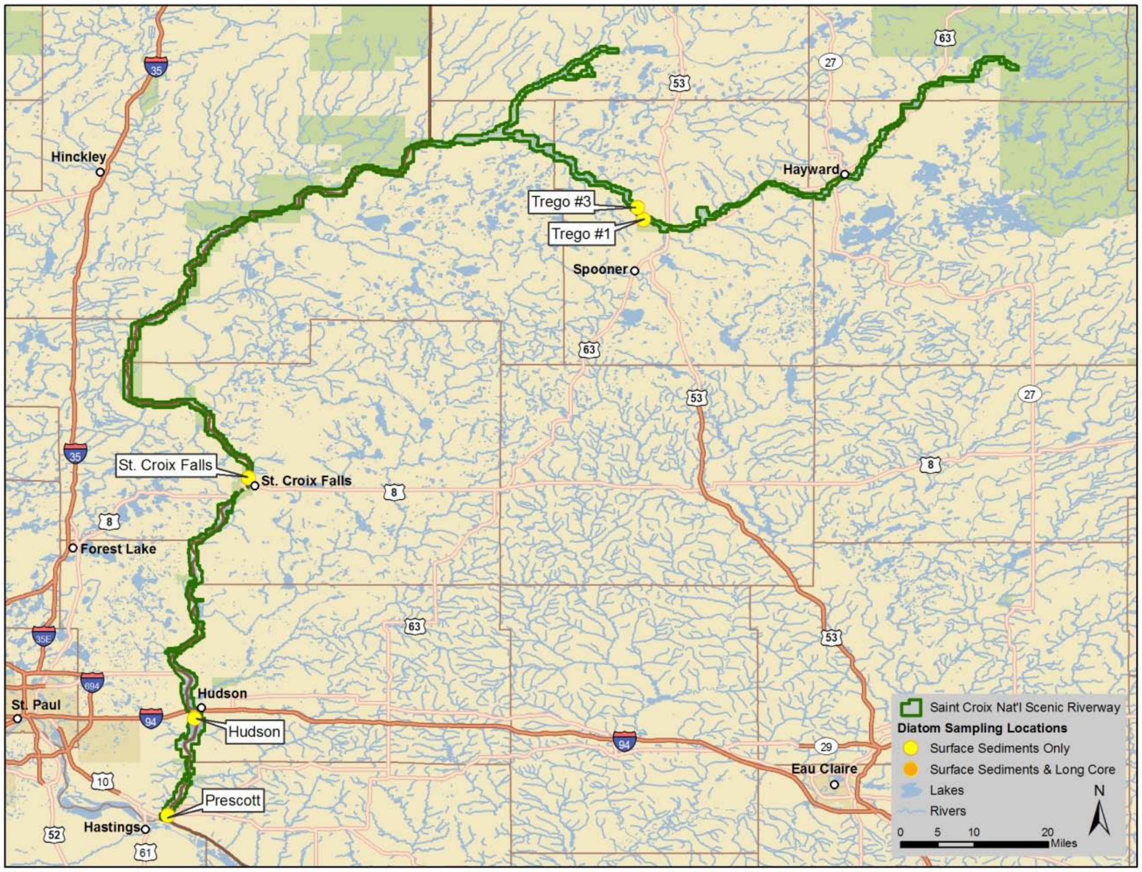


Figure 7. St. Croix National Scenic Riverway, Wisconsin/Minnesota, with sampling sites shown.

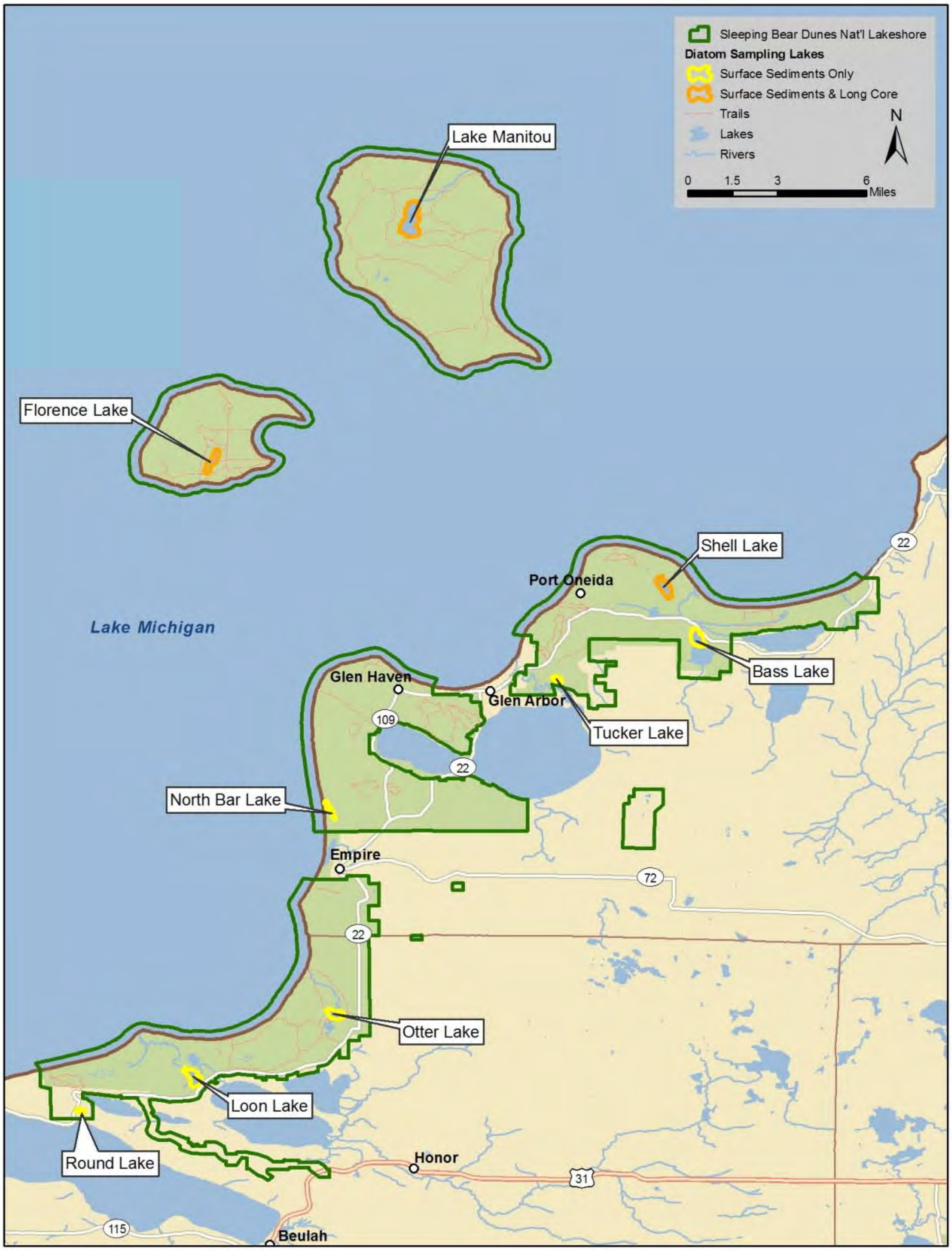


Figure 8. Sleeping Bear Dunes National Lakeshore, Michigan, with sampling sites shown.

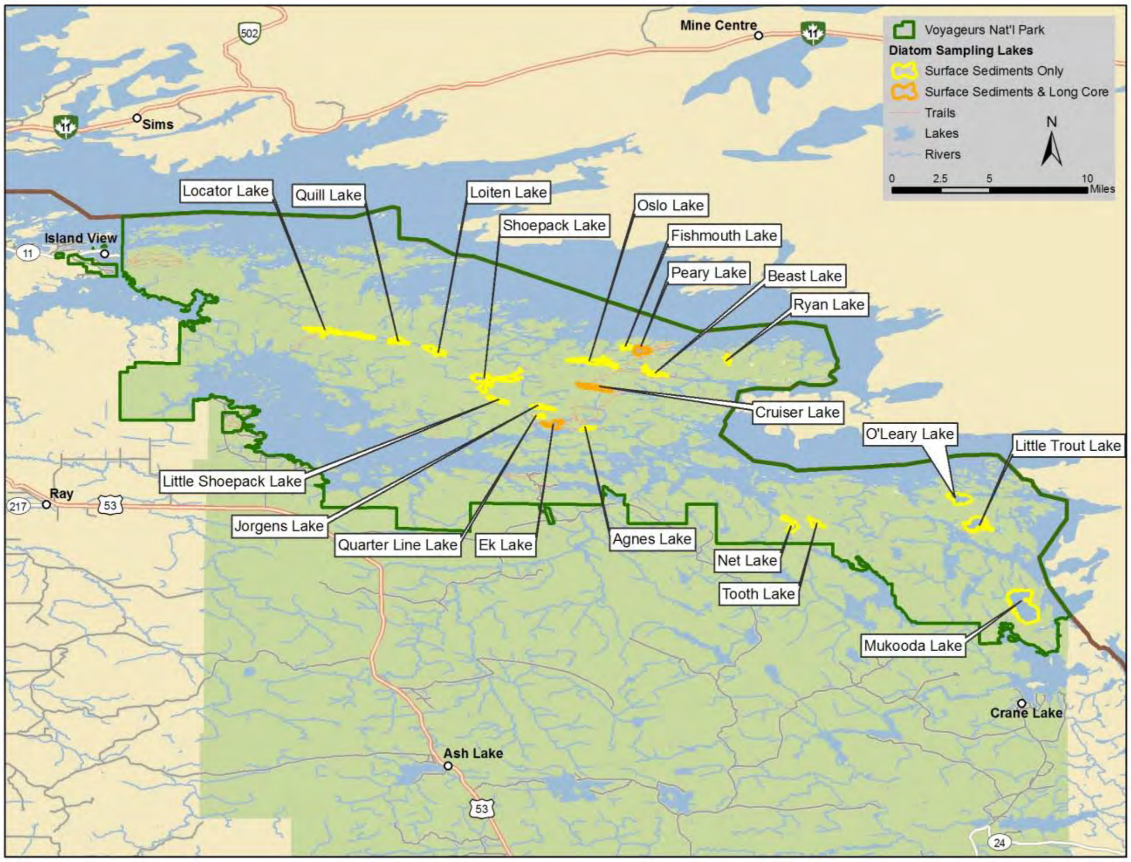


Figure 9. Voyageurs National Park, Minnesota, with sampling sites shown.

Table 1. GLKN lakes sampled for surface sediments, 2005-2009, including lake code, date of collection (YYYYMMDD), location, and sample depth.

Lake	Park	Code	Date	Longitude (°N)	Latitude (°W)	Depth (cm)
Loon	SLBE	SLLOON	20050926	44.70735	-86.12939	0-1
Round	SLBE	SLROND	20050926	44.69280	-86.18459	0-1
Florence	SLBE	SLFLOR	20050927	41.62116	-87.09347	0-1
Manitou	SLBE	SLMANT	20050927	45.12514	-86.02289	0-1
Bass (Leelanau)	SLBE	SLBASS	20050928	44.55341	-85.52993	0-1
Shell	SLBE	SLSHLL	20050928	44.94909	-85.90136	0-1
Tucker	SLBE	SLTUCK	20050928	44.70394	-85.95313	0-1
North Bar	SLBE	SLNBAR	20050930	44.84353	-86.06587	0-1
Otter	SLBE	SLOTTR	20080911	44.74002	-86.06137	0-1
Beaver	PIRO	PIBEAV	20051013	46.57194	-86.33476	0-1
Little Beaver	PIRO	PILTBV	20051013	46.55851	-86.36091	0-1
Grand Sable	PIRO	PIGRSA	20051014	46.64904	-86.03316	0-1
Chapel	PIRO	PICHAP	20051029	46.53018	-86.44797	0-1
Miners	PIRO	PIMINE	20051029	46.48080	-86.53833	0-1
Trappers	PIRO	PITRAP	20050914	46.58627	-86.31558	0-1

Table 1. GLKN lakes sampled for surface sediments, 2005-2009, including lake code, date of collection (YYYYMMDD), location, and sample depth (continued).

Jorgens	VOYA	VOJORG	20060918	48.48404	-92.84797	0-1
Quarterline	VOYA	VOQURT	20060918	48.47683	92.84521	0-1
Little Trout	VOYA	VOLTTR	20060920	48.39794	-92.52526	0-1
Little Trout2	VOYA	VOLTR2	20070907	48.39782	-92.52521	0-1
Mukooda	VOYA	VOMUKO	20060920	48.33404	92.48669	0-1
O'Leary	VOYA	VOOLRY	20060920	48.41597	92.53250	0-1
Agnes	VOYA	VOAGNS	20060921	48.46789	-92.81259	0-1
Ek	VOYA	VOEK	20060921	48.46993	-92.83500	0-1
Beast	VOYA	VOBEAS	20060923	48.50823	-92.75954	0-1
Net	VOYA	VONET	20060924	48.39551	92.65661	0-1
Tooth	VOYA	VOTOTH	20060924	48.39856	92.64328	0-1
Locator	VOYA	VOLOCA	20060925	48.53990	-93.00385	0-1
Loiten	VOYA	VOLOIT	20060925	48.52753	92.92865	0-1
Quill	VOYA	VOQUIL	20060925	48.53244	92.95327	0-1
War Club	VOYA	VOWRCL	20060925	48.53733	-92.98293	0-1
Cruiser	VOYA	VOCRUS	20060926	48.49899	-92.81183	0-1
Brown	VOYA	VOBRWN	20060927	48.51635	-92.79641	0-1
Fishmouth	VOYA	VOFSHM	20060927	48.52741	-92.78154	0-1
Oslo	VOYA	VOOSLO	20060927	48.51684	92.80659	0-1
Peary	VOYA	VOPEAR	20060927	48.52472	92.77260	0-1
Ryan	VOYA	VORYAN	20060927	48.51920	92.70761	0-1
Long	INDU	INLONG	20061003	41.61528	-87.21251	0-1
Little Shoepack	VOYA	VOLTSH	200609NA	48.49006	-92.88129	0-1
Shoepack	VOYA	VOSHOE	200609NA	48.49837	92.88759	0-1
MISS UMinn852	MISS	MS852	20061011	44.97020	-93.23763	0-1
MISS RM850	MISS	MS852	20081003	44.91805	-93.20089	0-1
MISS Coon Rapids	MISS	MSCNRP	20061011	45.15125	-93.32783	0-1
MISS Spring Lk	MISS	MSSPLK	20061012	44.76697	-92.95907	0-1
Michigan Lagoon	APIS	APMICH	20070917	46.87739	-90.51276	0-1
Outer Lagoon	APIS	APOUTR	20070917	47.00744	-90.45915	0-1
Stockton Lagoon	APIS	APSTCK	20070917	46.92521	-90.54798	0-1
Little Sand Bay Lagoon	APIS	APLSND	20070918	46.93901	-90.46239	0-1
Richie	ISRO	ISRICH	20070919	48.04105	-88.70051	0-1
George	ISRO	ISGORG	20070922	48.00777	-88.68525	0-1
Beaver	ISRO	ISBEAV	20070923	48.07990	-88.75723	0-1
Harvey	ISRO	ISHARV	20070923	48.05043	-88.79603	0-1
Ahmik	ISRO	ISAHMK	20070924	48.14788	-88.54151	0-1
Sargent	ISRO	ISSARG	20070925	48.09139	-88.66182	0-1
Feldtmann	ISRO	ISFLDT	20071005	47.85508	-89.17712	0-1
Siskiwit	ISRO	ISSISK	20080617	N/A	N/A	0-1
Desor	ISRO	ISDESR	20080623	47.97618	-88.98885	0-1
St. Croix River Trego #1	SACN	SC01a	20071009	45.92389	-91.87458	0-1
St. Croix River Trego #3	SACN	SC01b	20071009	45.94741	-91.88651	0-1
Lake St. Croix Hudson	SACN	SC09	20071010	44.94732	-92.75503	0-1
Lake St. Croix Prescott	SACN	SC11	20071011	44.75771	-92.80719	0-1
St. Croix River, St. Croix Falls Dam	SACN	SC05	20071012	45.41804	-92.64993	0-1

Sampling for physical and water chemistry parameters took place on 4-8 dates each year, depending on park and type of water body (lake vs. river) being sampled. Methods, initial compilation of data, and QC have been summarized previously (Elias 2006, Elias and Sieracki 2007, Elias and VanderMeulen 2008, Elias et al. 2008, Elias 2009). In preparation for statistical analyses, all physical and water chemistry data were converted to mean values of the ice-free season (Table 2; Ramstack et al. 2008).

Surface Sediment Coring

A line-operated gravity corer (design by Harold Wiegner, Harold.Wiegner@state.mn.us) was deployed from an anchored boat to collect the upper 0-1 cm and 1-2 cm of sediment at the same site that water quality was measured. These sediments represent a spatially and temporally integrated assessment of biological remains and lake conditions during the past 1 to 3 years. Collection sites were located by global positioning system (GPS) to allow resampling in the same location in subsequent years; sampling sites always target central depositional basins in each lake (Ramstack et al. 2008; see Table 1). After subsampling, all sediment samples were freeze-dried and archived in scintillation vials at the St. Croix Watershed Research Station, Science Museum of Minnesota.

Sediment Coring

Piston coring locations targeted central depositional basins in each lake, usually the same location where water quality was measured and surface sediments collected. The few lakes where water quality and coring sites differed included Cruiser Lake (VOYA), where a slightly shallower basin had to be cored due to depth limitations of coring gear, and Shell Lake (SLBE), where a more representative depositional basin was cored. Lakes were chosen for long sediment core collection based on several selection criteria including maximizing spatial and environmental gradients within park units, amount of previous research and data, accessibility, park resource priorities, and suitability for coring. Long cores of sediment were taken from an anchored boat using piston-coring methods that recover the very loose uncompacted sediment surface without disturbance (Wright 1991). All core locations were recorded using GPS. Sediment cores were extruded vertically from the coring tube in the field at 1-cm increments to 60-85 cm core depth and placed in polypropylene jars; the remainder of the core was capped. Cores and sectioned material were transported to 4°C laboratory storage for further processing.

Sediment samples were homogenized and subsampled for loss-on-ignition and diatom analyses. Remaining sediments were freeze-dried within the sample jars for ^{210}Pb dating and geochemical analysis and later archived in scintillation vials at the St. Croix Watershed Research Station (Science Museum of Minnesota). For diatom analysis, cores were sampled at approximately decadal intervals based on each core's date-depth model over the past 200 years to provide a chronology of environmental change following regional Euro-American settlement and a measure of reference or pre-Euro-American conditions.

Diatom Analysis

Surface sediments and increments from long sediment cores were prepared and analyzed similarly for diatom microfossils. Diatoms and chrysophyte cysts were prepared by placing approximately 0.25 cm^3 of homogenized sediment in a 50 cm^3 polycarbonate centrifuge tube and adding 2-5 drops of 10% v/v HCl solution to dissolve carbonates. Organic material was

Table 2. Mean physical and water chemistry values for the ice-free season. The following environmental variables were measured for all lakes in which surface sediments were collected: TP, TN, NO_3, NH_4, chlorophyll-*a*, DOC, alkalinity, Cl, SO_4, Ca, Na, K, Mg, SiO_2, pH, Secchi depth, and EC25.

Lake	**Park**	**Code**	**TP** (µg/L)	**TN** (mg/L)	**NO_3+NO_2** (mg/L)	**NH_4** (mg/L)	**DOC** (mg/L)	**Alk** (mg/L)	**Cl** (mg/L)	**SO_4** (mg/L)	**Ca** (mg/L)	**Na** (mg/L)	**K** (mg/L)	**Mg** (mg/L)	**SiO_2** (mg/L)	**Secchi** (m)	**pH** std. units	**EC25** (µS/cm)
Little Sand Bay	APIS	APLSND	22.0	0.647	0.003	0.010	15.0	33.0	1.80	4.10	9.00	1.90	0.60	3.30	1.20	1.25	7.20	82.0
Michigan	APIS	APMICH	11.0	0.615	0.002	0.041	9.8	55.0	1.30	1.40	15.80	1.20	0.70	4.30	5.10	1.25	7.60	115.0
Outer	APIS	APOUTR	10.0	0.613	0.002	0.012	11.5	4.0	0.80	8.70	2.90	1.00	1.00	1.30	0.40	1.25	7.10	38.0
Stockton	APIS	APSTCK	13.0	0.741	0.011	0.017	18.9	22.0	1.50	3.70	7.70	1.20	0.50	2.20	1.30	1.25	7.20	61.0
Long	INDU	INLONG	22.6	0.542	0.014	0.022	8.7	96.2	24.52	9.08	29.59	11.20	1.33	9.46	1.72	1.00	7.03	297.7
Ahmik	ISRO	ISAHMK	15.0	0.617	0.003	0.019	13.7	46.0	0.70	3.40	11.60	2.50	0.20	5.70	8.80	2.40	7.20	100.0
Beaver	ISRO	ISBEAV	15.0	0.446	0.001	0.004	10.3	48.0	0.80	3.50	10.60	2.60	0.30	5.30	9.50	3.20	8.00	102.0
Desor	ISRO	ISDESR	11.0	0.416	0.005	0.006	6.4	49.0	0.90	3.20	12.50	1.80	0.50	4.20	0.80	3.00	8.20	103.0
Feldtmann	ISRO	ISFLDT	12.0	0.604	0.003	0.006	12.0	28.0	1.10	5.80	10.20	1.40	0.40	2.30	0.60	2.70	8.00	77.0
George	ISRO	ISGORG	10.0	0.368	0.003	0.004	8.2	58.0	1.10	2.10	20.50	1.10	0.10	2.00	1.40	3.00	8.70	120.0
Harvey	ISRO	ISHARV	14.0	0.508	0.003	0.005	8.4	40.0	0.70	4.60	9.50	2.20	0.10	4.30	1.50	3.60	8.50	89.0
Richie	ISRO	ISRICH	34.0	0.664	0.004	0.011	9.2	36.0	1.30	3.70	9.50	1.60	0.30	3.00	6.80	1.40	8.50	80.0
Sargent	ISRO	ISSARG	13.0	0.396	0.003	0.006	7.4	39.0	1.00	4.60	9.90	2.20	0.20	4.00	5.10	3.40	8.00	88.0
Siskiwit	ISRO	ISSISK	4.0	0.241	0.019	0.003	4.5	28.0	0.80	5.20	8.50	1.30	0.40	2.40	2.80	7.80	7.90	69.0
UM852	MISS	MS852	69.9	1.268	0.477	0.021	10.4	108.8	16.80	20.27	47.23	12.37	2.87	17.68	7.03	0.51	8.25	374.3
Coon Rapids	MISS	MSCNRP	63.5	1.397	0.597	0.013	7.7	152.6	17.07	19.13	44.62	9.92	2.58	17.87	8.70	0.64	8.52	391.4
Spring Lake	MISS	MSSPLK	138.1	4.057	3.221	0.101	7.7	180.6	37.27	79.78	63.24	25.49	3.98	30.71	12.13	0.32	8.29	649.8
Beaver	PIRO	PIBEAV	12.2	0.180	0.006	0.070	3.6	76.0	0.37	6.65	26.00	1.09	0.62	5.46	9.29	3.90	8.20	164.0
Chapel	PIRO	PICHAP	8.6	0.230	0.016	0.090	7.3	86.0	0.28	8.31	21.91	0.80	0.68	10.49	4.41	3.60	8.10	187.0
Grand Sable	PIRO	PIGRSA	8.1	0.210	0.008	0.060	5.6	46.0	0.30	4.47	14.09	0.93	0.75	5.09	4.75	3.90	8.00	110.0
Little Beaver	PIRO	PILTBV	21.2	0.310	0.005	0.070	5.5	66.0	0.29	7.52	20.69	1.03	0.63	5.74	6.52	2.80	8.20	165.0
Miners	PIRO	PIMINE	16.3	0.420	0.097	0.130	5.6	142.0	1.24	8.41	32.77	1.30	0.63	16.83	6.60	2.50	7.80	278.0
Trappers	PIRO	PITRAP	10.0	0.740	0.010	0.110	9.7	70.0	0.28	4.45	23.26	1.06	0.59	5.52	5.88	3.30	8.50	148.0
Trego Lk #1	SACN	SC01a	27.9	0.491	0.103	0.011	9.9	64.3	4.10	5.20	19.60	3.22	0.90	6.00	10.50	1.16	7.59	161.4
Trego Lk #3	SACN	SC01b	27.9	0.491	0.103	0.011	9.9	64.3	4.10	5.20	19.60	3.22	0.90	6.00	10.50	1.16	7.59	161.4
St. Croix River, St. Croix Falls Dam	SACN	SC05	51.3	0.846	0.143	0.031	12.1	61.0	5.20	5.70	17.90	3.70	1.70	6.50	8.00	1.25	7.73	161.8
Lake St. Croix Hudson #1	SACN	SC09	45.4	0.914	0.213	0.058	9.4	79.7	7.00	6.30	22.30	4.30	1.80	8.70	8.20	1.25	7.83	183.6
Lake St. Croix Prescott #1	SACN	SC11	38.6	1.033	0.364	0.057	7.7	88.1	7.00	6.40	24.12	4.70	1.80	9.90	7.50	1.65	7.84	204.8
Bass	SLBE	SLBASS	9.3	0.590	0.008	0.130	9.4	100.3	4.51	3.14	31.49	2.98	0.92	10.08	3.65	3.20	8.60	229.0
Florence	SLBE	SLFLOR	14.1	0.650	0.011	0.030	8.9	43.8	0.75	3.15	12.97	0.63	0.63	5.74	0.39	2.50	8.40	111.0

Table 2. Mean physical and water chemistry values for the ice-free season. The following environmental variables were measured for all lakes in which surface sediments were collected: TP, TN, NO_3, NH_4, chlorophyll-*a*, DOC, alkalinity, Cl, SO_4, Ca, Na, K, Mg, SiO_2, pH, Secchi depth, and EC25 (continued).

Lake	Park	Code	TP (µg/L)	TN (mg/L)	NO_3+NO_2 (mg/L)	NH_4 (mg/L)	DOC (mg/L)	Alk (mg/L)	Cl (mg/L)	SO_4 (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	SiO_2 (mg/L)	Secchi (m)	pH std. units	EC25 (µS/cm)
Loon	SLBE	SLLOON	10.7	0.220	0.012	0.020	3.3	132.3	7.87	10.05	41.99	5.78	0.66	12.42	7.14	3.20	8.40	310.0
Manitou	SLBE	SLMANT	8.7	0.410	0.006	0.130	6.7	134.0	0.52	6.39	33.51	1.38	0.55	15.52	1.17	2.60	8.60	270.0
North Bar	SLBE	SLNBAR	10.9	0.510	0.122	0.060	3.5	145.5	4.07	9.41	44.29	1.59	0.57	15.38	5.48	2.20	8.30	329.0
Otter	SLBE	SLOTTR	11.0	0.477	0.086	0.041	5.6	124.0	7.70	9.07	33.30	3.90	0.80	14.00	6.70	3.40	8.35	281.0
Round	SLBE	SLROND	10.9	0.560	0.007	0.050	7.2	129.5	18.25	9.67	29.62	12.04	0.59	15.91	6.72	4.60	8.70	319.0
Shell	SLBE	SLSHLL	12.6	0.960	0.011	0.070	10.0	108.5	1.16	20.02	32.94	1.57	0.41	14.32	13.66	3.00	8.50	262.0
Tucker	SLBE	SLTUCK	17.5	0.760	0.007	0.025	12.0	123.0	1.26	4.83	35.08	1.05	0.32	12.67	7.72	2.80	8.30	262.0
Agnes	VOYA	VOAGNS	23.3	0.642	0.018	0.015	16.3	7.3	0.87	1.49	1.91	1.13	0.56	1.00	1.18	1.10	6.28	22.0
Beast	VOYA	VOBEAS	7.7	0.412	0.003	0.008	8.5	6.7	0.50	1.91	1.97	1.10	0.65	0.87	1.57	4.80	6.77	22.0
Brown	VOYA	VOBRWN	7.0	0.433	0.003	0.006	10.7	5.3	0.63	2.04	2.09	1.20	0.61	0.96	2.10	2.49	7.34	21.0
Cruiser	VOYA	VOCRUS	3.7	0.202	0.004	0.003	4.2	7.3	0.37	2.56	2.01	0.80	0.53	0.77	0.85	7.60	7.14	19.7
Ek	VOYA	VOEK	16.3	0.643	0.008	0.016	13.0	9.3	0.63	2.19	2.99	1.39	0.78	1.35	0.58	1.95	7.03	32.5
Fishmouth	VOYA	VOFSHM	7.3	0.511	0.022	0.008	9.1	7.0	0.43	1.81	2.03	0.99	0.73	1.06	0.60	3.10	7.08	23.7
Jorgens	VOYA	VOJORG	11.0	0.422	0.001	0.009	9.8	4.5	0.60	2.40	2.34	1.14	0.57	0.96	1.30	2.97	6.94	24.0
Locator	VOYA	VOLOCA	7.3	0.417	0.036	0.006	12.0	5.5	0.73	3.08	2.44	1.16	0.68	1.10	1.60	2.70	6.83	24.7
Loiten	VOYA	VOLOIT	5.3	0.363	0.020	0.007	9.4	7.0	0.60	3.61	2.33	1.17	0.68	1.12	2.00	3.73	7.02	25.3
Little Trout2	VOYA	VOLTR2	5.0	0.264	0.004	0.005	3.8	14.5	0.60	2.80	3.50	0.80	0.50	1.50	0.30	6.60	7.80	37.0
Little Shoe	VOYA	VOLTSH	12.7	0.528	0.001	0.008	11.7	8.0	0.63	2.63	1.97	1.20	0.58	1.02	1.07	2.35	7.01	22.3
Little Trout	VOYA	VOLTTR	5.0	0.273	0.014	0.004	5.1	13.0	0.47	3.03	4.05	1.00	0.56	2.05	0.30	6.29	7.71	35.3
Mukooda	VOYA	VOMUKO	8.3	0.374	0.050	0.006	6.1	20.0	0.50	2.04	5.70	1.35	0.80	2.94	0.30	5.32	7.95	52.7
Net	VOYA	VONET	27.0	0.686	0.013	0.013	14.7	10.3	1.00	3.31	3.62	1.43	0.64	1.97	1.47	1.43	6.81	36.0
O'Leary	VOYA	VOOLRY	9.3	0.398	0.004	0.005	7.4	27.7	0.47	2.48	7.09	1.36	0.80	3.37	0.47	5.50	7.70	60.0
Oslo	VOYA	VOOSLO	8.3	0.449	0.020	0.009	11.3	6.0	0.60	2.06	1.97	1.24	0.59	0.89	2.93	2.57	6.96	20.0
Peary	VOYA	VOPEAR	18.0	0.534	0.012	0.006	10.5	7.7	0.57	2.10	2.51	1.27	0.63	1.22	0.80	2.30	7.53	30.7
Quill	VOYA	VOQUIL	5.7	0.414	0.023	0.005	9.9	6.3	0.60	3.00	2.37	1.03	0.68	1.06	2.10	3.86	7.09	24.0
Quarterline	VOYA	VOQURT	15.7	0.583	0.011	0.011	16.3	6.3	0.93	2.21	2.17	1.16	0.58	1.20	1.70	1.46	6.52	24.0
Ryan	VOYA	VORYAN	9.0	0.495	0.009	0.009	12.0	6.0	0.57	3.59	2.61	1.21	0.50	1.04	2.60	2.79	6.90	28.7
Shoepack	VOYA	VOSHOE	28.7	0.655	0.007	0.031	15.3	7.0	0.87	3.48	2.23	1.21	0.61	1.02	1.10	1.38	6.38	22.7
Tooth	VOYA	VOTOTH	9.3	0.450	0.004	0.010	10.3	8.3	0.63	2.85	2.87	1.34	0.68	1.48	1.43	3.32	6.90	29.0
War Club	VOYA	VOWRCL	7.7	0.410	0.009	0.005	11.7	5.7	0.67	2.96	2.70	1.21	0.73	1.17	1.57	2.48	6.85	24.7

subsequently oxidized by adding 10 ml of 30% H_2O_2 and heating for 3 hr in an 85°C water bath. After cooling the samples were centrifuged and rinsed 4-6 times with deionized water to remove oxidation biproducts. Aliquots of the remaining material, which contain the diatoms, were dried onto 22x22 mm #1 coverglasses. Coverglasses were permanently attached to microscope slides using Zrax mounting medium (Ramstack et al. 2008).

Diatoms were identified along random transects to the lowest taxonomic level under 1250X magnification (full immersion optics of NA>1.3). A minimum of 400 valves was counted in each sample. Identification of diatoms relied on floras and monographs such as Hustedt (1927-1966, 1930), Patrick and Reimer (1966, 1975), Collins and Kalinsky (1977), Camburn et al. (1978, 1984-1986), Krammer and Lange-Bertalot (1986-1991), Cumming et al. (1995), Reavie and Smol (1998), Camburn and Charles (2000), Fallu et al. (2000), and the primary literature (e.g., Koppen 1975). For major taxa, digital images were taken and maintained in a database to achieve consistent taxonomy. All diatom counts were converted to percentage abundances by taxon; abundances are reported relative to total diatom counts in each sample.

Core Dating, Loss-on-ignition, and Geochemistry

Lake sediments and peat cores are widely used to study environmental history, and one of the most important analyses in such studies is accurate dating—establishing a chronology or age-depth relationship for a sediment core. Cores are usually dated with two goals in mind: (1) to establish the timing of past environmental change and (2) to determine the rate of accumulation of materials (e.g., sediment, pollutants, micro-fossils) in the lake or wetland. For studies of human impacts (e.g. pollution, eutrophication, erosion), which typically focus on the last 100-200 years, the dating method of choice is lead-210 (^{210}Pb). Lead-210 is a naturally occurring radioisotope in the ^{238}U-decay series formed by decay of ^{226}Ra, and the subsequent evasion of the intermediary ^{222}Rn (an inert gas) from the earth's surface. Radon-222 decays through a series of short-lived daughters to ^{210}Pb which is stripped from the atmosphere in precipitation and accumulates as “excess” (unsupported) ^{210}Pb in lake sediments and wetlands where it decays away with a half-life of 22 years. Cores are typically dated by measuring alpha or gamma radiation emitted during ^{210}Pb decay. The measured radioactive decay, which is directly proportional to the concentration of ^{210}Pb, is reported in units of "activity", picocuries (pCi), per gram of dry sediment. Lead-210 activity is measured in a series of 15-20 stratigraphic levels taken from the core surface to a depth where excess ^{210}Pb is no longer measurable above background (supported) ^{210}Pb. Supported ^{210}Pb is formed by the in situ decay of ^{226}Ra present in eroded mineral grains and remains constant over time. From the resulting profile of excess ^{210}Pb, dates are calculated according one of several mathematical models that make assumptions regarding the accumulation of ^{210}Pb and sediment at the core site.

Sediment cores were analyzed for ^{210}Pb activity to determine age and sediment accumulation rates for the past 150 to 200 years. Lead-210 activity was measured from its daughter product, ^{210}Po, which is considered to be in secular equilibrium with the parent isotope. Aliquots of freeze-dried sediment were spiked with a known quantity of ^{209}Po as an internal yield tracer and the isotopes distilled at 550°C after treatment with concentrated HCl. Polonium isotopes were then directly plated onto silver planchets from a 0.5 N HCl solution. Activity was measured for 1-3 x 10^5 s using an Ortec alpha spectrometry system. Supported ^{210}Pb was estimated by mean activity in the lowest core samples and subtracted from upcore activity to calculate unsupported

^{210}Pb. Core dates and sedimentation rates were calculated using the constant rate of supply model (Appleby and Oldfield 1978). Dating and sedimentation errors represented first-order propagation of counting uncertainty (Binford 1990). Early 19th century dates and sedimentation rates represented down-core extrapolations of mean dry-mass accumulation immediately pre-Euro-American settlement.

Dry-density (dry mass per volume of fresh sediment), water content, organic content, and carbonate content of sediments were determined by standard loss-on-ignition techniques (Dean 1974). In short, weighed sediment subsamples were dried at 105°C for 24 hr to determine dry density, then heated at 550°C and 1000°C to detect organic and carbonate content from post-ignition weight loss, respectively.

The same fifteen samples from each long core that were analyzed for diatoms were also examined for biogenic silica (BSi).Weighed subsamples (30 mg) from each primary core were digested for BSi analysis using 40 mL of 1% (w/v) Na_2CO_3 solution heated at 85°C in a reciprocating water bath for five hours (DeMaster 1979, Conley and Schelske 2001). A 0.5 g aliquot of supernatant was removed from each sample at 3, 4, and 5 hr. After cooling and neutralization with 4.5 g of 0.021N HCl solution, dissolved silica was measured colorimetrically on a Lachat QuikChem 8000 flow injection autoanalyzer as molybdate reactive silica (McKnight 1991).

Statistical Analysis

Modern Species-Environment Relationships

Statistical approaches for exploring modern diatom species-environment relationships in lakes from the GLKN parks are outlined in Ramstack et al. (2008). Multivariate statistical analyses were performed in the software package R (Ihaka and Gentleman 1996) and construction of transfer functions and environmental reconstructions in cores were completed using the software package C2 (Juggins 2003). In short, the relationship between modern diatom assemblages and modern measured water quality variables was explored using multivariate ordination techniques to identify water quality parameters that independently explained significant variation in the diatom species data. The combined set of samples with water quality and diatom species data was referred to as the calibration or training set. Environmental variables that independently explained significant variation in species distributions was as predictor variables to develop models called transfer functions that produced quantitative estimates of water quality variables of interest from a diatom assemblage. Transfer functions were developed using weighted averaging (WA) regression and calibration using bootstrap error estimation (Birks et al. 1990, Juggins 2003). The transfer functions represented each taxon's environmental optimum and tolerance for specific environmental variables. To reconstruct a water quality parameter from a diatom community, each taxon's environmental optimum was weighted by its relative abundance in the sample; the summed weighted optima of the entire species assemblage in the diatom community represented the diatom-inferred water quality estimate (Birks et al. 1990).

The following environmental variables were measured for all lakes in which surface sediments were collected: TP, TN, NO_2+NO_3, NH_4, chlorophyll-*a*, DOC, alkalinity, Cl, SO_4, Ca, Na, K, Mg, SiO_2, pH, Secchi depth, and EC25 (Table 2). Water temperature, DO, and depth were also measured but were not included in the analysis of species-environment relationships. All variables were $\log_{10}$ transformed prior to analysis, with the exception of pH, which is already on a log scale, to obtain a normal distribution. Other data transformations were also tested (e.g., square root, 1/x, 1/square root) and normality of the transformed distributions assessed using skewness and kurtosis. Principal Components Analysis (PCA), an unconstrained ordination, was used to explore the patterns in water chemistry variables among sites (Ramstack et al. 2008). Visual examination of the ordinations led to all three sites from MISS being removed as outliers in terms of water chemistry. MISS sites were removed as outliers from the water quality PCA, because they had much higher nutrient levels than other GLKN sites so that environmental gradients in remaining sites would be less obscured by the strong influence of the MISS sites.

A total of 1,196 diatom species was found in 60 surface sediment samples collected from eight GLKN parks. Species at 1% or greater abundance in more than one sample were used in analysis, the exception was any species with a single occurrence at greater than 5% abundance; this criterion led to 138 species being used (Ramstack et al. 2008). Detrended Correspondence Analysis (DCA), an unconstrained ordination, was used to explore the similarities in diatom species assemblage among sites. DCA was used because the data had an arch when Correspondence Analysis (CA) was used to graphically display these data (Ramstack et al. 2008). Visual examination of the ordinations showed that the 3 MISS sites, Trappers Lake (PIRO), Shell Lake (SLBE), and Michigan, Stockton, and Outer Lagoons in APIS were outliers in terms of species assemblage.

To explore the relationships among diatom community assemblages in the modern surface sediments and measured water chemistry, Canonical Correspondence Analysis (CCA), a constrained ordination, was used. At this step, all sites were put back into the analysis to determine if any were outliers when diatom species data and environmental data were analyzed together. The same sites that were outliers in terms of species assemblage (see above) were also identified as outliers based on visual inspection of the constrained CCA ordination: the three MISS sites, Trappers Lake (PIRO), Shell Lake (SLBE), and Michigan, Stockton, and Outer Lagoons in APIS. After removing these sites and reapplying the above criterion for species (occurrence at 1% or greater abundance in more than one sample, or 5% or greater abundance in one sample), 110 species were used to develop the calibration set.

After removing outliers, manual forward selection was used to determine the best subset of environmental variables that independently explained variation in species data. First, a series of single-variable CCAs was used to test significance of each environmental variable. Manual forward selection was then conducted with each environmental variable identified as significant in a single-variable CCA. For all CCA ordinations, rare taxa were downweighted and Monte Carlo permutation run to test for significance. From the set of environmental variables that significantly and independently explained variation in diatom species abundance, transfer functions were constructed for pH, logTP, and logEC25 using weighted averaging regression and calibration with inverse deshrinking and bootstrap validation (Birks et al. 1990, Juggins 2003). The strength of the transfer function was evaluated by calculating the squared correlation coefficient (r^2) and the root mean square error (RMSE) between the observed transformed variables with the model estimates of each transformed variable for all samples. Bootstrapping is used in model validation to provide a more realistic error estimate (RMSEP, the root mean square error of prediction) because the same data are used to both generate and test the WA model (Fritz et al. 1999). Transfer functions were applied to the 13 long sediment cores recovered from the GLKN parks. Reconstructed estimates of EC25, pH, and TP for each downcore sample were determined by taking the environmental optimum of each species, weighting it by species abundance in each sample, and determining the average of the combined weighted species optima (Birks et al. 1990).

Long Sediment Core Data Analysis

Relationships among diatom communities within a sediment core were explored using Principal Components Analysis, Correspondence Analysis, or Detrended Correspondence Analysis. For the GLKN cores, DCA was determined to be the most suitable analysis based on gradient lengths (Ramstack et al. 2008). Core depths were plotted in ordinate space and their relationships and variability used to identify periods of change, sample groupings, and ecological variability among core samples. A general rule for interpreting these ordinations is that samples that plot closer to one another have more similar diatom species assemblages. A constrained cluster analysis was also performed on each of the cores to determine stratigraphic groupings of samples based on similarity of diatom assemblages. Downcore diatom data for each sediment core were also passively plotted over the environmental-diatom CCA to examine whether changes or "ecological trajectories" in the historical diatom assemblages were correlated to differences among modern GLKN diatom species-environment relationships. For example, we might explore whether historical changes in the diatom assemblages in a sediment core follow similar species changes in modern GLKN diatom assemblages along the pH or nutrient gradient. This technique can help identify potential environmental stressors that are impacting or have impacted a lake.

Core stratigraphies were constructed for diatoms present at ≥5% relative abundance in each long core. Stratigraphic zones identified with DCA and cluster analysis were overlain on the stratigraphies to identify periods of change in the ecological history of each lake. For each long core, transfer functions were applied to the downcore diatom communities to reconstruct historical pH, logTP, and logEC25 using weighted averaging with inverse deshrinking (Birks et al. 1990). Values for logEC25 and logTP were backtransformed to TP (µg/L) and EC25 (µS/cm) before plotting.

Land Use Histories

A record of major land-use changes from each park unit throughout the last 150-200 years has been assembled from the literature and with the assistance of resource managers at the park units. For PIRO, Lora Loope provided an Excel file of major changes in the park (Table 3) and a resource report specific to water management and logging at PIRO's Beaver Lake was consulted (Loope 1993). For SLBE, a historical record of agriculture and Euro-American settlement was published by Haswell and Alanen (1994) and by MacDonald and Alanen (2000). A historiography from VOYA was assembled by Larry Kallemeyn and coauthors as part of a separate project (Edlund et al. 2010). Information on land-use history of Outer Island (APIS) was provided by Peggy Burkman, APIS Biologist. Busch (2008) synthesized the general cultural history of APIS. Karamanski et al. (1988), Shelton (1975), Stottlemyer et al. (1998), and Huber (1983) were consulted to understand the land-use and historical setting of ISRO. Land use history for SACN has been previously compiled and analyzed in the context of ecological change recorded in sediment cores from Lake St. Croix (Edlund et al. 2009a, b). Land-use histories were compared with stratigraphic changes and trophic reconstructions from the sediment cores to determine whether major changes in lake condition were temporally correlated with specific disturbances in the watershed.

Table 3. History and land use changes at Pictured Rocks National Lakeshore, 1800-2005. Prepared by Lora Loope, resource manager, PIRO.

Calendar Years	Activity / Occurrence	Citation
16th century	Mega-drought (inferred)	Booth *et al.* 2004
1659	Radisson and Groseilliers leave written record of their travels along Lake Superior's south shore.	Symon 1986
1688	Grand Sable Dunes appear on French maps.	Symon 1986
1840s	Alger County was surveyed by US Gov't	Symon 1986
1845	Iron ore discovered in Marquette Co. (adjacent county to the west).	Cleveland Cliffs Iron Co. 1920
1861	First trading post at Grand Marais.	Symon 1986
1871	Commercial fishing begins from Grand Marais.	Symon 1986
1874	Au Sable Lighthouse built at Au Sable Point.	park historic documents
1879	First sawmill in Grand Marais.	Symon 1986
Ca. 1880	Anthropogenic disturbance horizon (logging and fire 21 cm & 38 cm downcore from ponds 37 km WSE of GSL), ^{210}Pb dating.	Lytle 2005
	Euro-American settlement (20-21 cm downcore of bog 26 km from GSL): increased pollen of *Ambrosia*, Compositae, Chenopodiaceae/Amaranthaceae, *Plantago, Morus.*	Futyma 1990
1883	Logging began in Beaver Basin surrounding Beaver Lake.	Hall 1971
1882 - 1885	Logging camp operated at Sullivan's Landing on Lake Superior (22 km W of GSL).	Frederick et al. 1977
1890 - 1895	Most logging activity and slash burning on Kingston Plains occurred (inferred from tax evaluations).	Barrett 1995
	White pine and hemlock logging (16 cm downcore of bog 26 km W of GSL): charcoal peak, pine/fern pollen changes.	Futyma 1990, Booth et al. 2004
1905	Earthen dam with wooden sluiceway constructed at outflow of Beaver Lake.	Loope 1993
Ca. 1910	Major fire in Kingston Plains area, 37 km SW of GSL.	Frederick et al. 1977
Ca. 1915 - 1930s	Drought and wildland fires (1939 aerial photos; testate amoeba-inferred paleohydrology from bog 16 km S of GSL)	Booth et al. 2004, Barrett 1995
	fires: charcoal peak (7 cm downcore of bog 26 km from GSL).	Futyma 1990
1936	Fire on eastern Kingston Plains, ca. 37 km SW of GSL	Barrett 1995
1930s -1950s	Seasonal rental cabins present in 1930s; most cabins were built in 1940s; but a few were built in the 1950s. There was only 1 year- around home on property adjacent to the lake.	per. comm. Brody Block of Grand Marais (2/23/2007)

Table 3. History and land use changes at Pictured Rocks National Lakeshore, 1800-2005 (continued).

Calendar Years	Activity / Occurrence	Citation
ca. 1946	County Road H-58 from Grand Marais to Kingston Corners, which is adjacent to the north end of Grand Sable Lake, was upgraded from a two-track road to a graded road about 1946.	per. comm. Brody Block of Grand Marais (2/23/2007)
1908-1950	Smallmouth bass stocked in Grand Sable Lake by Michigan Department of Natural Resources (MiDNR).	MiDNR, Vogel 1999
1934-1939	Bluegill stocked in Grand Sable Lake by MiDNR.	MiDNR, Vogel 1999
1937-1942	Walleye (not native to the lake) stocked in Grand Sable Lake by MiDNR, but not observed since.	MiDNR, Vogel 1999
1940-2005	Lake trout (not native to the lake) stocked in Grand Sable Lake by MiDNR.	MiDNR, Vogel 1999
1950-1953	Rainbow smelt (non-native) stocked in Grand Sable Lake by MiDNR.	MiDNR, Vogel 1999
1951-1962	Rainbow trout/steelhead (exotic) stocked in Grand Sable Lake by MiDNR.	MiDNR, Vogel 1999
1965-1982	Splake (non-native hybrid) stocked in Grand Sable Lake by MiDNR.	MiDNR, Vogel 1999
1969-1972	Ca. 30 cabins/seasonal homes removed from the east shore of Grand Sable Lake.	park historic documents
1997	*Bythotrephes* first observed from sample collected in Beaver Lake.	per. comm. Lora Loope
2003	*Bythotrephes* first observed from sample collected in Grand Sable Lake.	per. comm. Lora Loope

Diatom QA/QC

Ten percent of surface sediment collections were counted by a second QC analyst for quality assurance and control (Ramstack et al. 2008). The first analyst scribed a line using a diamond objective marker on each microscope slide indicating their transect starting point. A minimum of 400 diatoms was identified and counted, and the analyst scribed a second line as the stopping point. The second QC analyst chose 10% of the microscope slides and identified and counted diatoms along the same transects counted by the first analyst. Percent difference between the two analyst counts was calculated as:

$$\%\text{Difference} = (1 - \sum \min(a,b)) * 100$$

where a and b are the relative proportions recorded for each taxon by the primary analyst (a) and the QC analyst (b).

Repeat or Future Sampling

In October 2008 the first set of repeat sediment samples was collected at PIRO from Beaver, Miners, Grand Sable, and Chapel lakes. In April-June 2009, repeat surface sediments were collected from eight lakes at SLBE: Bass, Florence, Loon, Manitou, North Bar, Round, Shell, and Tucker. Samples were prepared and analyzed for diatom communities following project protocols (Ramstack et al. 2008). Surface sediments were also sampled from Narada Lake at SLBE in spring of 2009. To determine the amount of floristic change in the diatom community between repeat surface sediment samplings and in the context of community change recorded in the long sediment cores, a squared chord distance measure was used. Squared chord distance is a dissimilarity measure with values ranging from 0 (samples are exactly the same) to 2 (samples are completely different). Meaningful change can be assessed using percentile cutoffs from randomly generated, approximately normally distributed data, that range from the lower to upper limits of the squared chord distance (0 to 2) (Bennion et al. 2004; Simpson et al. 2005). Here we used squared chord distances greater than 0.39 to represent meaningful floristic change; this value was determined by Simpson et al. (2005) and Simpson (personal communication), and represented the fifth percentile in distribution of pairwise comparisons based on the above method. Squared chord distances less than this fifth percentile limit have been found to be representative of low floristic change (Bennion et al. 2004, Simpson personal communication).

For each of the long sediment cores, DCA axis 1 scores and squared chord distance between samples were examined for an appropriate time period to use as "background" for each lake (a time before significant changes such as logging and land clearance had affected the diatom community). For each lake this background time period was in the 1800s, and similar time periods were used for each park. For each core, two periods in the lake's history were used as a baseline of floristic changes. First, the squared chord distance from background (pre-Euro-American settlement) to the core top was calculated as a measure of floristic change between pre-Euro-American and the most recent samples, that is, floristic change during the longest period of significant anthropogenic impacts to the lake. Second, squared chord distance was also calculated from the time of park formation (plus or minus seven years from 1970 for SLBE, 1966 for PIRO, 1940 for ISRO, 1975 for VOYA, and 1970 for APIS) to the core top, i.e., the amount of floristic change under NPS management in each lake.

Squared chord distance was calculated between repeat samplings of surface sediments using a similar approach to the long sediment cores. In the case of SLBE, we compared the floristic change between the 2005 surface sediment calibration set samples and the repeat surface sediment samples collected in April-June 2009. For PIRO, we compared the floristic change between the 2005 surface sediment calibration set samples and the repeat surface sediment samples collected in October 2008 (i.e., the sample collected for the calibration set and the repeat sampling at that lake). In addition to calculating the squared chord distance between the calibration set sample and the resample, the repeat samples were passively plotted on the calibration set to determine if floristic change in the lakes was correlated with one or more of the environmental axes. Shell Lake (SLBE) was not passively plotted because it had been previously removed from the calibration set as an outlier. Instead, Shell Lake was passively plotted on the unconstrained analysis (DCA) of the Shell Lake core. The 2009 sample collected from SLBE's Narada Lake represents that lake's first sampling; the 2009 sample will represent the baseline diatom community against which future community change will be measured in Narada Lake.

Results

Surface Sediment Training Set

WQ Summary

Annual (ice-free) means were calculated for all 60 lakes selected for combined WQ monitoring and surface sediment collection (Table 2). Environmental variables that were measured in all lakes included: TP, TN, NO_2+NO_3, NH_4, DOC, alkalinity, Cl, SO_4, Ca, Na, K, Mg, SiO_2, pH, Secchi depth, and EC25. A principal components analysis of all park lakes (three MISS sites removed as outliers) identified the primary environmental gradients among the park lakes (Figure 10). Lakes from each park unit were well-grouped in the ordination with VOYA lakes clustered to the right along PCA axis 1 and SLBE and PIRO lakes clustered to the left along PCA axis 1. The ISRO lakes were distributed along PCA Axis 2. The strongest environmental

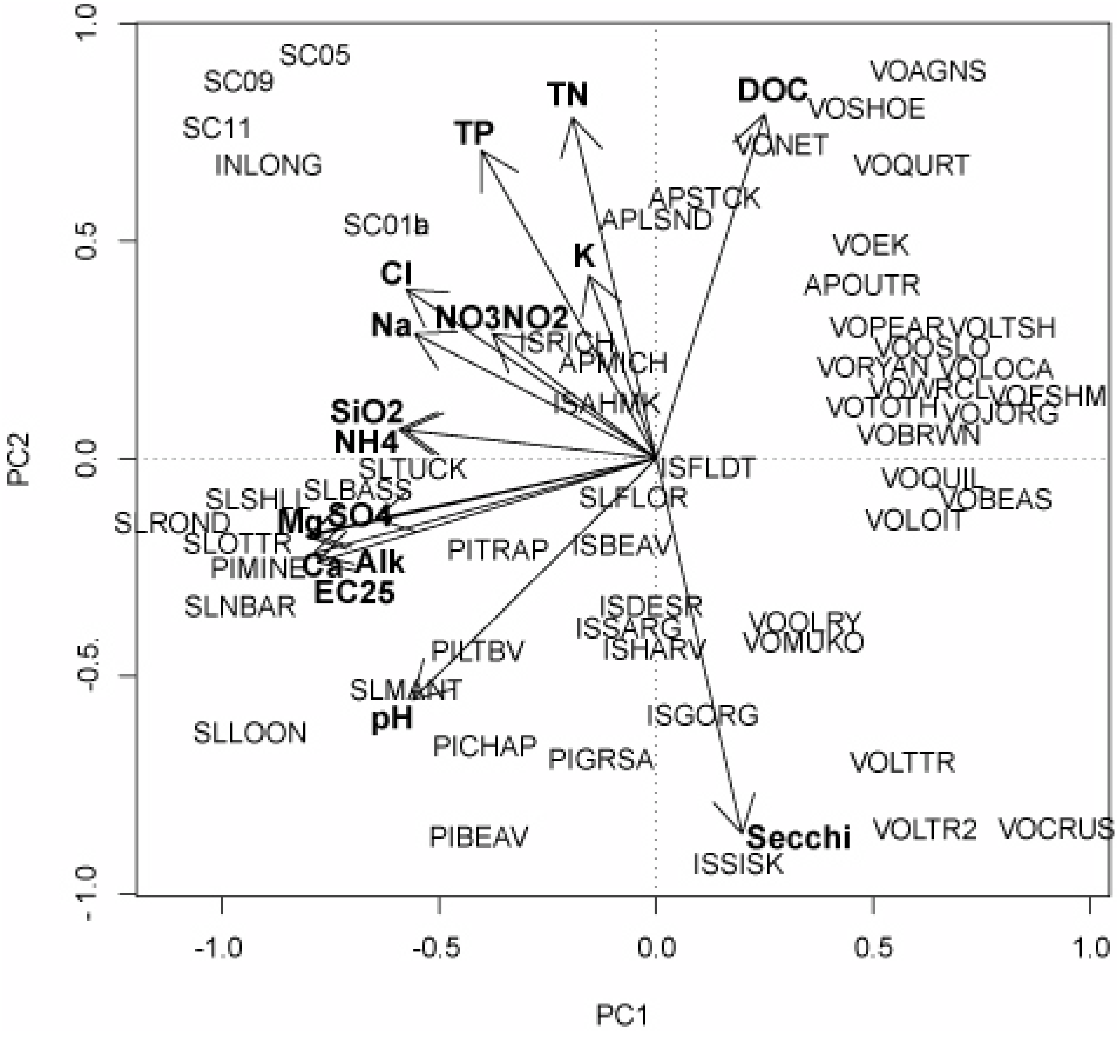


Figure 10. Principal components analysis (PCA) of fifteen water quality variables and sites at SLBE, PIRO, VOYA, INDU, MISS, SACN, and APIS. Sites displayed on PCA axes 1 and 2 with environmental vectors scaled at 0.7 and outliers removed (see text).

vectors aligned with PCA axis 1 were associated with ionic strength and included EC25, alkalinity, and the dominant ions Ca^{2+}, Mg^{2+}, and SO_4^{2-} (Figure 10) with the SLBE lakes grouped at the high end of these gradients in contrast to the VOYA lakes at the lower end. Environmental vectors strongly aligned with PCA axis 2 included the nutrient and productivity measures such as TP, TN, and Secchi depth. Lake color, as measured by DOC, was also aligned with PCA axis 2. Lakes distributed along axis 2 included the SACN and INDU lakes at the high end of nutrient gradients, and ISRO's Siskiwit and several VOYA lakes at the low end. The stained VOYA lakes (Agnes, Net, Shoepack) represented the highest values along the DOC axis.

Species-Environment Relationships

A total of 1,196 diatom species was found in the 60 surface sediment samples collected from eight GLKN parks. A DCA ordination based on species relative abundance showed the three sites from MISS, Trappers Lake (PIRO), Shell Lake (SLBE), and Michigan, Stockton, and Outer Lakes in APIS to be outliers so they were removed from further species-environment analyses. A final DCA of species data showed many of the lakes grouped by park unit (Figure 11) with VOYA lakes grouped to the left on DCA axis 1, and SLBE lakes pulled to the right on DCA axis one but separated into two subgroups along DCA axis 2; a similar pattern is seen among ISRO lakes. PIRO lakes were grouped near the center of the ordination. These distributions of GLKN lakes in ordinate spaces reflect similarities and differences among their diatom communities. For example, grouping of VOYA lakes results from their shared softwater diatom flora dominated by *Tabellaria* species and the planktonic *Eunotia zasuminensis* (Figure 12). SLBE and ISRO lakes grouped in upper right of the ordination include lakes with plankton dominated by small *Cyclotella* species (e.g., *C. comensis*, *C. michiganiana*). Samples that are pulled to the lower right on the ordination, including the shallower SLBE, ISRO, and SACN sites, have diatom communities dominated by benthic species including small fragilarioid and naviculoid diatoms.

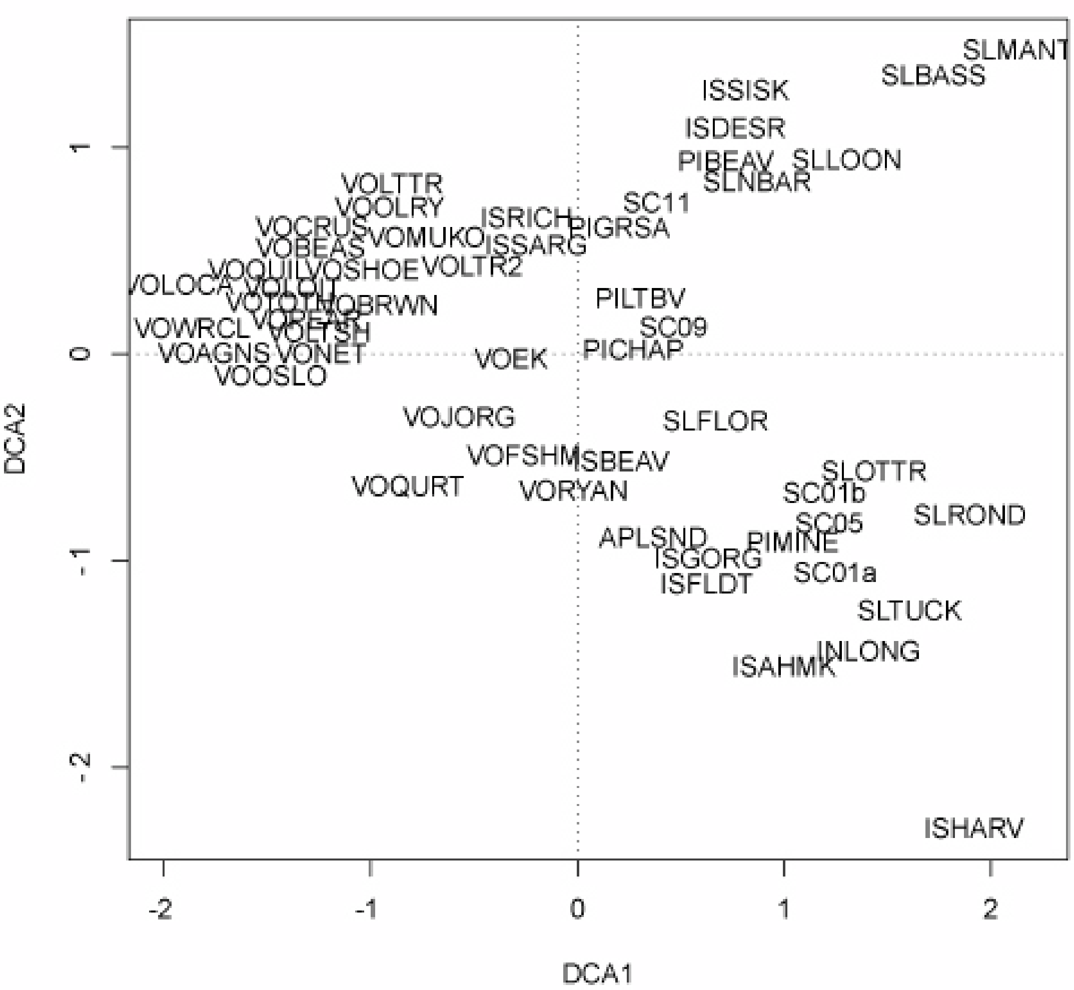


Figure 11. DCA of species data from surface sediments collected at sites at SLBE, PIRO, VOYA, INDU, MISS, SACN, and APIS. Sites displayed on DCA axes 1 and 2, outliers removed.

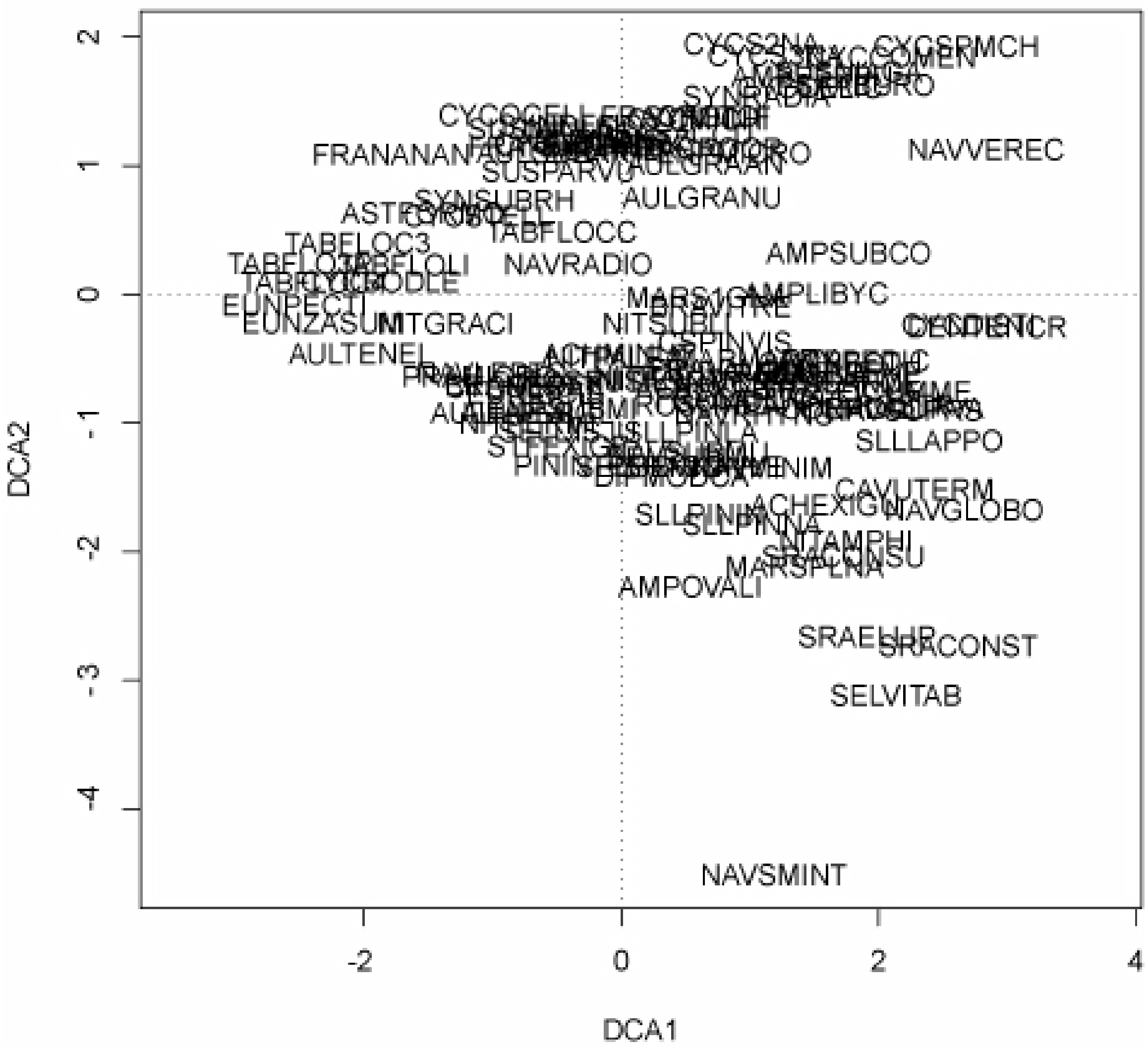


Figure 12. DCA of species data from surface sediments collected at sites at SLBE, PIRO, VOYA, INDU, MISS, SACN, and APIS (species displayed on DCA axes 1 and 2, outliers removed).

A CCA was subsequently run on the species-environment data set following removal of the eight outlier sites. The full set of 15 environmental variables explained 48.2% of variation in species data. The environmental vectors oriented similar to PCA results (Figure 10) with an ionic strength gradient along CCA axis 1 and a nutrient-productivity gradient along CCA axis 2 (Figure 13). Based on manual forward selection of environmental variables, the following six environmental variables were found to explain significant, independent variation (in parentheses) in the diatom species data: EC25 (11.25%), pH (9.09%), TP (6.29%), NH_4 (5.84%), DOC (5.67%), and NO_3NO_2 (4.07%) (Figure 14). Together, these six environmental variables uniquely explained 28.7% of the variation in species data, not including interactive effects. As expected, lakes from specific park units were strongly grouped in CCA ordinate space (Figure 14). Softwater VOYA lakes were grouped on the low end of the conductivity gradient and higher pH SLBE lakes on the high end. The nutrient-rich SACN lakes grouped at the high end of the TP gradient along CCA axis 2.

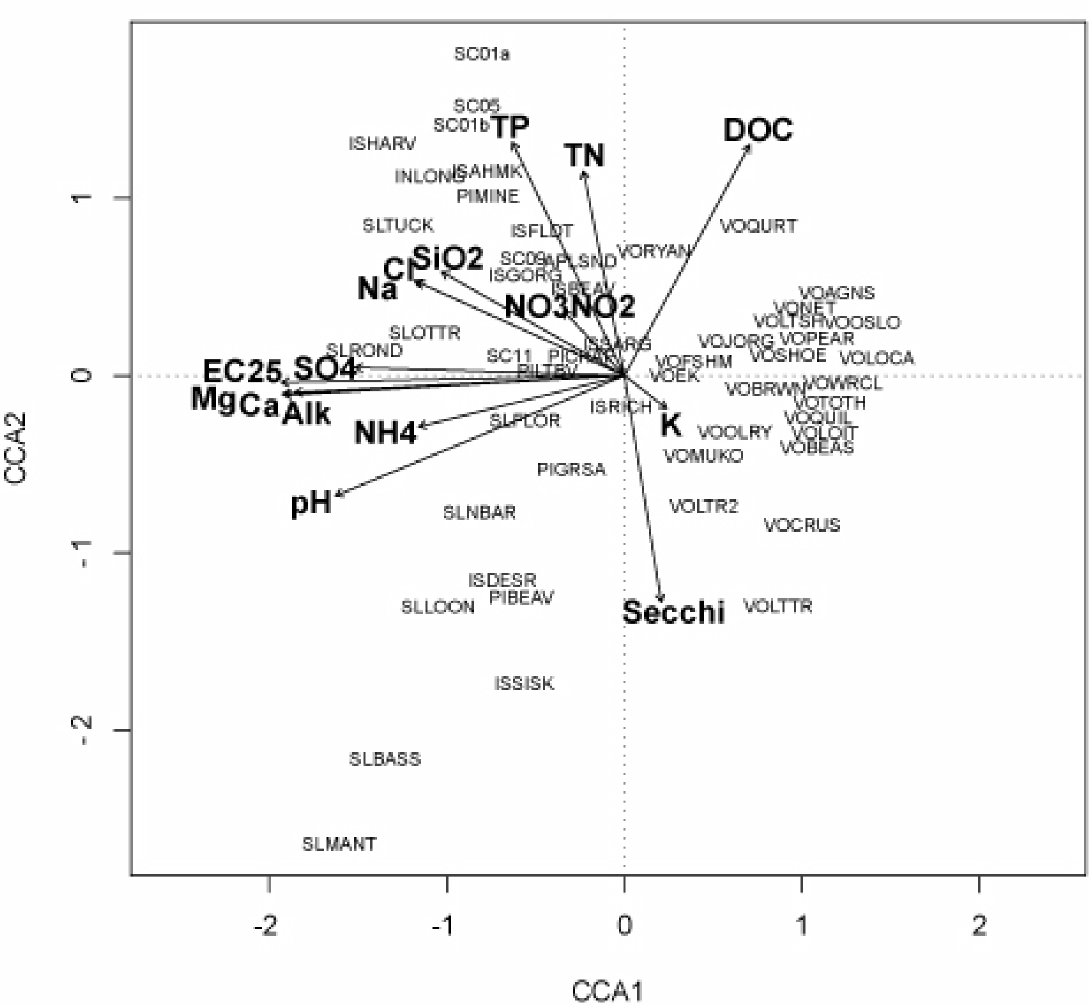


Figure 13. CCA without forward selection. Canonical correspondence analysis (CCA) of diatom species-environment relationships in SLBE, PIRO, VOYA, APIS, ISRO, SACN, MISS and INDU lakes. Environmental vectors and site scores plotted on CCA axes 1 and 2. Outlier sites removed from analysis.

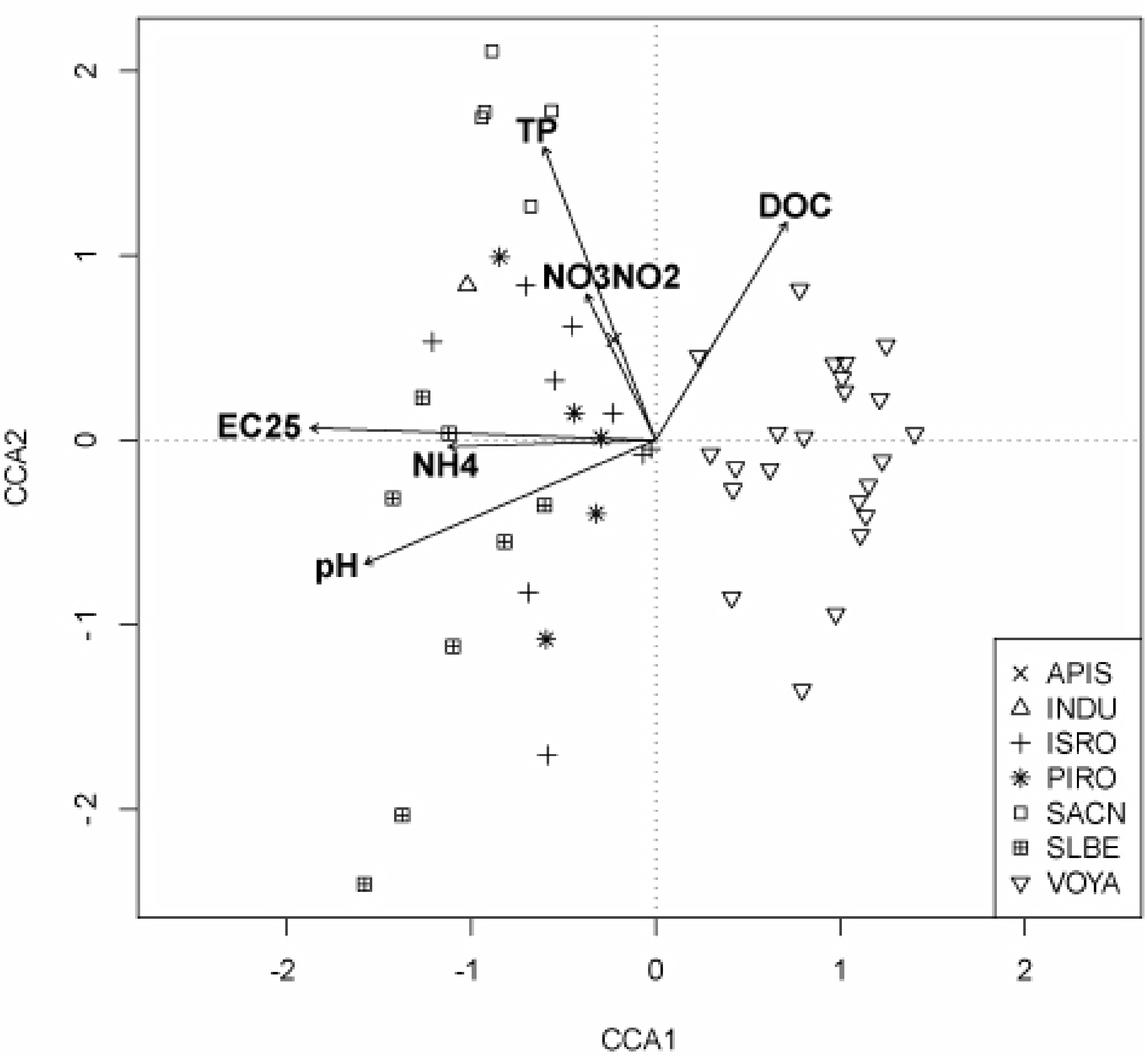


Figure 14. CCA with forward selection of variables (outliers removed). Canonical correspondence analysis (CCA) of diatom species-environment relationships in SLBE, PIRO, VOYA, and INDU lakes. Environmental variables that explain significant and independent variation in the species data are identified. Site scores plotted on CCA axes 1 and 2.

Transfer Functions

Environmental variables that independently explained significant variation in species distributions were then used as predictor variables to develop transfer functions to quantitatively reconstruct environmental variables of interest from sediment diatom assemblages. Transfer functions for three most explanatory variables (logEC25, pH, and logTP) were created using weighted averaging (WA) with inverse deshrinking and bootstrapping validation. Transfer functions could also generated for other variables that explain independent variation in diatom species data especially if passive plotting of downcore communities indicated that shifts were being driven, for example, by DOC. Performance statistics for each model are summarized in Table 4 and Figures 15-17. Transfer functions were applied to all downcore samples in long sediment cores from GLKN parks; results of those reconstructions will be discussed below in a park-by-park basis.

Table 4. Performance statistics for three transfer functions created from the GLKN surface sediment calibration set. Performance statistics include the squared correlation coefficient (r^2) and the root mean square error (RMSE) between observed transformed variables with model estimates of transformed variables for all samples. Validation of the model used bootstrapping; bootstrapped performance statistics include bootstrapped squared correlation coefficient (r^2_{boot}) the root mean squared error of prediction ($RMSEP_{boot}$).

Model	**r^2**	**RMSE**	**r^2_{boot}**	**$RMSEP_{boot}$**
EC25	0.8937	0.1355	0.8344	0.1804
pH	0.7773	0.3101	0.6552	0.4007
TP	0.7463	0.1319	0.5439	0.1896

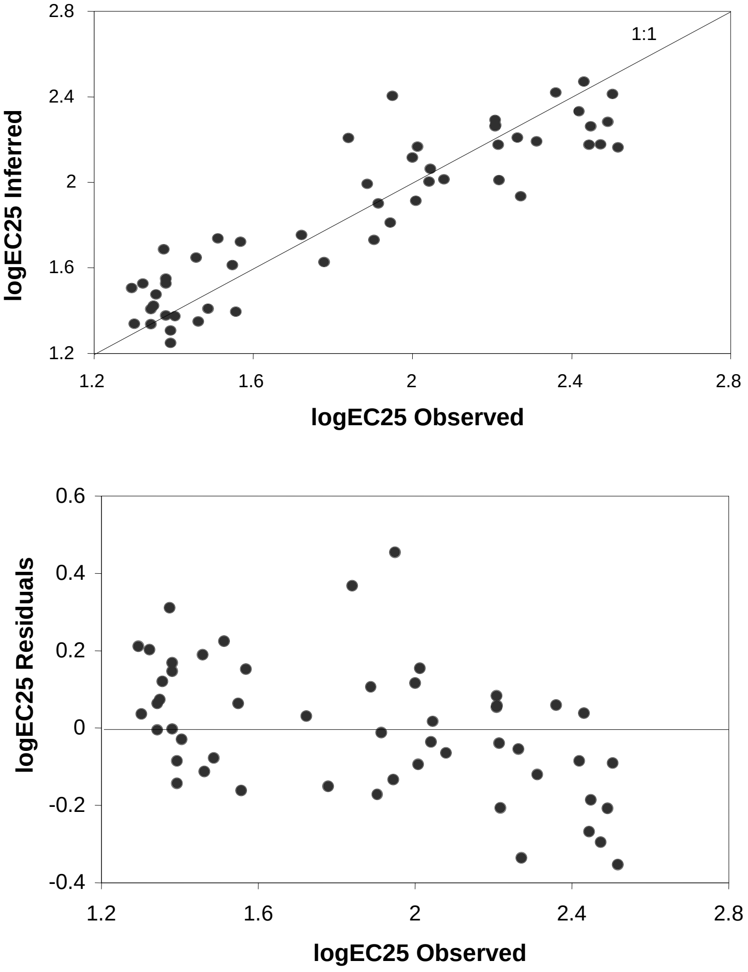
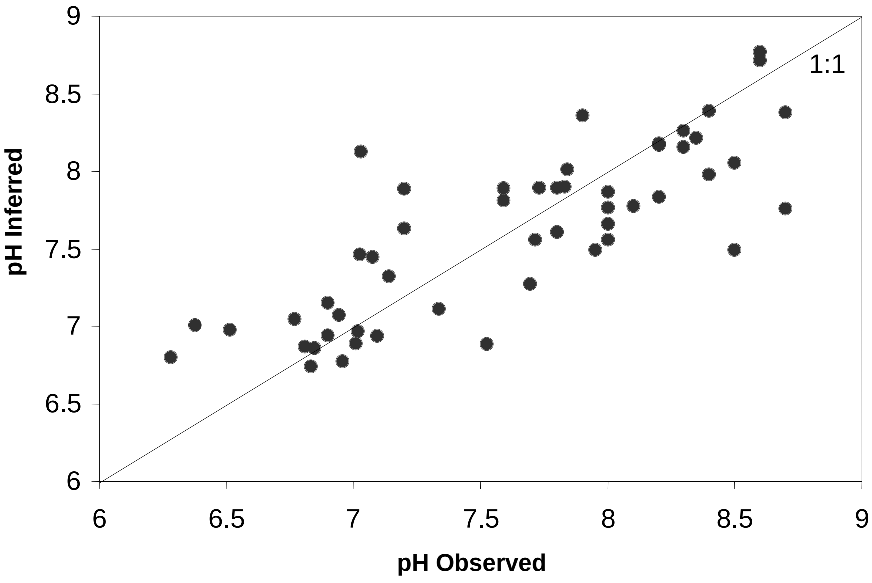


Figure 15. Observed vs. inferred values (top panel) and plots of residuals (bottom panel) for EC25 transfer function.



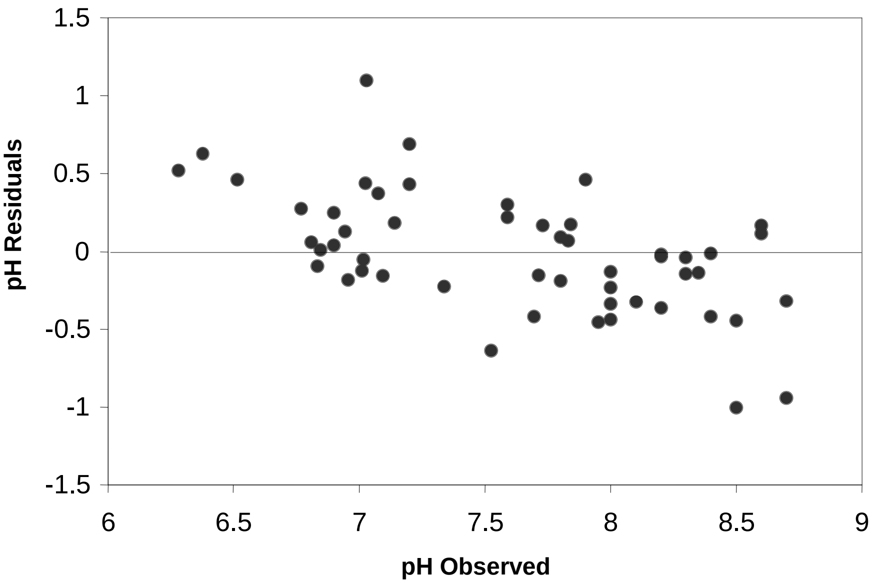


Figure 16. Observed vs. inferred values (top panel) and plots of residuals (bottom panel) for pH transfer function.

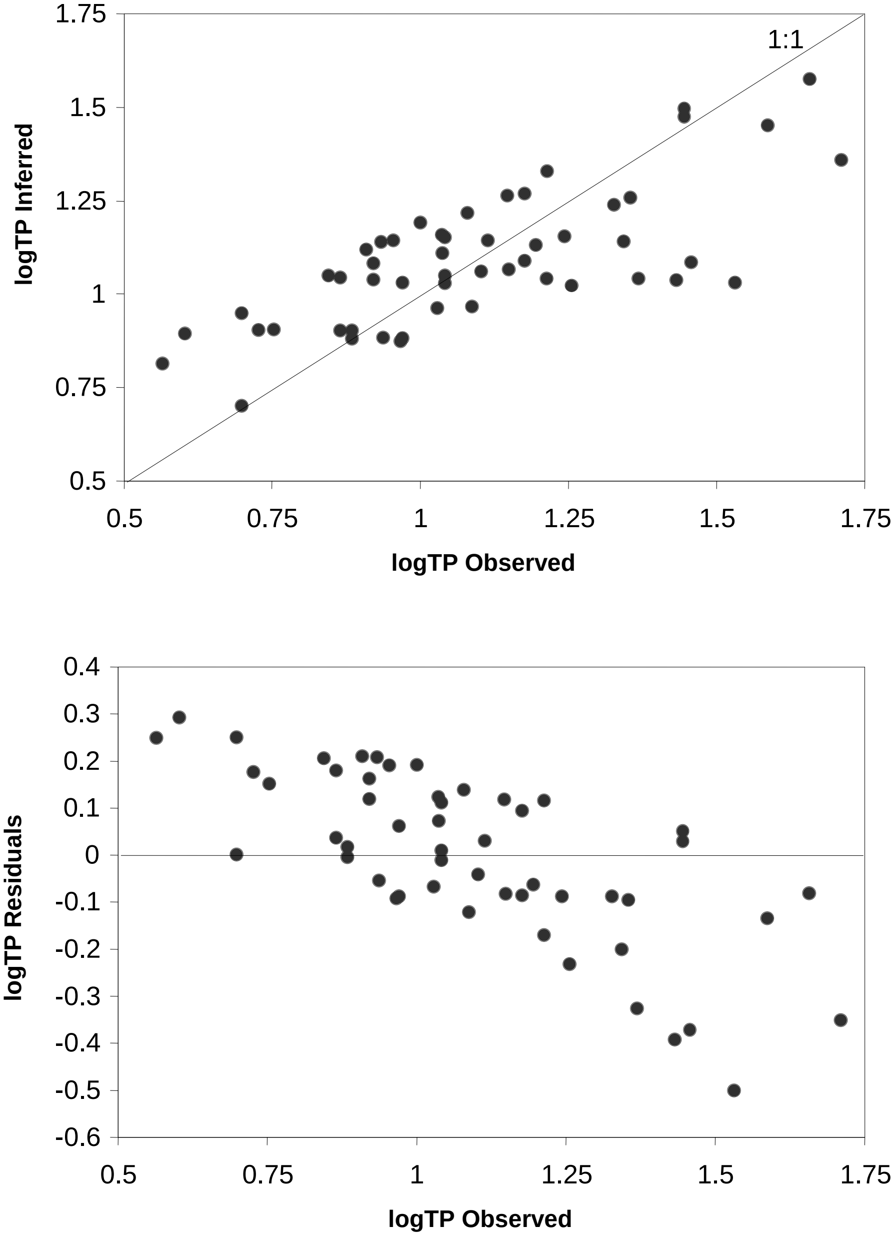


Figure 17. Observed vs. inferred values (top panel) and plots of residuals (bottom panel) for TP transfer functions.

QA/QC

Ten percent of the surface samples were recounted by a second QC analyst to estimate percent taxonomic difference between analysts. Percent difference between counts ranged from 8.5% to 18.4% (Table 5) with all counts well within the 30% cutoff set by Ramstack et al. (2008). Samples with higher percent differences were used to help focus on diatom groups that require taxonomic discussions. These groups include the small cyclotelloids, *Aulacoseira*, and the long fragilarioids.

Table 5. Percent taxonomic difference between the primary diatom analyst and a Quality Control analyst, estimated on ten percent of surface sediment samples.

Surface sediment sample	% difference
SACN Prescott 0-1 cm surf 2008	18.4
PIRO Grand Sable 0-1 cm, 2005 surf	14.7
VOYA Cruiser 0-1 cm surf 2006	10.6
ISRO Siskiwit 2008 0-1cm surf	17.9
MISS, Miss. R. Coon Rapids 0-1 cm	18.4
SLBE 2005 Manitou 0-1cm surf	8.5

Long Sediment Cores (SLBE)

Core Collection

Long cores of sediment were collected from four lakes at Sleeping Bear Dunes National Lakeshore (Table 6). Cores from Bass Lake (107 cm), Manitou Lake (110 cm), and Shell Lake (110 cm) were recovered in September 2005. In September 2008, a 112 cm core was recovered from Florence Lake.

Table 6. Long cores collected from 13 sites in five GLKN parks. Date of collection (YYYYMMDD), location, date, depth of lake at sample site (Z in meters), and length of recovered core (cm).

Lake	Park Unit	Date	Longitude (°N)	Latitude (°W)	Z (m)	Core length (cm)
Bass	SLBE	20050928	44.92235	-85.88322	7.9	107
Manitou	SLBE	20050927	45.12693	-86.02370	13.07	110
Shell	SLBE	20050928	44.94742	-85.89938	4.03	110
Florence	SLBE	20080910	45.01085	-86.11990	7.28	112
Grand Sable	PIRO	20050729	46.64787	-86.03357	19.19	141
Beaver	PIRO	20080909	46.56524	-86.34362	8.75	178
Outer	APIS	20070725	47.00753	-90.45967	0.76	73
Harvey	ISRO	20070804	48.05067	-88.79602	4.31	117
Richie	ISRO	20070806	48.04092	-88.70236	10.54	118
Ahmik	ISRO	20070805	48.14787	-88.54153	2.61	110
Cruiser	VOYA	20060809	48.49753	-92.80225	21.72	88
Ek	VOYA	20060807	48.46975	-92.83600	5.64	135
Peary	VOYA	20060808	48.52423	-92.77164	5.03	88

Core Dating, Loss-on-ignition and Geochemistry

Bass Lake: Total ^{210}Pb activity declines to supported levels below 100 cm core depth (Figure 18). The Bass Lake coring was problematic in that the first core collected in September 2005 was too short to reach supported levels of ^{210}Pb. A new core was collected in September 2008 with the anticipation that a longer core would be recovered; however the new core had peaty material

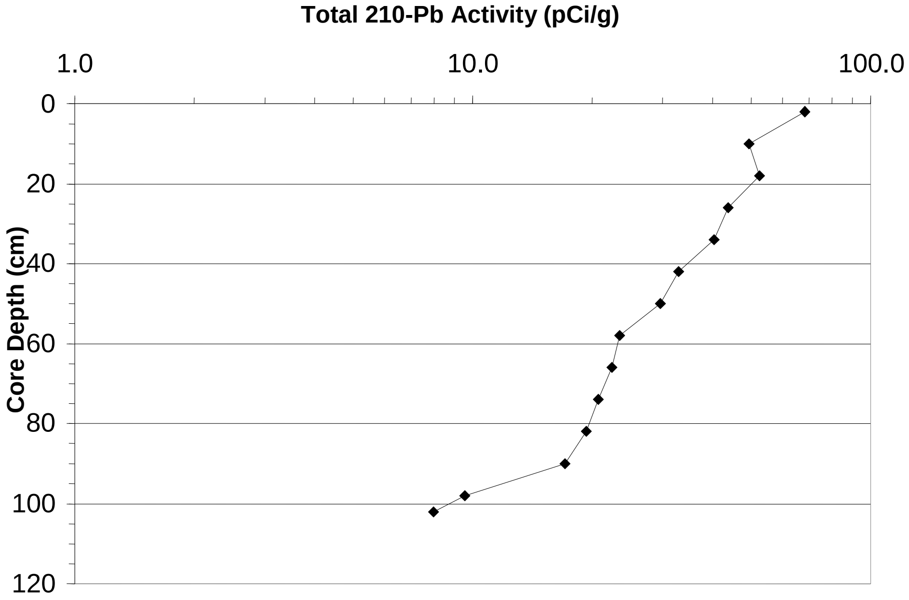


Figure 18. Total 210-Pb activity plotted against core depth (cm), Bass Lake (SLBE).

just below 100 cm depth indicating that sedimentation in the lake had been very different in the past. The new core allowed supported^{210}Pb in Bass Lake to be estimated and that value was then used to finish the dating model for the 2005 Bass Lake core (Figure 19). Because of its limited length and change in sediment composition below 100 cm, the record in our 2005 core was truncated in the 1880s. The late 1880s was represented by 102 cm depth. The dating model indicated that sedimentation rates increased from 100 cm to 60 cm or from the 1880s to 1970s (Figures 20, 21). Sedimentation rates have remained relatively stable from the 1970s to present at about 0.05 g/cm^2/yr (Figure 21). Sediments in Bass Lake have always been dominated by the organic component which increased in proportion from 55% dry weight (1880s) to modern levels of almost 70% (Figure 22). Mirroring the trends in organics in Bass Lake sediments is a decreasing proportion of inorganics; inorganics decreased from just less than 40% dry weight to approximately 25% in the most recent sediments. Carbonates remained a minor component (5% dry weight) of Bass Lake sediments. Flux of sediment components increased upcore most significantly in organics and inorganics (Figure 23). Biogenic silica (BSi) content was variable in Bass Lake sediments during the last 125 years ranging from 6% to 14% dry weight, with somewhat higher content (but still variable) after the 1960s (Figure 24). Flux of BSi increased in Bass Lake from an average of 1.5 mg/cm^2/yr from the 1880s-1960 to levels around 5.0 mg/cm^2/yr from the 1970s-2005.

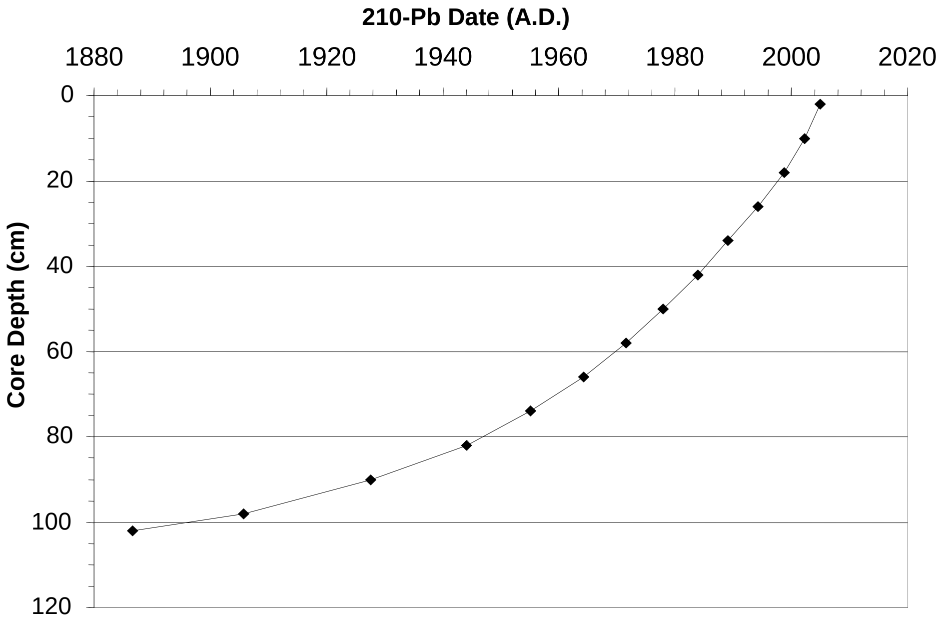


Figure 19. Resulting 210-Pb dating model for Bass Lake (SLBE) core.

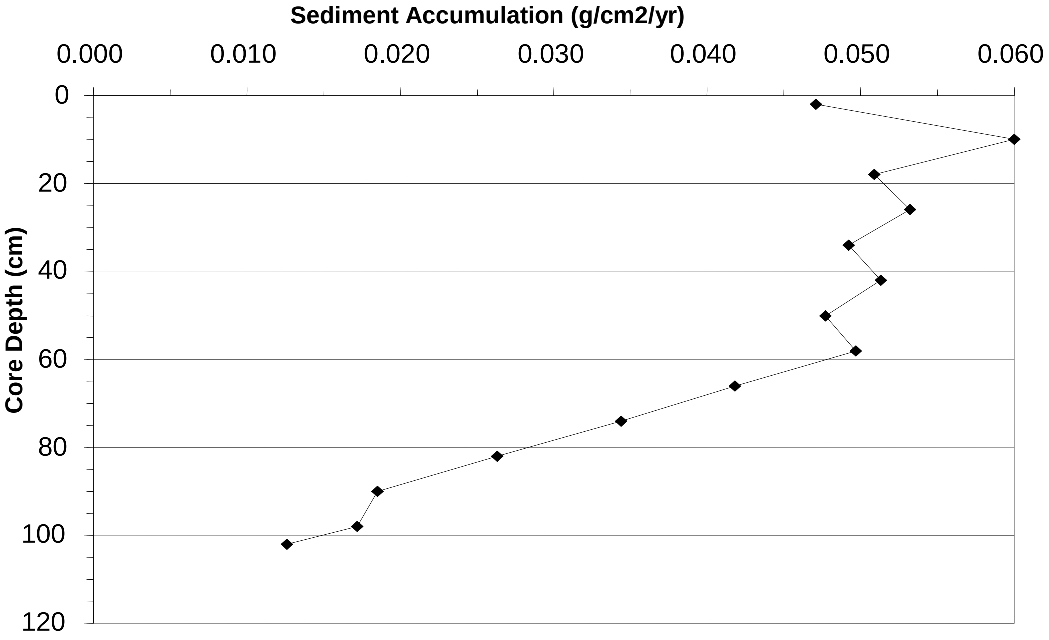


Figure 20. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Bass Lake (SLBE).

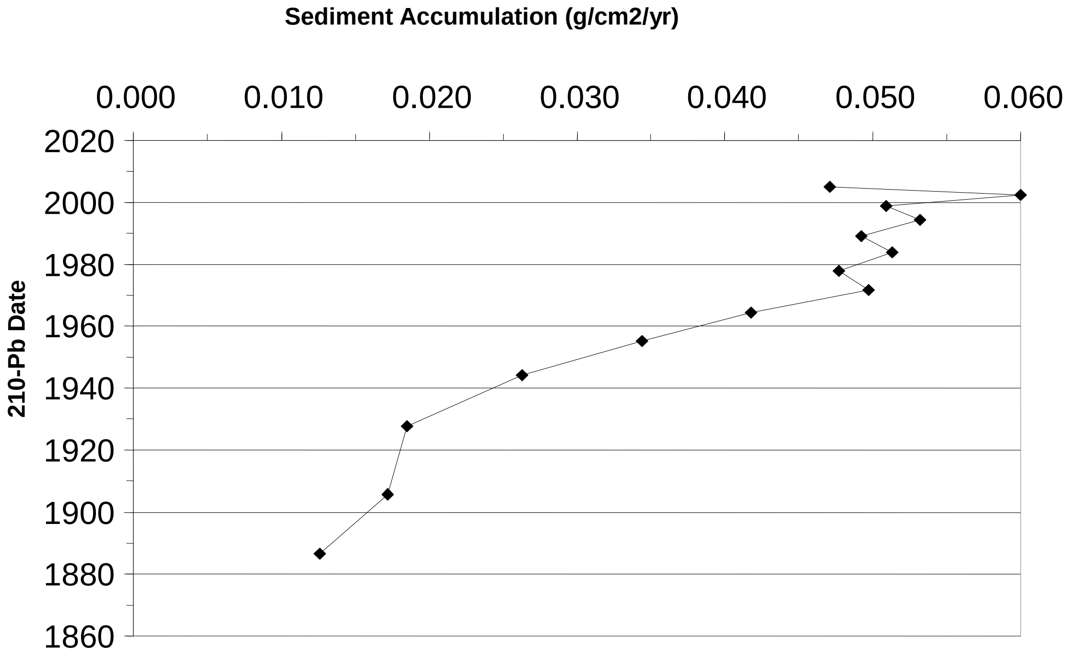


Figure 21. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Bass Lake (SLBE) core

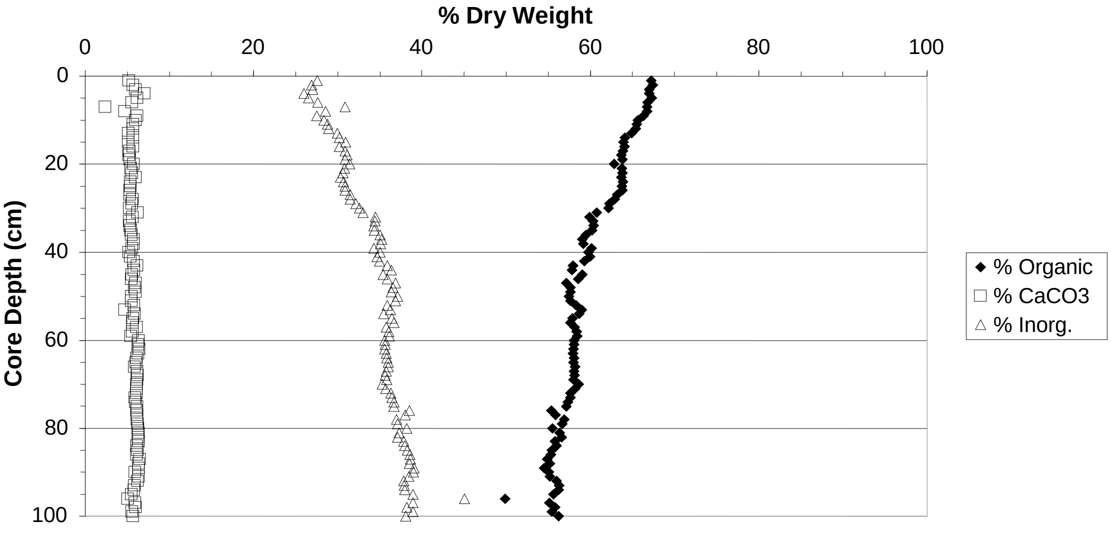


Figure 22. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Bass Lake (SLBE) core.

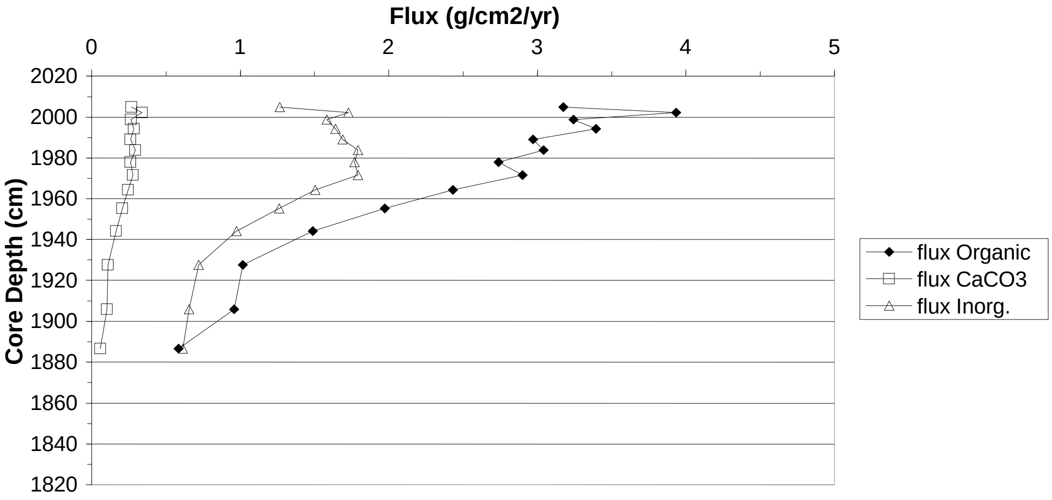


Figure 23. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Bass Lake (SLBE) core.

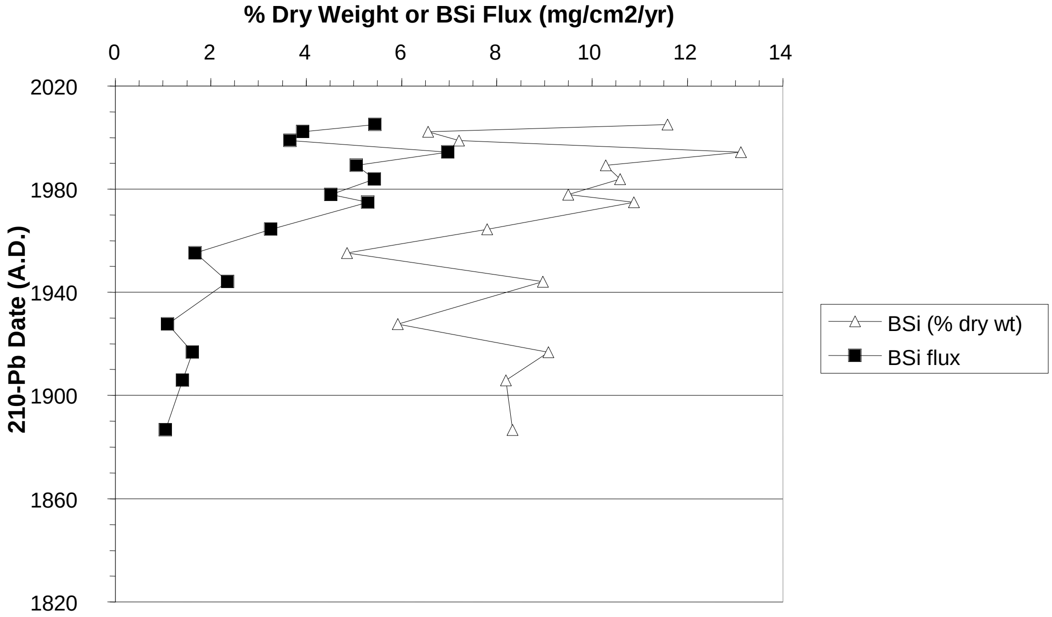


Figure 24. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Bass Lake (SLBE) core.

<u>Shell Lake</u>: Shell Lake sediments steadily declined in ^{210}Pb activities and reached supported levels in samples below 53 cm (Figure 25). Pre-Euro-American settlement sediments were present below 41 cm (ca. 1847) (Figure 26). Sedimentation rates increased dramatically in Shell Lake after 1880 from pre-1880 rates of <0.01 g/cm^2/yr to a peak in sedimentation of >0.035

g/cm^2/yr from the 1920s - 1960s (Figures 27, 28). Recent sedimentation rates were approximately 0.03 g/cm^2/yr or about three times pre-Euro-American levels. The geochemistry of Shell Lake sediments changed dramatically from pre-Euro-American sediments that were alternately dominated by organics or rarely by carbonates (Figure 29). The change in geochemistry began in the 1880s (36 cm) with a shift from about 50% dry weight organic content to less than 25% from 1920 to 1970. Simultaneously the carbonate content increased from about 15 to 20% dry weight to more than 50%. However, after the 1970s (above 15 cm), carbonate content decreased and organic content increased; both components have modern values of approximately 35 to 55% dry weight. Inorganics have usually been the minor sediment component in Shell Lake at about 20%. Notable in the inorganic record is a peak between 30 and 40 cm depth (ca. 1860-1910) that may correspond to logging at SLBE, and a slight decrease in inorganics near the core top (Figure 20). Accumulation rates of major sediment constituents also changed after about 1900 in Shell Lake. Carbonate flux increased to a peak in the 1960s before dropping in the last 25 years. Organic flux generally increased upcore, whereas inorganic flux rose from 1900 to 1960 before decreasing to current levels that are only slightly higher than pre-Euro-American rates (Figure 30). Pre-Euro-American BSi levels were about 6% dry weight in Shell Lake but dropped to 1 to 3% dry weight from the 1890s to present (Figure 31). Modern BSi values are from 2 to 3%. Flux of BSi varied little in Shell Lake in contrast to BSi percent dry weight due to the increased sedimentation rates in the 20th century.

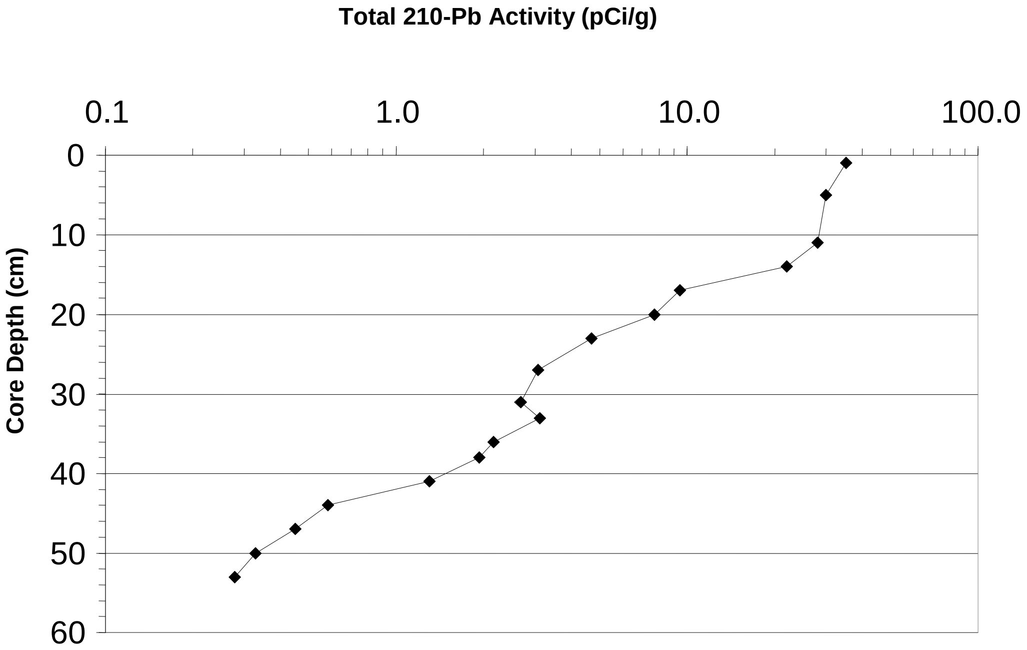


Figure 25. Total 210-Pb activity plotted against core depth (cm), Shell Lake (SLBE).

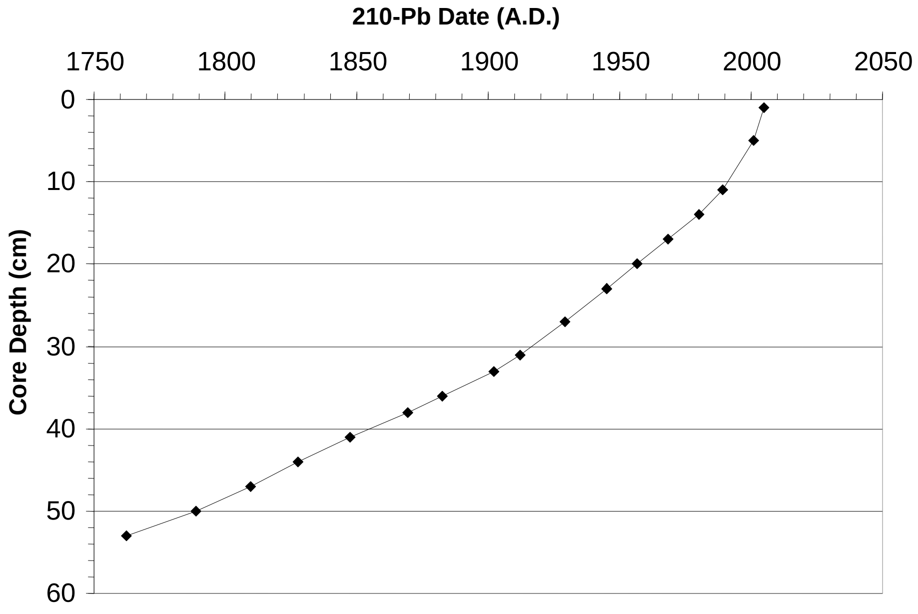


Figure 26. Resulting 210-Pb dating model for Shell Lake (SLBE) core.

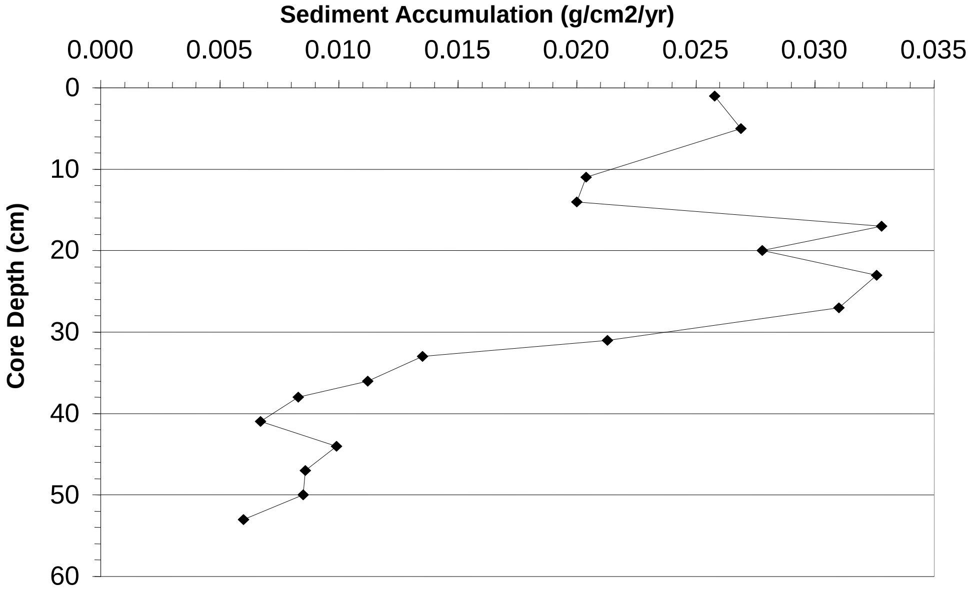


Figure 27. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Shell Lake (SLBE).

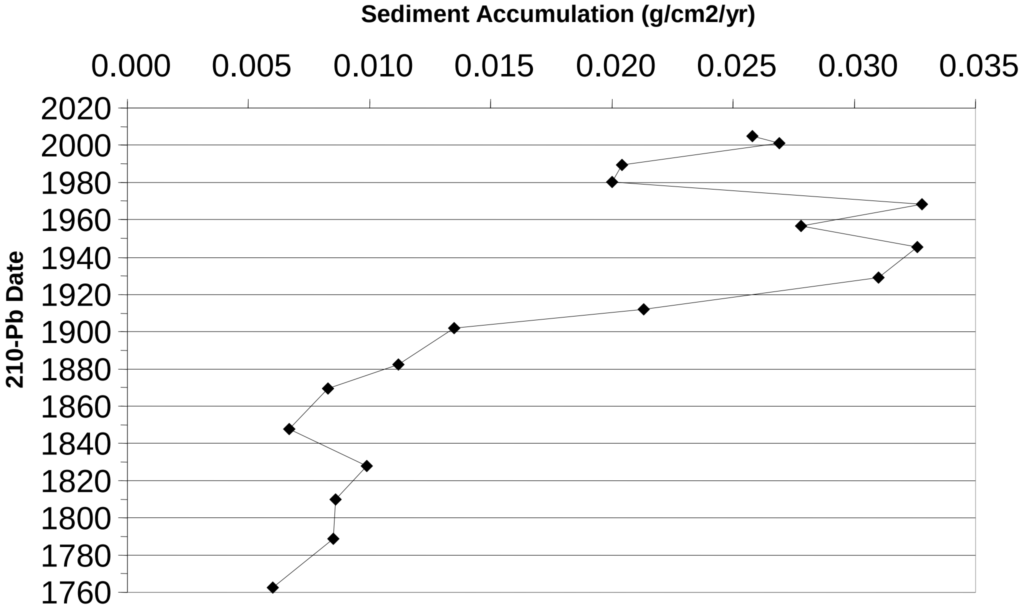


Figure 28. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Shell Lake (SLBE) core.

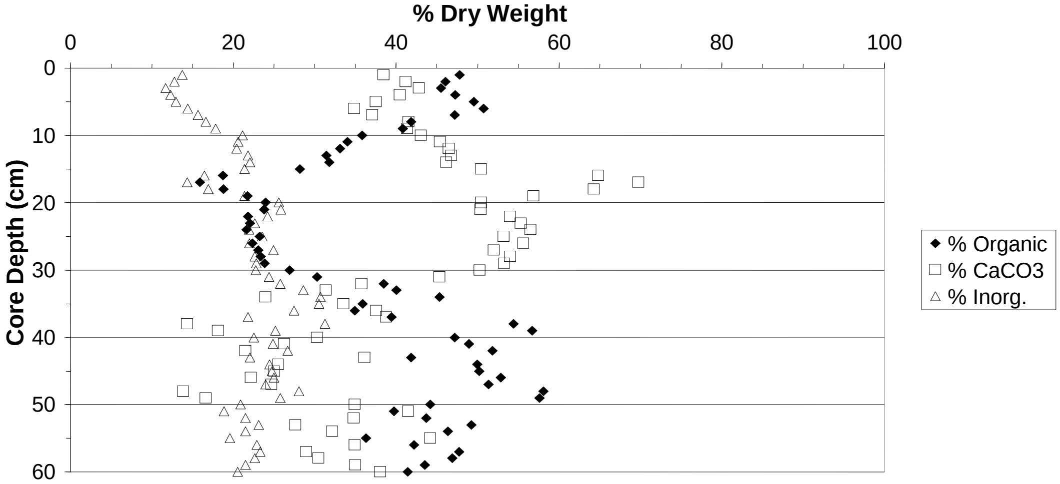


Figure 29. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Shell Lake (SLBE) core.

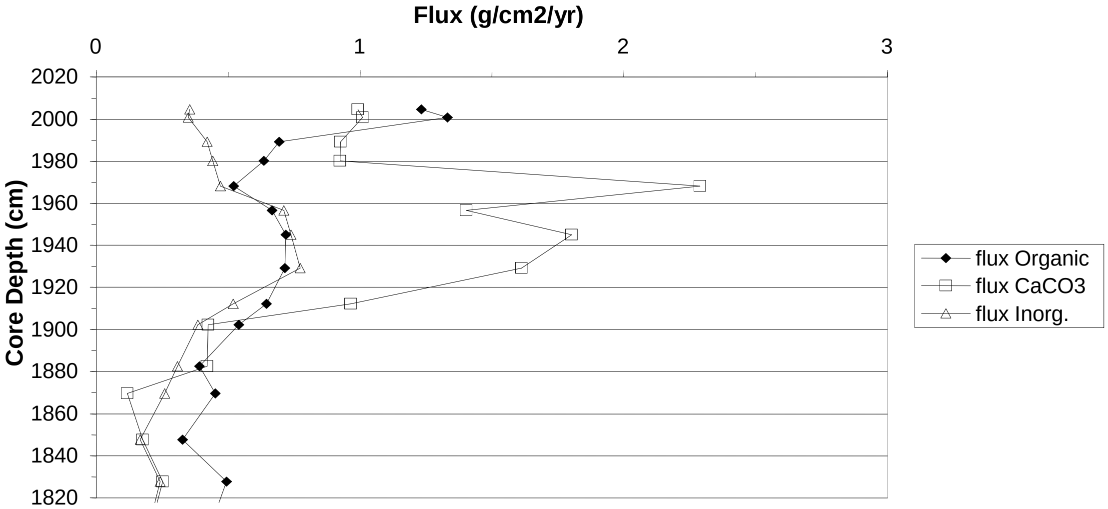


Figure 30. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Shell Lake (SLBE) core.

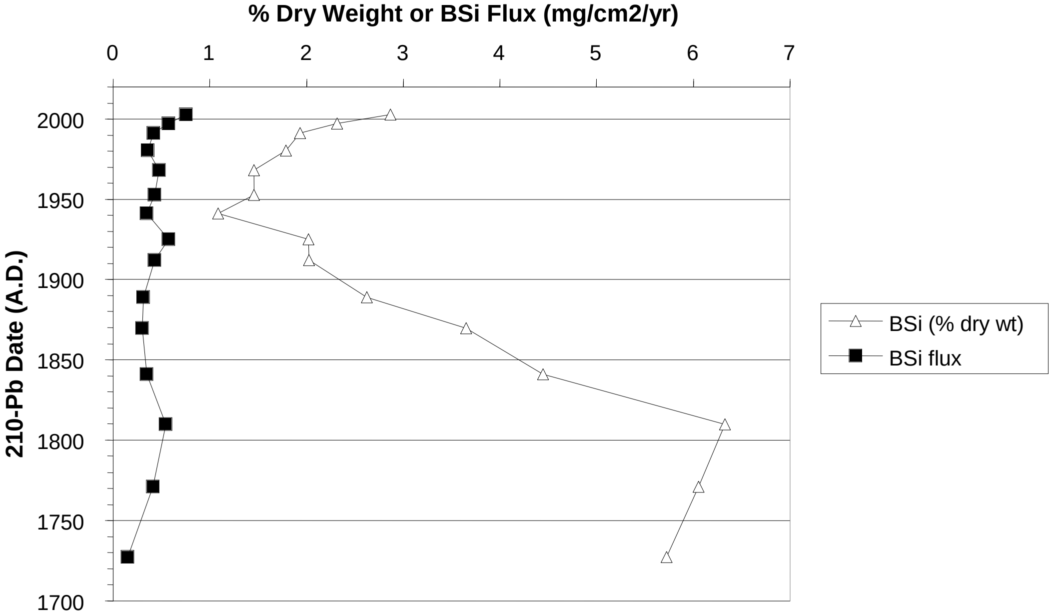


Figure 31. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Shell Lake (SLBE) core.

Manitou Lake: Lake Manitou cores illustrated a steady decline in ^{210}Pb activity reaching supported levels at approximately 75 cm core depth (Figures 32, 33; ca. 1830). Sedimentation rates in Lake Manitou varied considerably throughout the last 150 years. Most notable was a large increase in sedimentation rate between 1900 and 1920 that corresponded to land use changes on the island (Figures 34, 35). Modern sedimentation rates were approximately three-fold higher than pre-Euro-American settlement rates. The pre-Euro-American sediment was largely organic; however, dramatic changes occurred at about 50 to 55 cm depth (1890s) to a carbonate-dominated sediment (Figures 36, 37). Return to pre-settlement sediment composition or sedimentation rates did not take place after the large shift in the 1890s despite abandonment of all North Manitou Island farms by the 1950s. The large increase in carbonates is of interest and was probably a result of increased productivity, but we would then expect a similar increase in organics. We suggest that hydrology in the basin changed to bring additional carbonates into the lake, likely via groundwater sources. BSi content and flux temporally changed similar to organic and carbonates in Lake Manitou. BSi increased from < 3% dry weight before 1890 to modern values of 7 to 10% (Figure 38). BSi peaked in concentration and flux (16% dry weight and 5 mg/cm^2/yr, respectively) between the 1920s and 1940s in Manitou Lake before it decreased to modern concentration and flux levels that are three-fold higher than pre-Euro-American settlement rates.

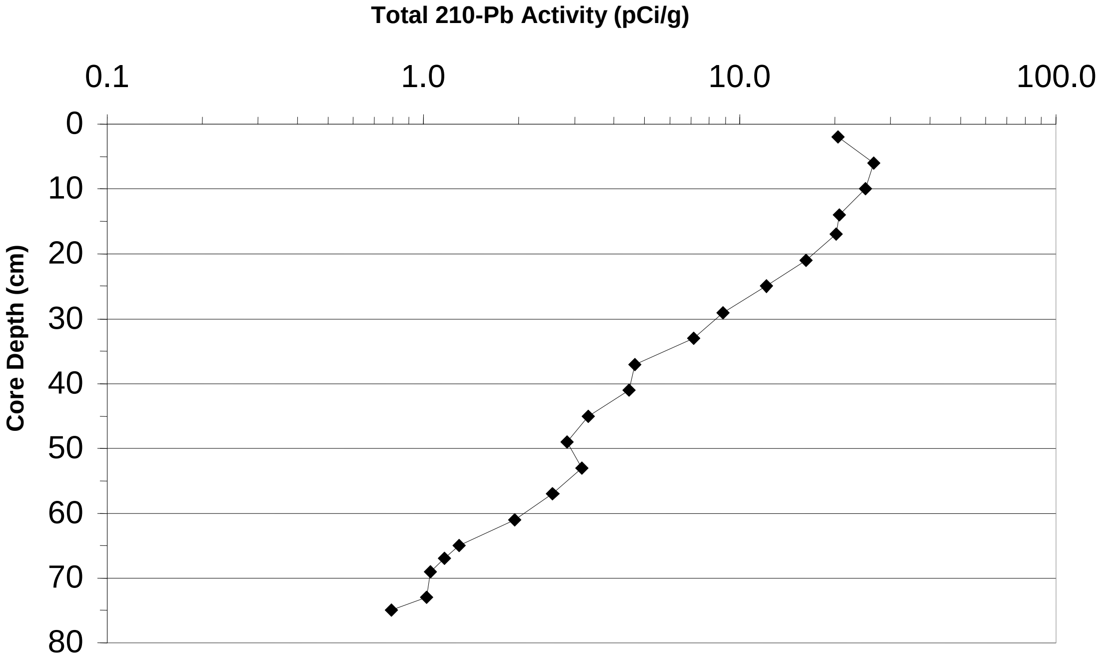


Figure 32. Total 210-Pb activity plotted against core depth (cm), Manitou Lake (SLBE).

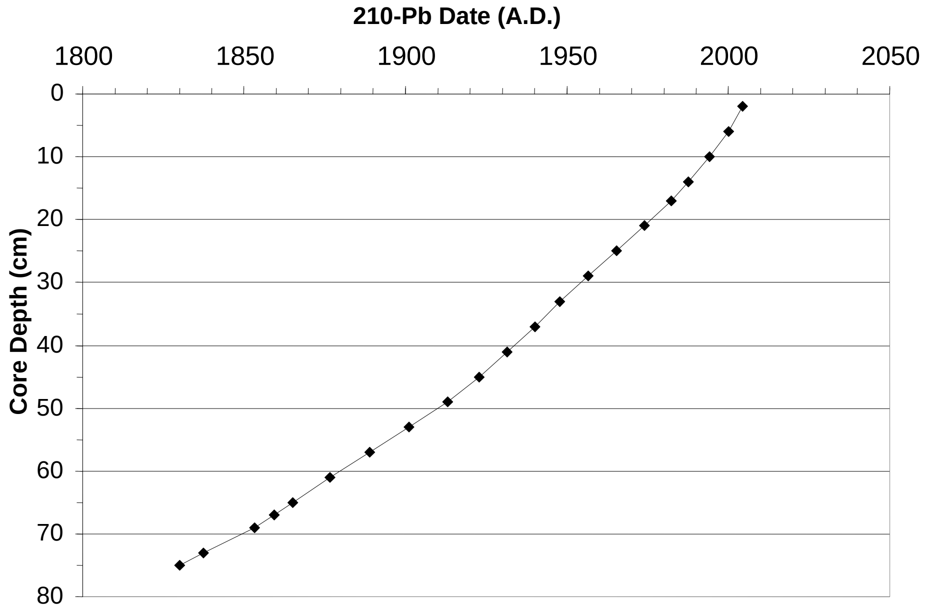


Figure 33. Resulting 210-Pb dating model for Manitou Lake (SLBE) core.

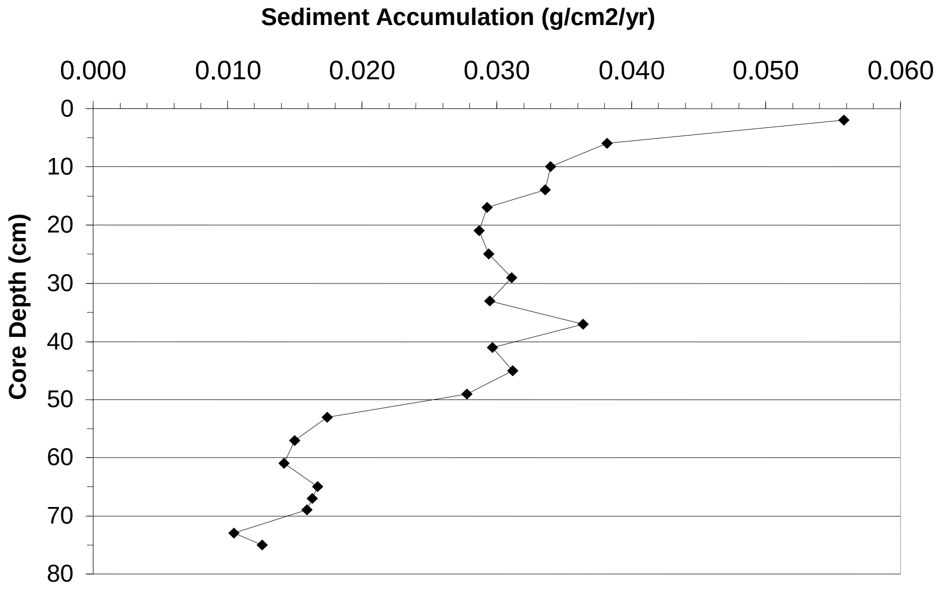


Figure 34. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Manitou Lake (SLBE).

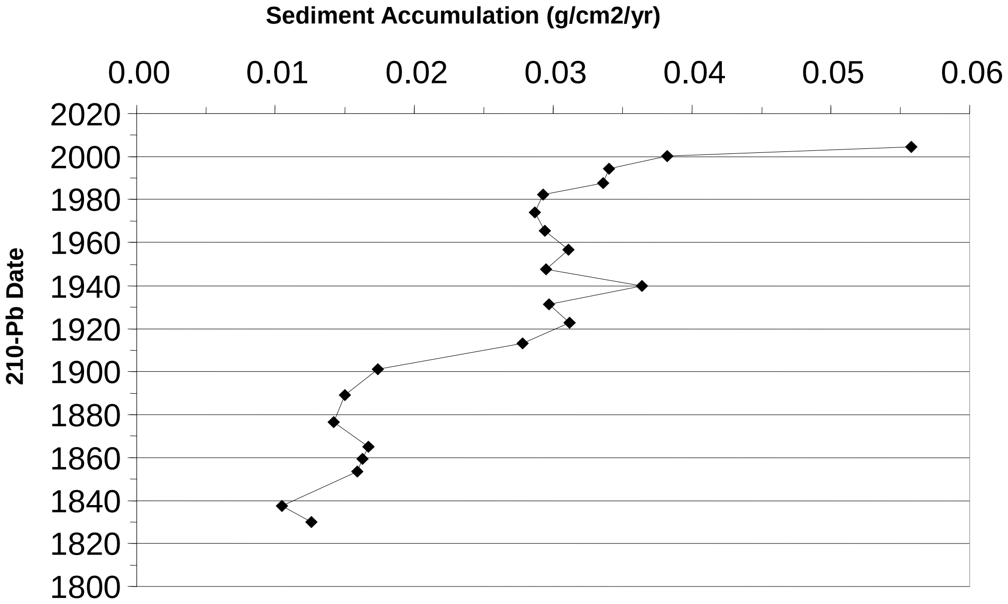


Figure 35. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Manitou Lake (SLBE).

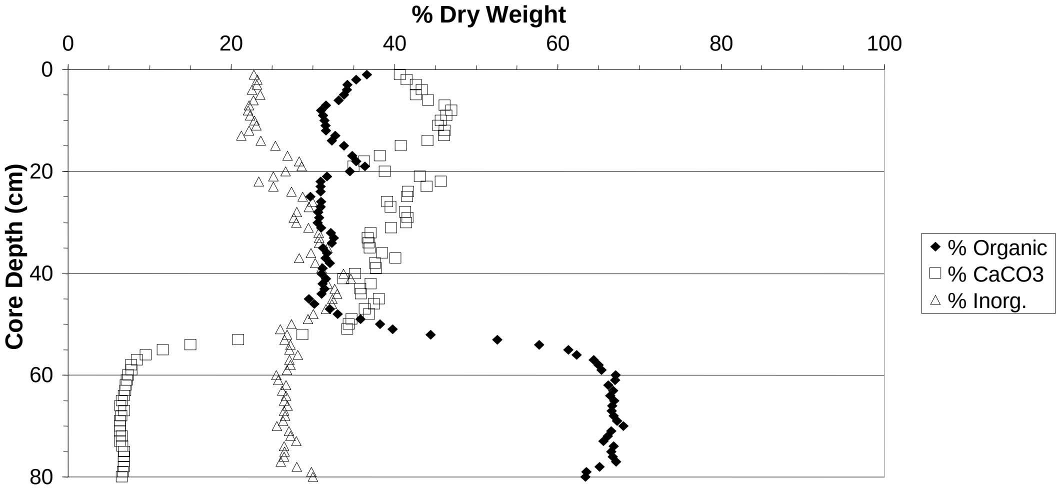


Figure 36. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Manitou Lake (SLBE) core.

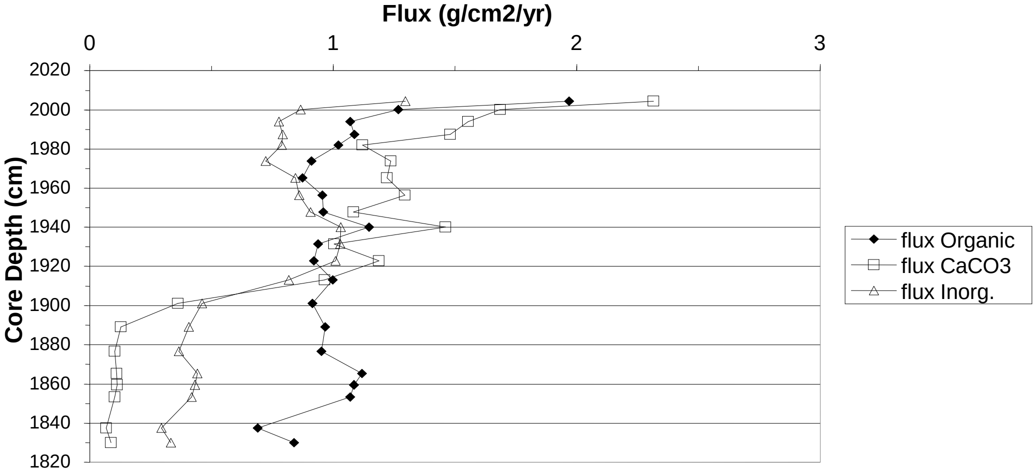


Figure 37. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Manitou Lake (SLBE) core.

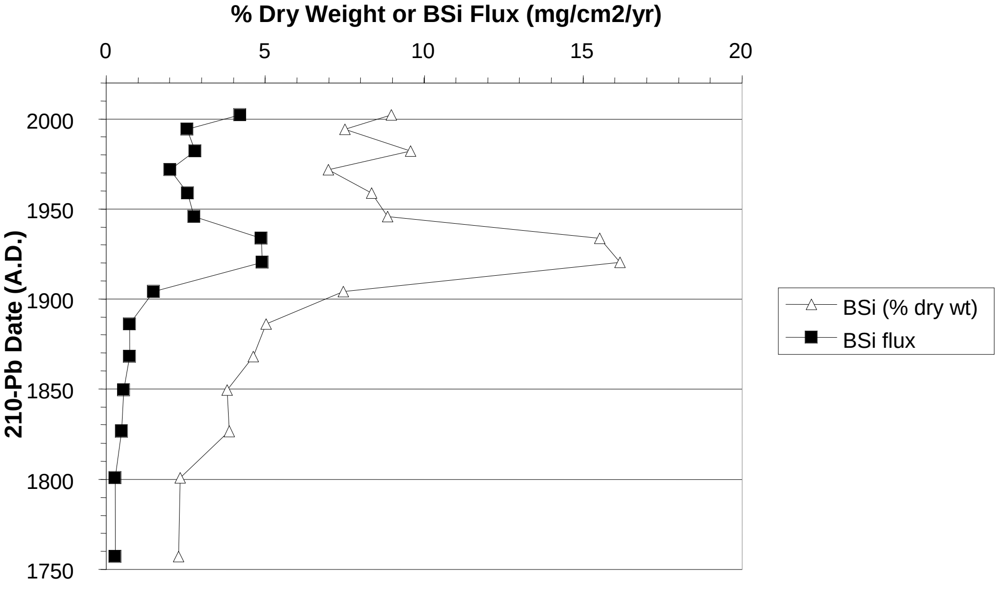


Figure 38. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Manitou Lake (SLBE) core.

<u>Florence Lake</u>: Levels of ^{210}Pb declined steadily to supported levels at 52 cm depth (Figure 39). Pre-Euro-American sediments were below 40 cm depth (ca. 1850) (Figure 40). Sediment accumulation rates in Florence lake increased above 40 cm from a pre-Euro-American rates of approximately 0.008 g/cm^2/yr to rates after the 1920s (30 cm) of about 0.013 to 0.016 g/cm^2/yr (Figures 41, 42). Sediments in Florence Lake were historically dominated by organic component with pre-Euro-American settlement proportions reaching over 60% dry weight. Inorganics were present at approximately 35 to 40% and carbonates made up less than 5% of pre-Euro-American

sedimentation in Florence Lake. Sediment composition changed sharply after 1850 or above 40 cm depth: organics decreased to ca. 45% dry weight and inorganics increased to about 50%.; In contrast, carbonate content altered little along the length of the Florence Lake core. Above 15 cm depth (ca. 1975) organics again increased and inorganics decreased in abundance to pre-Euro-American levels (Figure 43). Accumulation rates of organics and inorganics increased substantially after 1880 in Florence Lake until modern levels of 0.6-0.8 g/cm^2/yr were reached (Figure 44). BSi content of Florence Lake sediments varied between 4% and 5.5% dry weight. Flux of BSi increased from about 0.40 to 0.75 m g/cm^2/yr in post-1900 sedimentation (Figure 45).

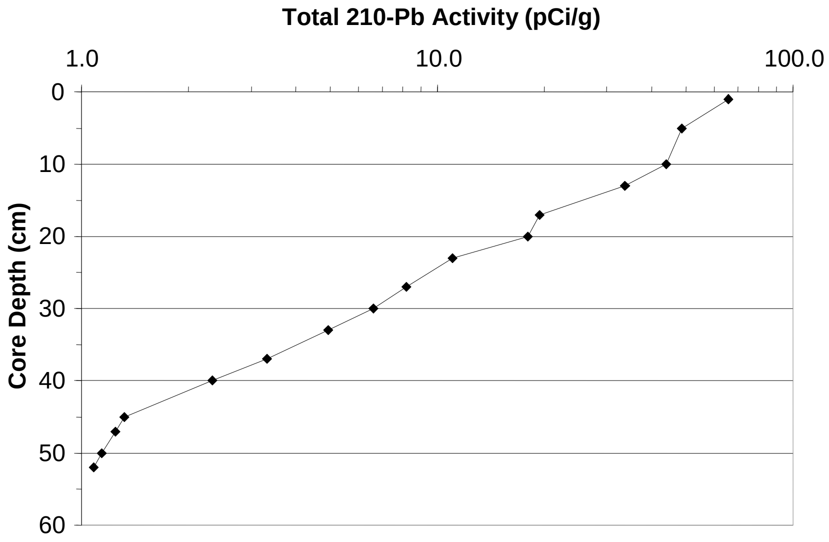


Figure 39. Total 210-Pb activity plotted against core depth (cm), Florence Lake (SLBE).

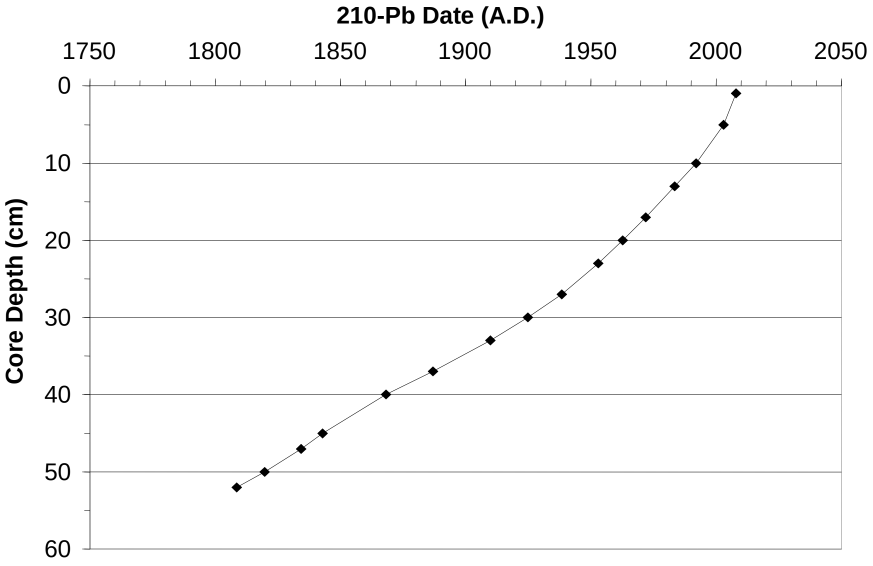


Figure 40. Resulting 210-Pb dating model for Florence Lake (SLBE) core.

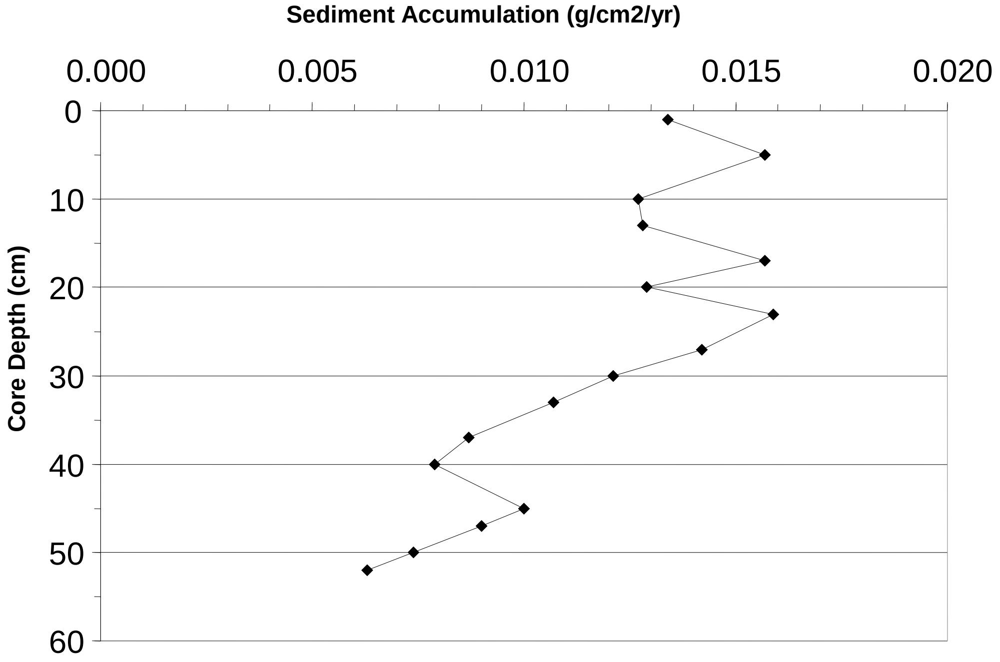


Figure 41. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Florence Lake (SLBE).

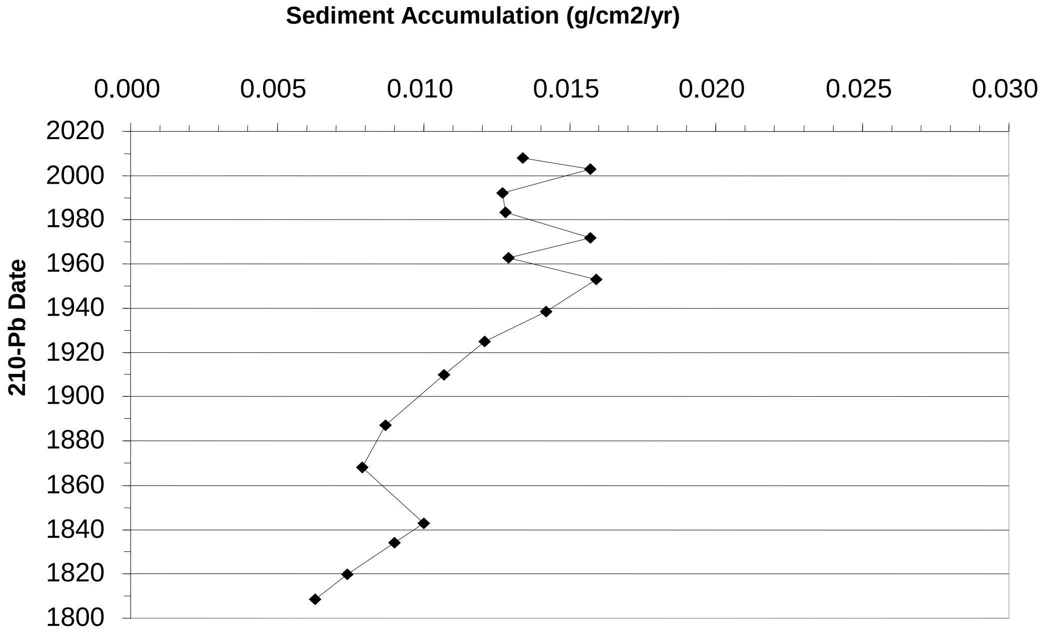


Figure 42. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Florence Lake (SLBE).

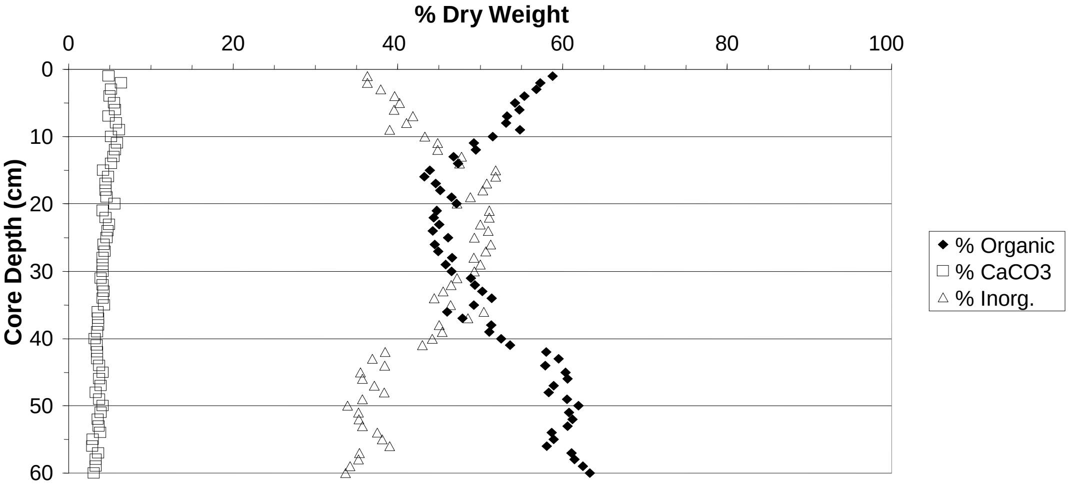


Figure 43. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Florence Lake (SLBE) core.

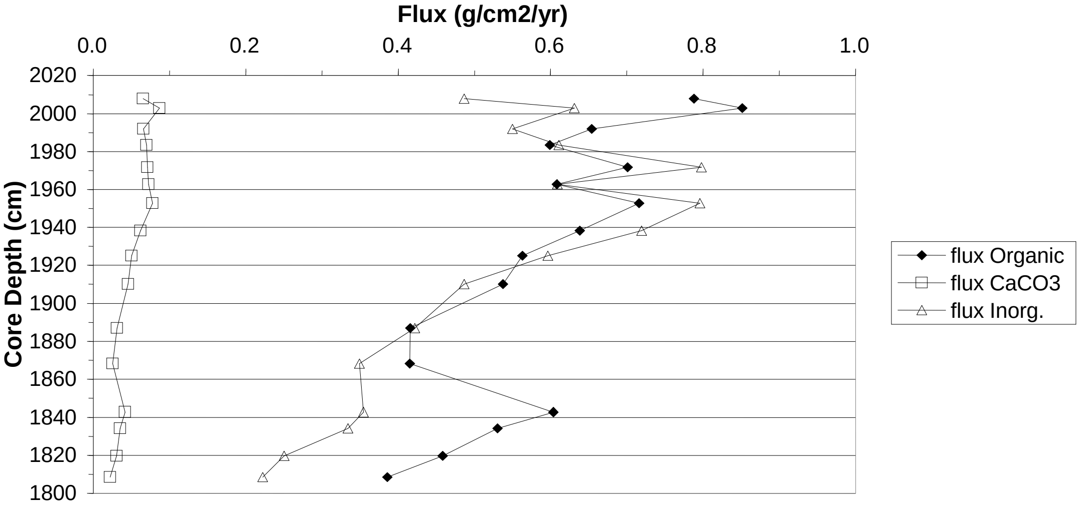


Figure 44. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Florence Lake (SLBE) core.

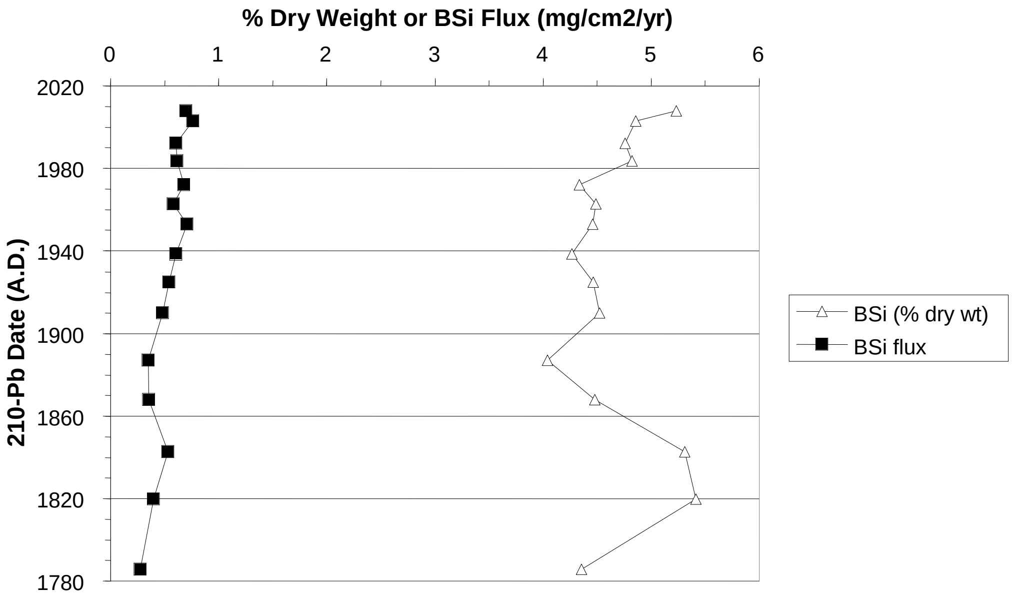


Figure 45. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Florence Lake (SLBE) core.

Downcore Diatom Communities (stratigraphy, cluster, ordinations)

Bass Lake: Sediments dated from 1887 to 2005 were analyzed for diatoms in the Bass Lake core. A DCA and constrained cluster analysis of subfossil diatom communities identified three stratigraphic zones: Zone 1 (1887-1944), Zone 2 (1955-1999), and Zone 3 (2002-2005) (Figures 46, 47). The flora of Bass Lake (Figure 48) was dominated by small *Cyclotella* or *Discostella* species including *C. comensis, C. michiganiana*, *D. stelligera*, and an unknown that we provisionally call *C.* sp. *mich-like*. Other minor components included small attached forms such as *Staurosira construens*, *Pseudostaurosira brevistriata* v. *inflata*, *Achnanthes saccula*, and *Achnanthidium minutissimum*. The stratigraphic zones were defined by their respective diatom floras. The planktonic forms *C. michiganiana*, *D. stelligera*, *Asterionella formosa*, and *Fragilaria crotonensis* and the attached forms *Staurosira construens*, *Pseudostaurosira brevistriata* v. *inflata*, *Achnanthes saccula*, and *Achnanthidium minutissimum* distinguished Zone 1 sediments. Zone 2 contained greater relative abundance of *C. comensis, C.* sp. *mich-like*, and a single peak of *Asterionella formosa* and decreased relative abundance of the attached forms and other planktonic taxa. The most recent sediments, Zone 3 had a greater relative abundance of *C.* sp. *mich-like*.

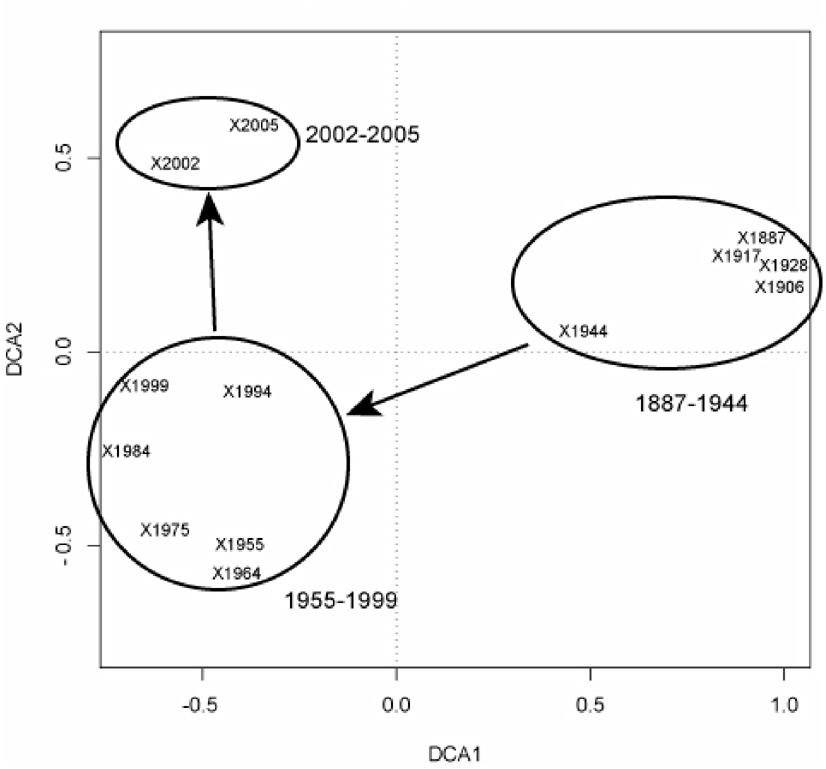


Figure 46. DCA of downcore diatom assemblages from Bass Lake core (SLBE, 1887-2005); axes 1 and 2 loadings plotted for core depths-dates.

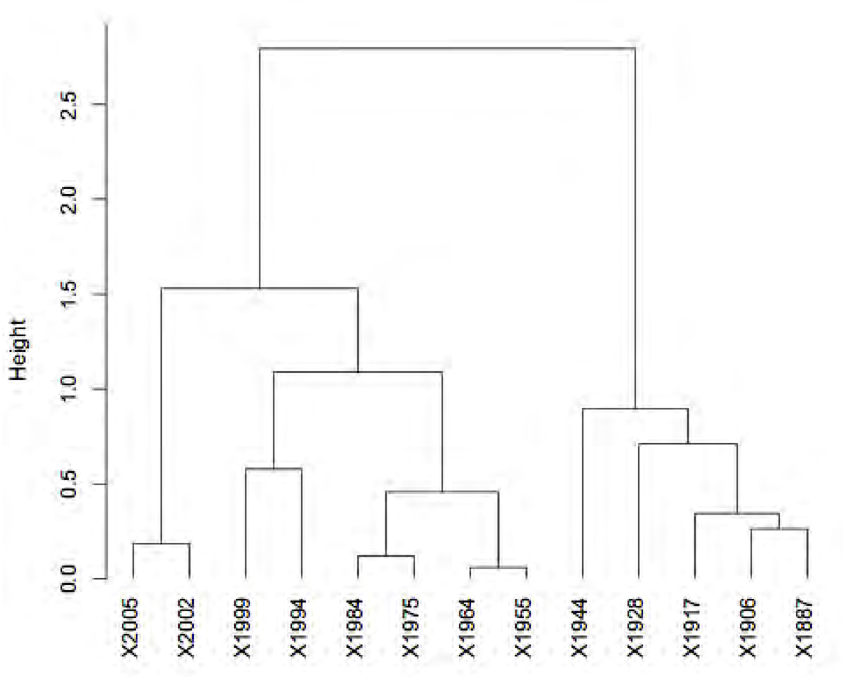


Figure 47. Constrained cluster analysis of downcore diatom assemblages from Bass Lake core (SLBE, 1887-2005).

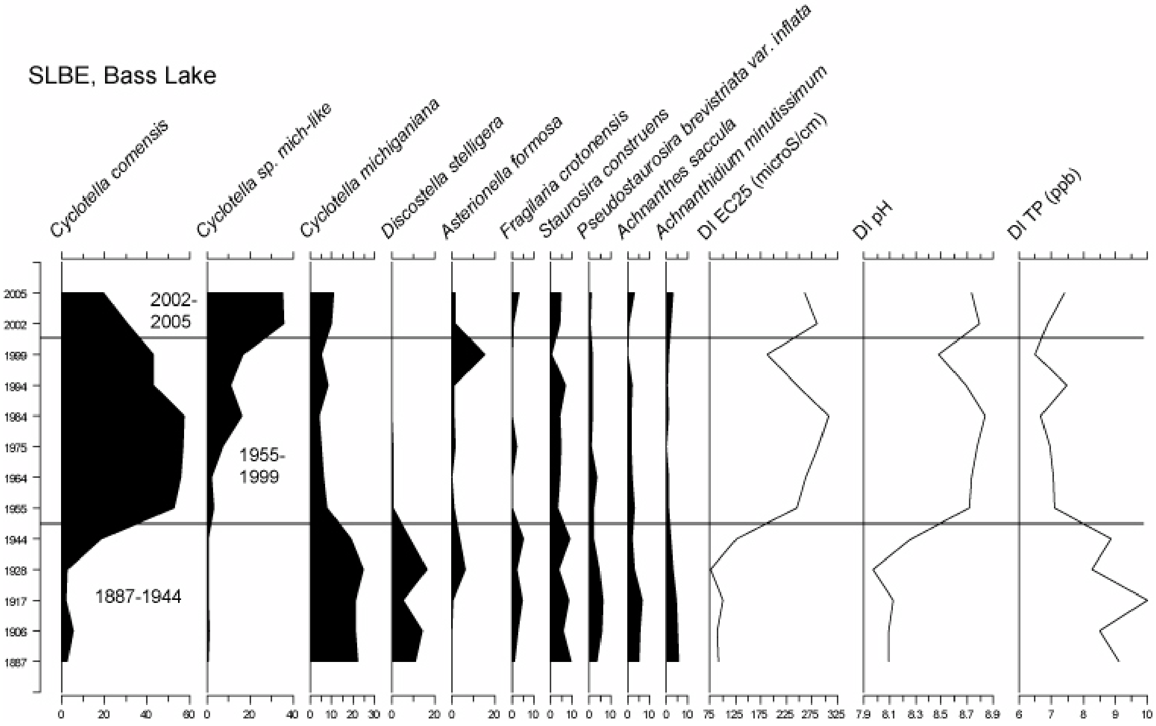


Figure 48. Stratigraphic diagram of relative abundance of dominant diatoms in Bass Lake core (SLBE, 1887-2005) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Shell Lake: Fifteen depths from the Shell Lake core were analyzed for diatoms and covered a period from 1727 to 2005. Three biostratigraphic zones were identified in the core using a DCA and a constrained cluster analysis: Zone 1 (1727-1870), Zone 2 (1889-1968), and Zone 3 (1980-2003) (Figures 49, 50). Shell Lake is very different than other SLBE lakes as its diatom community is currently and has been historically dominated by benthic diatoms, especially *Denticula kuetzingii* (Syn: *Nitzschia denticula*). Other benthic species common in Shell lake sediments included *Navicula vulpina*, *N. cryptotenella*, *N. rhynchocephala*, *N. cf. abiskoensis*, *Amphora libyca*, *Sellaphora laevissima*, and *S.* cf. *blackfordensis* (Figure 51). The only common planktonic form in Shell Lake was *Cyclotella michiganiana*, which was rarely present at greater than 2% relative abundance. Zone 1 sediments as a group had less variable diatom communities than other more recent periods in the history of Shell Lake. In addition to *Denticula kuetzingii*, Zone 1 sediments were dominated by *Navicula vulpina*, *N. rhynchocephala*, *Aneumastus tusculum*, among others. Zone 2 sediments were characterized by continued abundance of *Denticula kuetzingii* except in samples dated 1941 and 1953, when *Psammothidium abundans* var. *rosenstockii* dominated Shell Lake sediments. Zone 2 sediments also contained a peak in relative abundance of *Sellaphora laevissima*, *Placoneis explanata*, *Amphora libyca*, and *Achnanthidium minutissimum var. macrocephala*. Zone 3 was represented by four samples and diatom communities shifted toward a new ecological trajectory in contrast to Zone 2 assemblages. Driving this shift in Zone 3 sediments was continued relative abundance of *Denticula kuetzingii*, the establishment of *Navicula cryptotenella*, and loss or lower abundance of many Zone 2 diatoms including monoraphids, and the raphid taxa *Sellaphora laevissima*, *Sellaphora* cf. *blackfordensis*, and *Amphora libyca* (Figure 51).

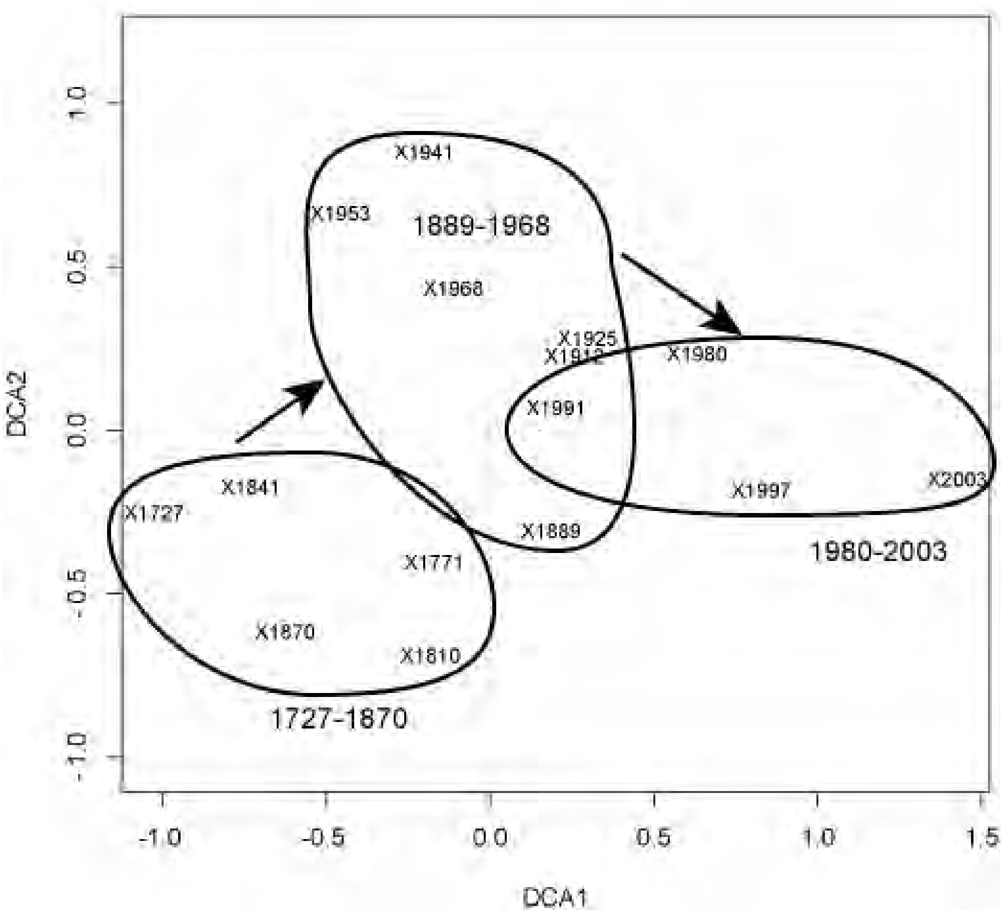


Figure 49. DCA of downcore diatom assemblages from Shell Lake core (SLBE, 1727-2003); axes 1 and 2 loadings plotted for core depths-dates.

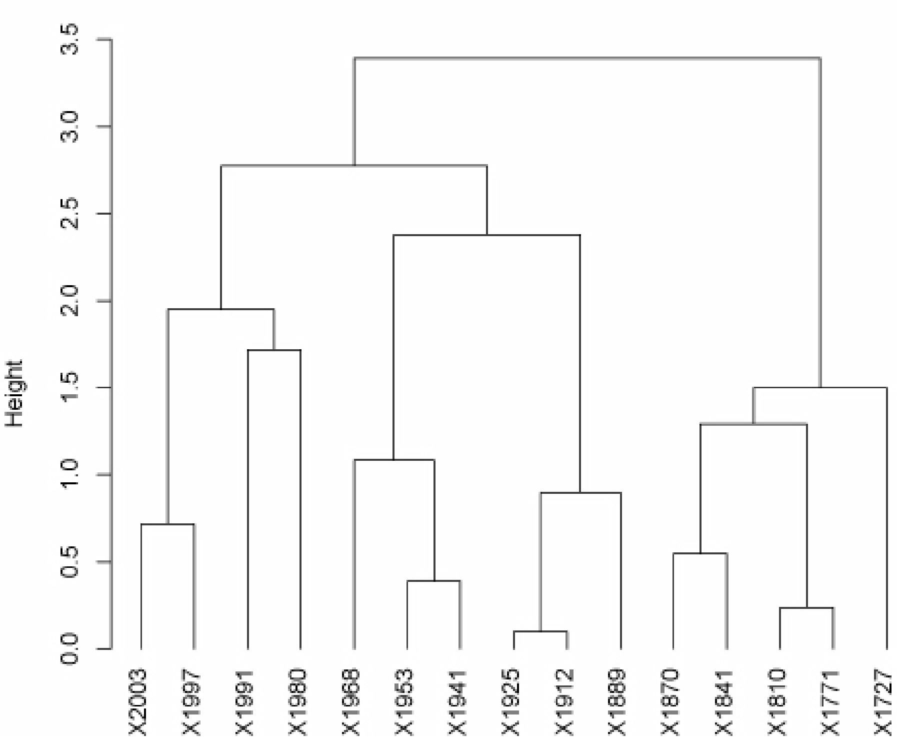


Figure 50. Constrained cluster analysis of downcore diatom assemblages from Shell Lake core (SLBE, 1727-2003).

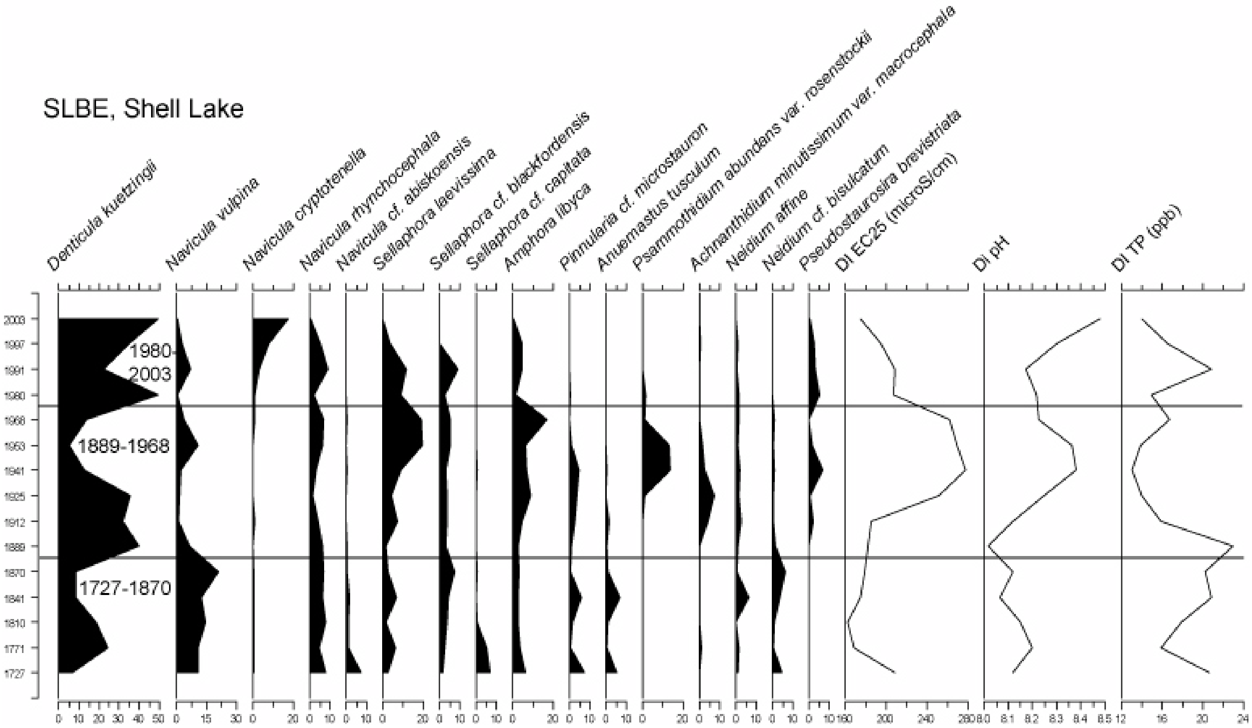


Figure 51. Stratigraphic diagram of relative abundance of dominant diatoms in Shell Lake core (SLBE, 1727-2003) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

<u>Manitou Lake</u>: Diatom communities were analyzed in 15 core sections covering 1757 through 2005. DCA and constrained cluster analysis of Manitou Lake show two periods of dramatic ecological change separating three historical assemblage zones: Zone 1 (1757 – 1886), Zone 2 (1904-1972), and Zone 3 (1982-2002) (Figures 52, 53). The planktonic diatom *Aulacoseira ambigua* dominated the diatom flora of Manitou Lake. Modern sediments were secondarily dominated by small *Cyclotella* species and *Asterionella formosa*; whereas historical assemblages had greater abundance of benthic species such as *Staurosira construens* and its var. *venter*, *Staurosirella pinnata,* and *Pseudostaurosira brevistriata* (Figure 54). The tight cluster in Zone 1 of the DCA indicated minimal ecological variability during this period of pre-Euro-American settlement. The Zone 1 diatom assemblage was characterized by greater abundance of benthic araphid taxa including *Staurosira construens* and its var. *venter*, *Staurosirella pinnata,* and *Pseudostaurosira brevistriata* and the raphid and monoraphid taxa *Sellaphora vitabunda* (not illustrated) and *Achnanthes zeigleri*, respectively. Zone 2 sediments showed greater variability among diatom assemblages. Zone 2 sediments were dominated by a rapid increase in abundance of *Aulacoseira ambigua*, establishment of planktonic centric diatoms *Cyclotella michiganiana, Discostella stelligera*, *Stephanodiscus minutulus* and *S. niagarae*, and araphid planktonic taxa *Fragilaria crotonensis* and *Asterionella formosa*, and a decreased representation by araphid taxa that dominated Zone 1 sediments. Zone 3 sediments represented a new trajectory for diatom assemblages in Manitou Lake. In Zone 3 sediments we see that dominance shifted from *Aulacoseira ambigua* to sudden dominance by small centric planktonic species (*Cyclotella comensis* and *Cyclotella* sp "*mich-like*"). *Stephanodiscus niagarae*, *Fragilaria crotonensis,* and *Asterionella formosa* remained important parts of the Zone 3 assemblage; however, other small centrics common in Zone 2 become less important in Zone 3. Similarly, benthic taxa common in Zone 1 were poorly represented in Zone 3 sediments.

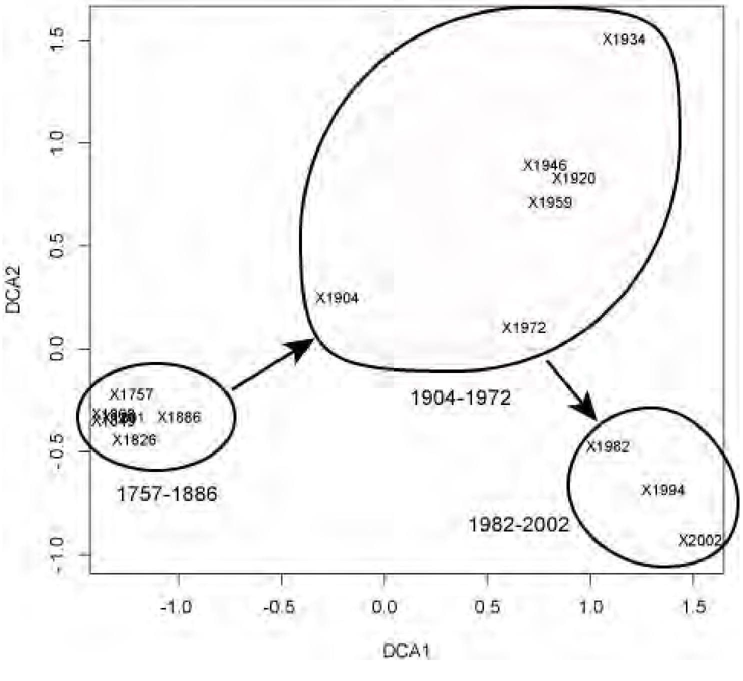


Figure 52. DCA of downcore diatom assemblages from Manitou Lake core (SLBE, 1757-2002); axes 1 and 2 loadings plotted for core depths-dates.

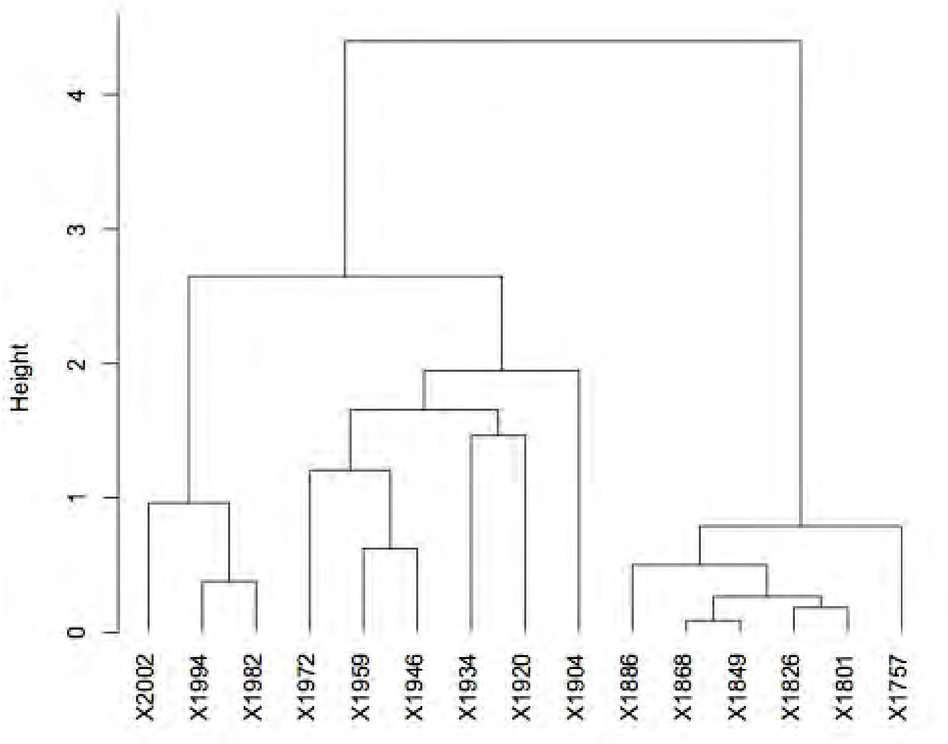


Figure 53. Constrained cluster analysis of downcore diatom assemblages from Manitou Lake core (SLBE, 1757-2002).

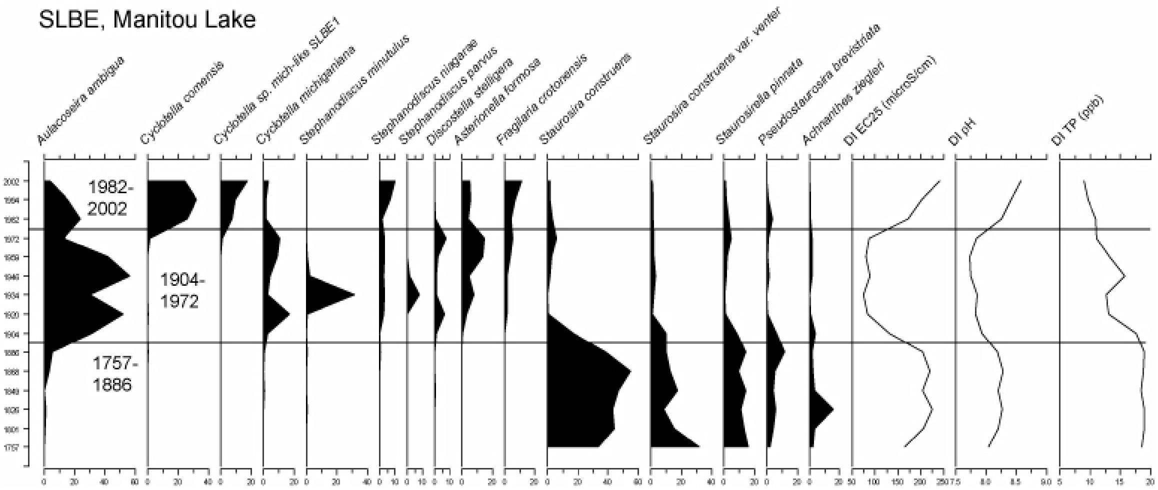


Figure 54. Stratigraphic diagram of relative abundance of dominant diatoms in Manitou Lake core (SLBE, 1757-2002) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Florence Lake: Sediment samples dating from 1786 to 2008 were analyzed for diatom remains in the Florence Lake core. A DCA and a constrained cluster analysis identified three biostratigraphic zones: Zone 1 (1786-1925), Zone 2 (1938-1984), and Zone 3 (1992-2008) (Figures 55, 56). A possible secondary splitting of Zone 1 sediments between 1843 and 1868 was also apparent in the DCA and cluster dendrogram (Figures 55, 56); Zone 1 sediments indicated the most variability in diatom communities among the levels we analyzed. From the perspective of Florence Lake's diatom community, the historical dominance of a single taxon, *Staurosira construens* v. *venter*, is noteworthy (Figure 57). This tiny species commonly grows attached to fine-grained sediments and can be abundant in shallow lakes. In Florence Lake, *S. construens* v. *venter* reached its highest abundance in Zone 2 sediments. Florence Lake sediments were secondarily dominated by planktonic *Cyclotella michiganiana*. Zone 1sediments, especially sediments dated 1786 to 1843, had an abundance peak of *C. michiganiana*. Other characteristics of Zone 1 included the first abundance of planktonic *Discostella stelligera* and *Puncticulata bodanica*, and abundance peaks of the benthic forms *Achnanthidium minutissimum*, *Navicula leptostriata*, and *Encyonopsis subminuta*. These attached forms had slightly lower abundance in Zone 2 sediments, a zone mostly characterized by a peak in abundance of *S. construens* v. *venter*. Zone 3 sediments had slightly greater abundances of *A. minutissimum* and *E. subminuta* and lower abundance of *S. construens* v. *venter* (Figure 57).

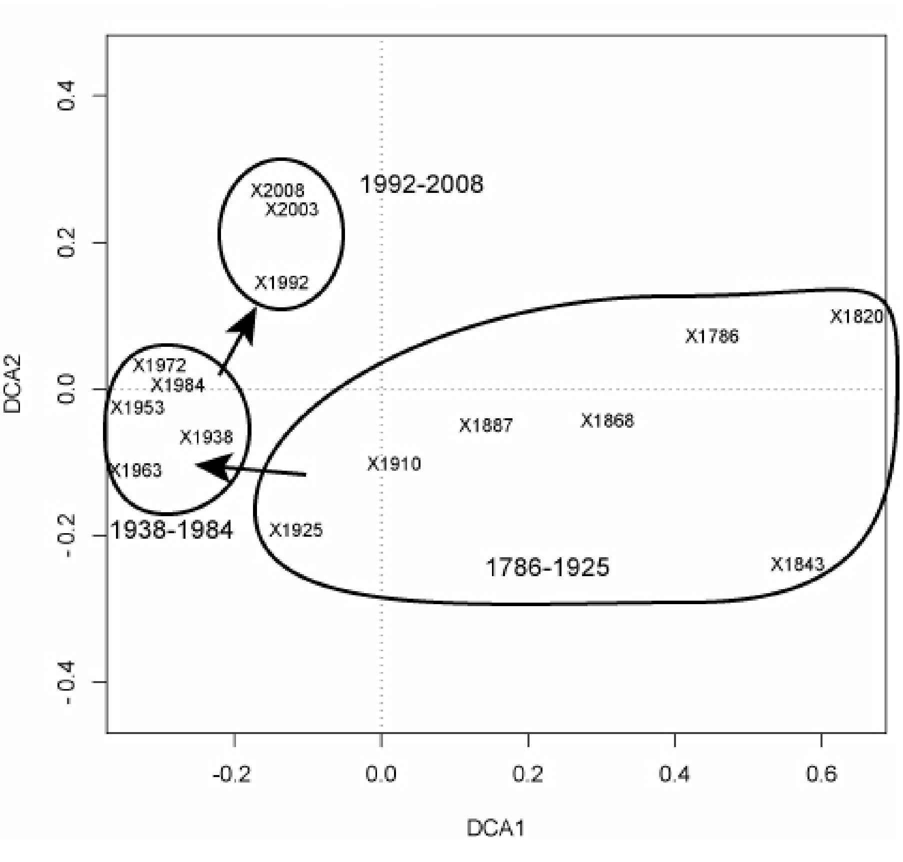


Figure 55. DCA of downcore diatom assemblages from Florence Lake core (SLBE, 1786-2008); axes 1 and 2 loadings plotted for core depths-dates.

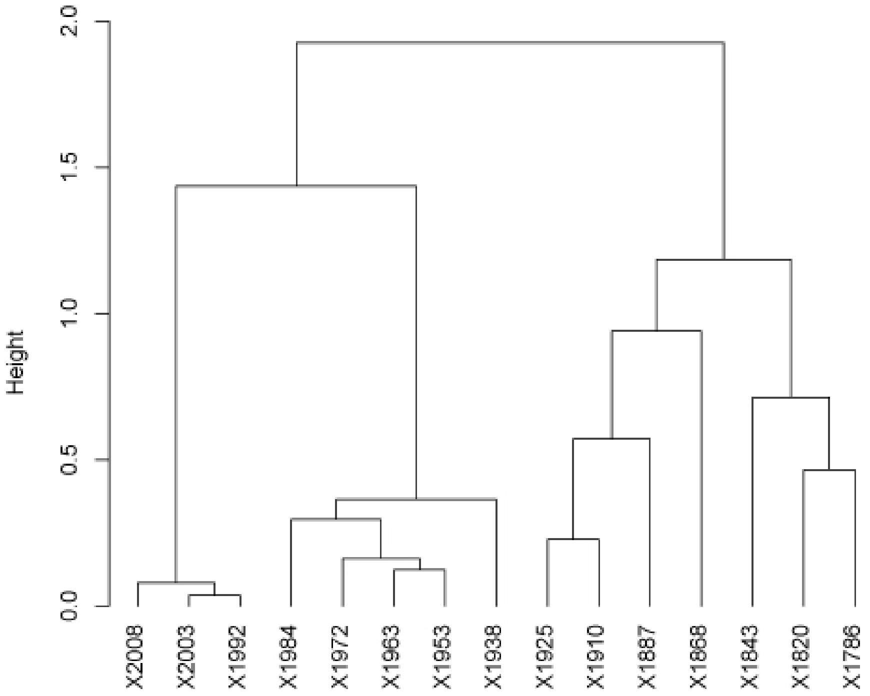


Figure 56. Constrained cluster analysis of downcore diatom assemblages from Florence Lake core (SLBE, 1786-2008).

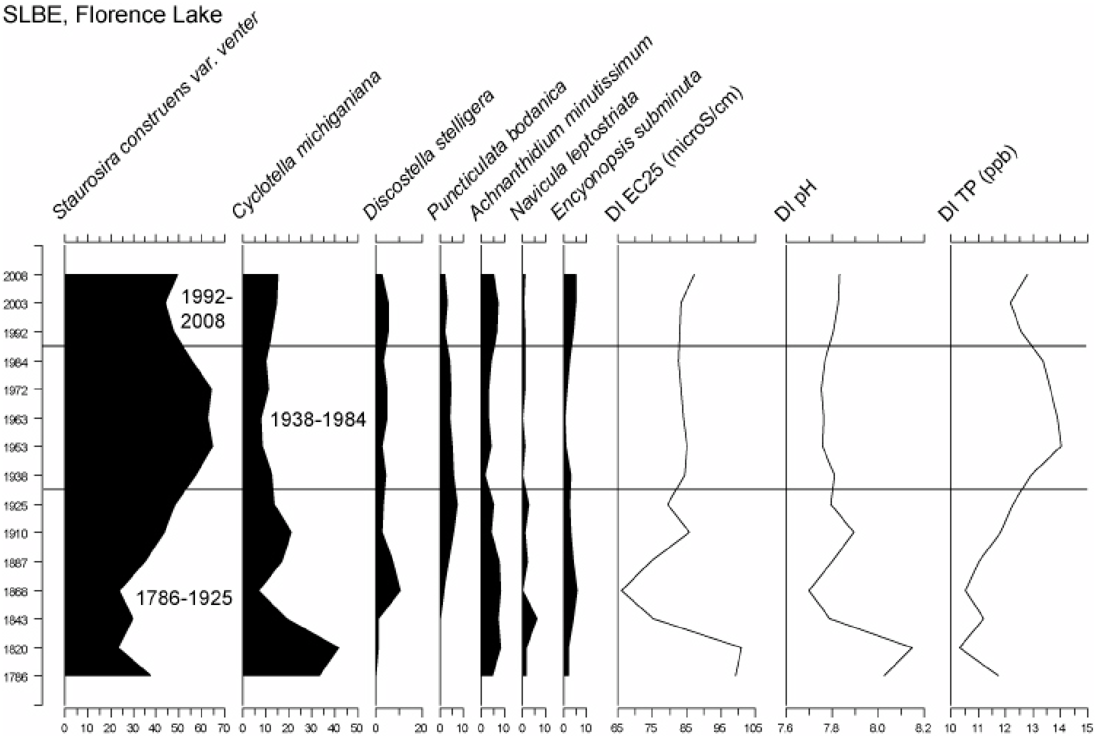


Figure 57. Stratigraphic diagram of relative abundance of dominant diatoms in Florence Lake core (SLBE, 1786-2008) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Environmental Reconstructions

Bass Lake: Diatom communities preserved in Bass Lake sediments were used to reconstruct historical water quality parameters including conductivity, pH, and total phosphorus. Diatom-inferred TP showed a slight trend toward lower values upcore; however, the changes cannot be considered significant. In contrast, diatom-inferred pH and conductivity showed significant increases between the 1920s and 1950s as pH increased from 8.0 to 8.7 and conductivity increased from 100 to 275 µS/cm (Figure 48). These inferred changes were most strongly controlled by the large shift in Bass Lake plankton community during this time period from domination by *Cyclotella michiganiana* and *Discostella stelligera* to overwhelming dominance by *Cyclotella comensis* (Figure 48). A passive plot of Bass Lake diatom communities in the sediment core on a CCA of the GLKN calibration set showed the large change in the lake between 1944 and 1955 reflected as a negative shift on axes 1 and 2 suggesting an increase in conductivity and pH of Bass Lake as well as significant movement along the DOC gradient (Figure 58).

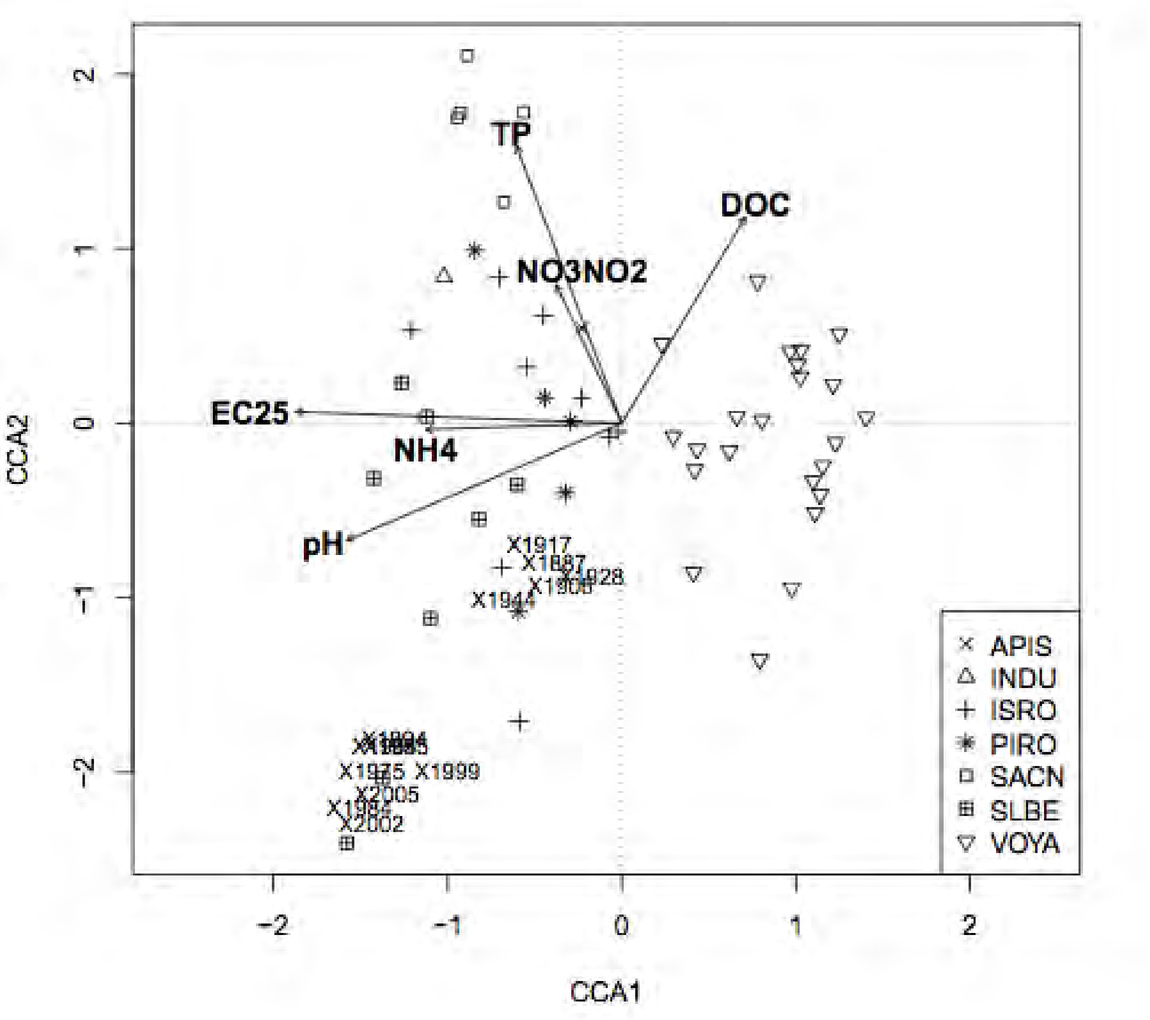


Figure 58. Diatom assemblages from the Bass Lake core (SLBE, 1887-2005) passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance.

Shell Lake: Diatom-inferred reconstructions of historical pH, conductivity, and TP of Shell Lake indicated several periods of significant change in the lake's past (Figure 51). Results of this analysis must be weighed carefully given that the Shell Lake surface sediment sample was considered an outlier for species assemblage and removed from the species-environment dataset during the development of transfer functions. Inferred pH showed a slight increasing trend upcore; however, the change was not significant based on model error estimates. Similarly, inferred TP varied from 13 to 23 ppb in the core with lowest values between 1940s and two peaks in the late 1800s and 1990s. Conductivity increased significantly from 180 µS/cm to nearly 260-280 µS/cm between the 1910s and the 1960s before returning to pre-Euro-American settlement levels by the 1980s-2000s. A passive plot of the Shell Lake core on a CCA of the GLKN calibration set showed small community shifts in comparison to all GLKN lakes with a mid-20th century decline along the TP gradient. (Figure 59).

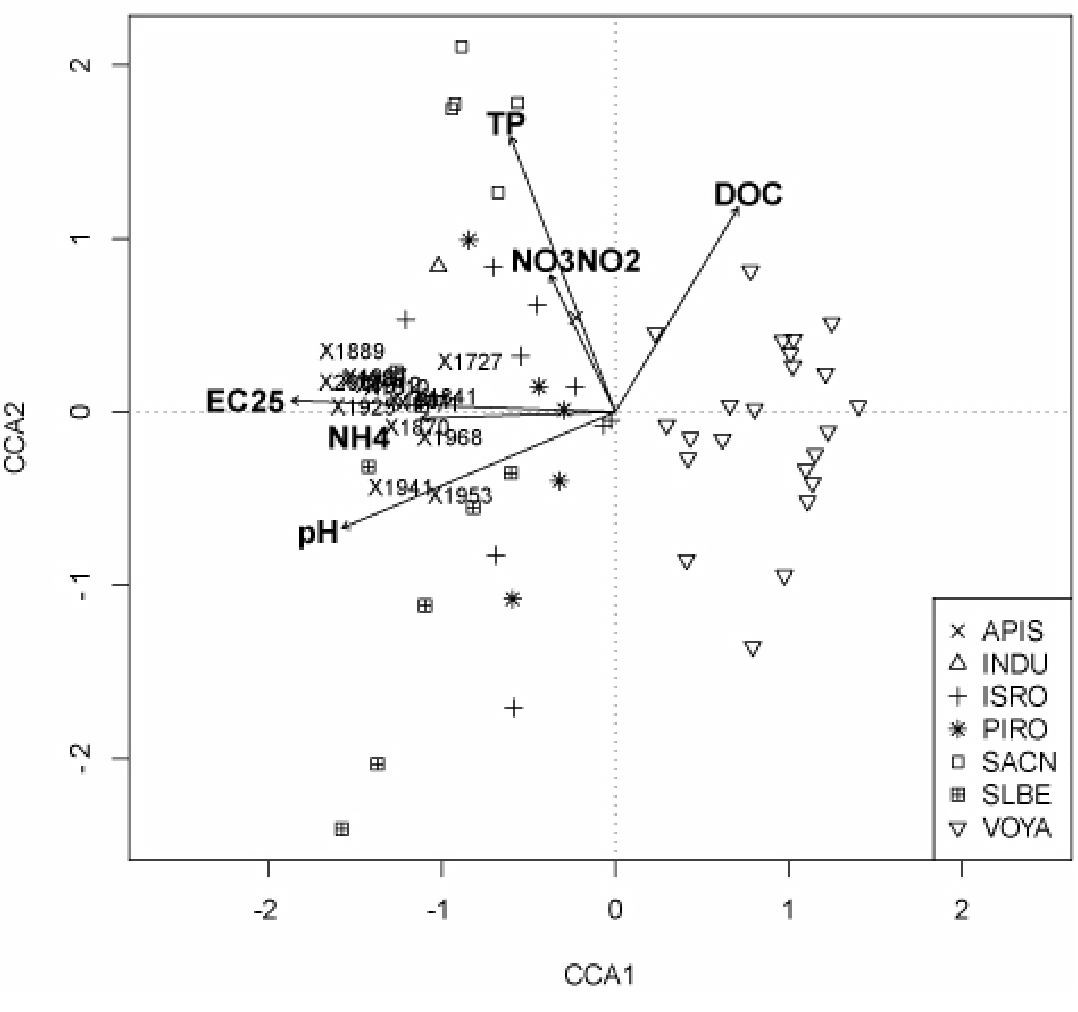


Figure 59. Diatom assemblages from the Shell Lake core (SLBE, 1727-2003) passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance.

Manitou Lake: With the large changes in geochemistry and diatom communities in Manitou Lake, inferred historical water quality changed significantly between 1757 and 2002 (Figure 54). Total phosphorus level decreased upcore; the shift from basal levels of 18 to19 ppb to upcore levels of 8 ppb was weakly significant based on model error estimates. Diatom-inferred pH varied between 7.7 and 8.5 in Manitou Lake. The pH between the 1960s and the core top increased significantly. Inferred conductivity varied between 240 and 75 µS/cm with lowest values between the 1920s and 1970s, concomitant with the large shift towards planktonic dominance by *Aulacoseira ambigua*. A passive plot of the Manitou Lake core's diatom communities on a CCA of the GLKN calibration set helped visualize the changes in Manitou Lake as core trajectory moved negative on CCA axis 2 (declining TP), and positive along CCA axis 1 in the middle of the core as pH and conductivity decreased (Figure 60).

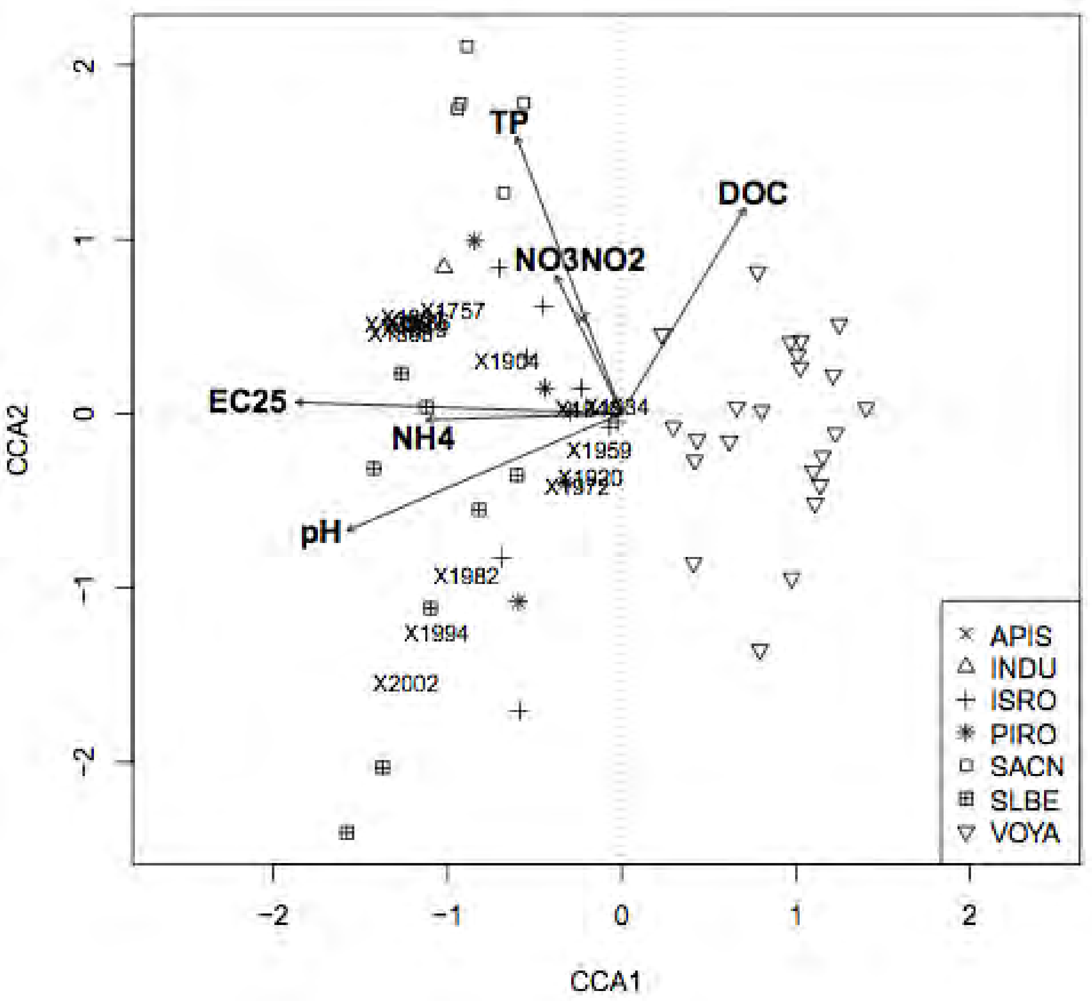


Figure 60. Diatom assemblages from the Manitou Lake core (SLBE, 1757-2002) passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance.

Florence Lake: Diatom-inferred changes in historical water quality of Florence Lake were less pronounced than other SLBE lakes (Figure 57). Changes in historical TP were not significant, between 10 and 14 ppb. Similarly, pH remained near ca. 7.8 during the last 220 years in Florence Lake except for a small peak of 8.1 at the core base when *Cyclotella michiganiana* dominated the plankton. Conductivity varied between 65 and 100 µS/cm with variability only in the pre-Euro-American period of the lake's history; upcore conductivity varied little and reconstructed around 85 µS/cm. A passive plot of Florence Lake diatom communities onto the GLKN calibration set CCA showed minor change in cores, although the 1820 sample was pulled from the main group along the pH axis (Figure 61).

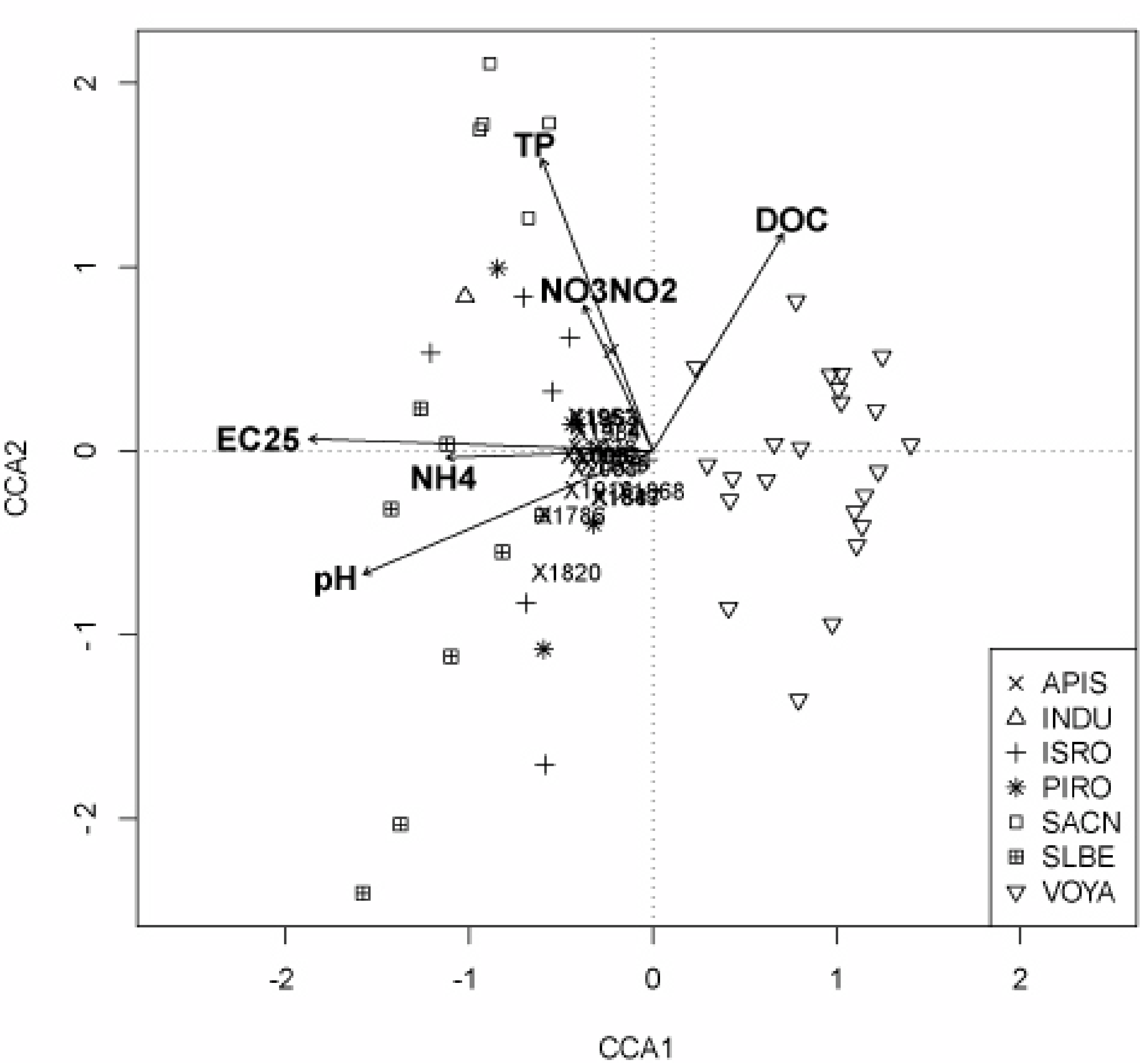


Figure 61. Diatom assemblages from the Florence Lake core (SLBE, 1786-2008) passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance.

Relation to Land Use/History

Because of its tempered Great Lakes climate, land use history of SLBE was dominated by agricultural activity (Haswell and Alanen 1994, MacDonald and Alanen 2000) more than many other GLKN parks. Several Native American villages were present before the 1840s and included some subsistence agriculture. Euro-American settlers arrived in the 1840s with an economy centered on supplying cordwood for Great Lakes steamships. Settlers also engaged in subsistence agriculture raising potatoes and corn. Increasing numbers of foreign settlers arrived in the 1860s with communities focused on cordwood production for fueling steamships, but with increased agricultural interests. By the 1870s the cordwood industry declined; however, the arrival of rail and improved roads opened up markets for agricultural products, especially fruit production. Rail also opened up additional forests for logging and by the 1890s, forest products dominated the local economy. The 1890s began the decline of logging, but with increased orchard production and beginnings of the tourist industry in the area. Following the turn of the 20th century, farming began a slow decline that persists today. The number of farms decreased, but remaining farms increased in size. Following World War II, farming steeply declined with loss of 40% of the farms between 1945 and 1950. This trend continued into the 1970s and was concomitant with land also being removed from production. For example, in 1910 approximately 50% of Benzie County was in agricultural production, but by 1969 only 19% of the land was in crop production. North Manitou Island saw an earlier decline in farming beginning in the 1890s with the last independent farmer leaving the island in 1940 (MacDonald and Alanen 2000). South Manitou Island was one of the first places settled in Michigan's northwest Lower Peninsula. A steamboat landing providing cordwood to steamships was present as early as 1838 at which time the island's forests began to be cut (Vent 1973). Homesteaders arrived in the 1850s bringing much of the cutover area on the island into agricultural production, while the island continued to be a stopping point for ships for wood and supplies. The population of South Manitou Island peaked at around 100 residents in the 1880s, with most residents involved in farming. Logging continued through the early 1900s. Efforts to develop the island as a tourist destination began at the end of the 19th century and continued through the 1940s as various groups invested in developing the island. But, as the steamship economy in the region changed to railroad and truck transportation in the 1920s, the ability to market fruit and crops from the island became unprofitable and farms started to be abandoned. Agriculture continued into the 1940s with the island having some fame for its seed production of rye and pea beans (Vent 1973). With the decline in agriculture throughout the Sleeping Bear Dunes region, tourism, retirement, and hobby homes increased in the area. In October 1970, Sleeping Bear Dunes National Lakeshore was established.

Park Summary

Among the GLKN parks where long sediment cores were studied, historical changes in the inland lakes of SLBE were the most variable and showed some of the greatest biological shifts, partly due to the relatively large range of lake types present. Bass Lake presented some difficulties in interpretation because we were unable to recover pre-Euro-American sediments; our lowest core depth recovered was dated 1887 AD.

Common patterns among the SLBE inland lakes included increased sedimentation rates at the time of Euro-American settlement and initial land clearance that could be dated between 1880 and 1900. Geochemical changes often accompanied changes in sedimentation rates; carbonates increased substantially in Shell Lake and Manitou Lake at the time of Euro-American settlement and inorganics increased slightly in Florence, Manitou, and Shell lakes. The latter response was common among many GLKN lakes, whereas the increase in carbonates was a feature of only the two SLBE lakes. Increased carbonate content and flux is sometimes attributed to increased algal productivity (Edlund et al. 2009a). Supporting evidence for productivity changes were found in higher BSi in Manitou Lake; however, no such change was observed in the Shell Lake record, where BSi flux remained constant throughout the core. Alternatively, alterations in hydrology following land clearance may have also led to increased delivery of carbonates via groundwater sources.

Biological changes recorded in the SLBE sediment cores were not temporally consistent among lakes. Both Shell Lake and Manitou Lake showed initial changes in diatom communities during the late-1800s, consistent with landscape and lake responses to initial Euro-American settlement and land clearance. In contrast, the first major shifts in diatom communities in Florence Lake occurred between 1925 and 1938. The diatom communities in Florence Lake were highly variable between 1786 and 1925; perhaps only after initial logging, Euro-American settlement, and collapse of farming did Florence's diatom communities establish any stability. Lastly, initial alterations in Bass Lake in response to Euro-American settlement and land clearance were possibly not captured in the sediment core we analyzed.

Additional biological changes occurred in upcore sediments of the SLBE lakes concomitant with park formation and/or with diatom community trends that may be linked to climate warming (Rühland et al. 2008). The latter shift in diatom communities occurred as early as 1968 to 1980 in Shell Lake and as late as 1984-1992 in Florence Lake. The biological and limnological response was more difficult to interpret from the benthic-dominated communities in Shell and Florence Lakes; whereas, a similar pattern of increase in cyclotelloid plankters as seen in other GLKN lakes occurred in Bass and Manitou Lakes. Likewise, decreased abundance of *Aulacoseira* occurs in Manitou Lake around 1982. These patterns have been linked to changes in lake stratification and nutrient cycling (Rühland et al. 2008).

Long Sediment Cores (PIRO)

Core Collection

Two long cores were collected from lakes in Pictured Rocks National Lakeshore to understand how lakes have changed during the last 150 to 200 years (Table 6). In July 2005, a 141 cm long core was recovered from Grand Sable Lake. A 178 cm long core was collected from Beaver Lake in September 2008.

Core Dating, Loss-on-ignition and Geochemistry

Grand Sable Lake: The Grand Sable Lake core reached supported levels of ^{210}Pb activity levels at approximately 23 cm core depth (ca. 1855; Figures 62, 63). Sediment accumulation rates were somewhat variable over the period of analysis at approximately 0.06 g/cm^2/yr but without clear historical trends (Figures 64, 65). Grand Sable Lake sediments were largely inorganic with some post-Euro-American settlement decrease in inorganic content concomitant with a post-Euro-American increase in organic and carbonate content (Figure 66). As sedimentation rates were relatively constant, these changes may reflect some post-settlement changes in lake productivity (Figure 67) or dune stabilization. In Grand Sable Lake, pre-Euro-American concentrations of BSi were approximately 2 to 3% dry weight (Figure 68). BSi content increased after 1830 in Grand Sable Lake to peak weight percent and flux values in the late 1940s (7% dry weight, 11-12 mg/cm^2/yr). BSi levels remained high since 1950 with weight percent and flux rates approximately three-fold higher than pre-1830 levels (Figure 68).

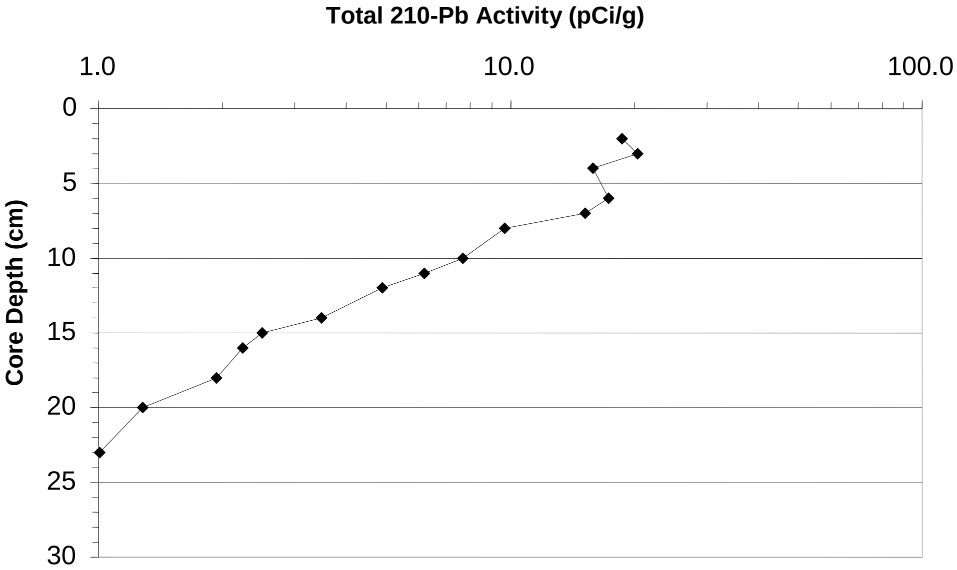


Figure 62. Total 210-Pb activity plotted against core depth (cm), Grand Sable Lake (PIRO).

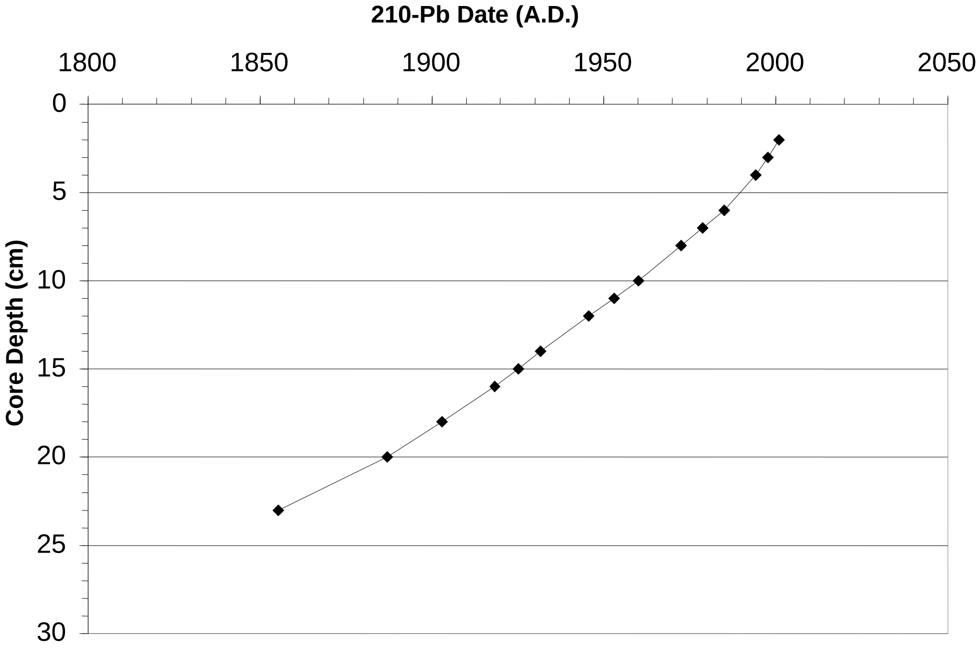


Figure 63. Resulting 210-Pb dating model for Grand Sable Lake (PIRO) core.

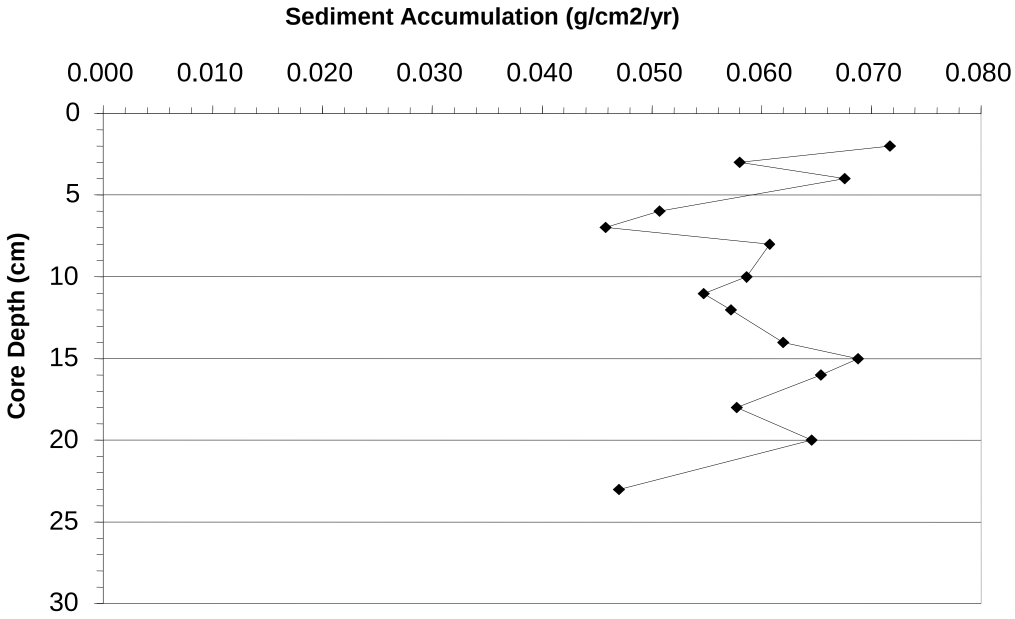


Figure 64. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Grand Sable Lake (PIRO).

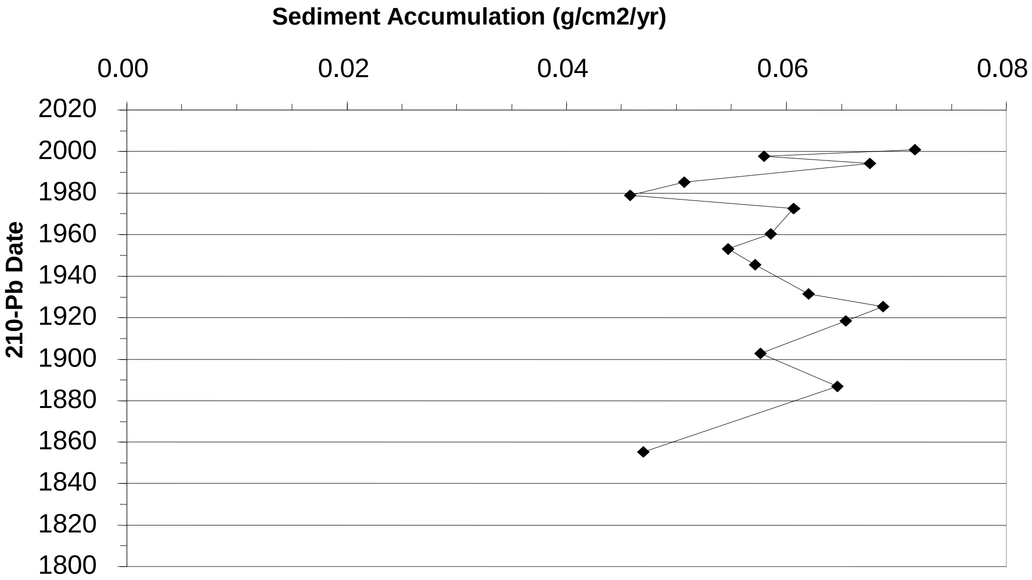


Figure 65. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Grand Sable Lake (PIRO) core.

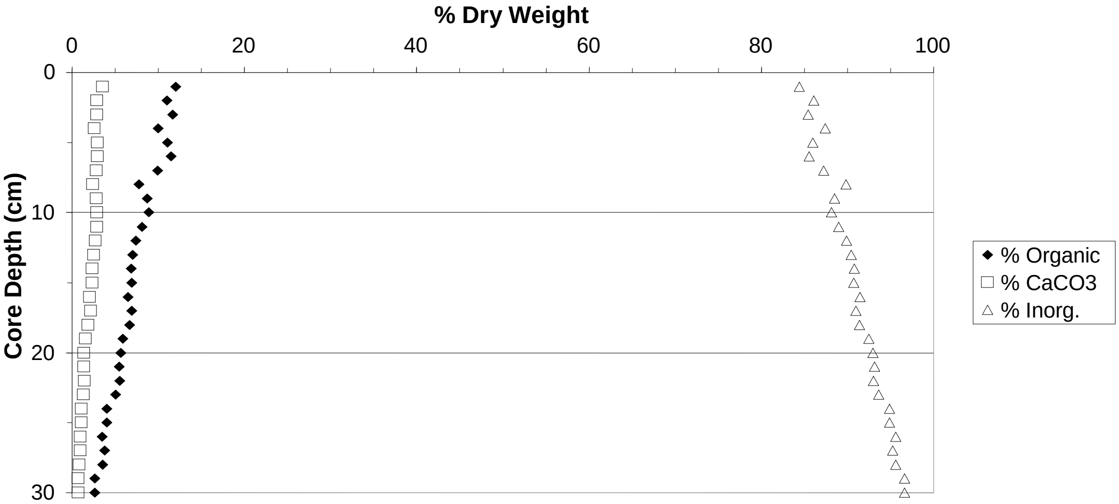


Figure 66. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Grand Sable Lake (PIRO) core.

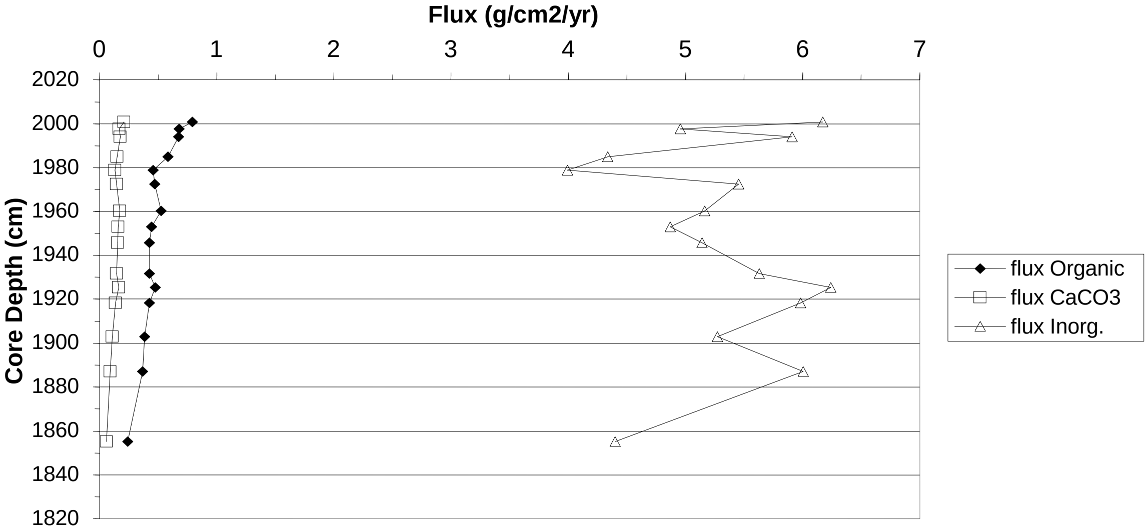


Figure 67. Flux of sediment components (g/cm^2/yr) by date (A.D), Grand Sable Lake (PIRO) core.

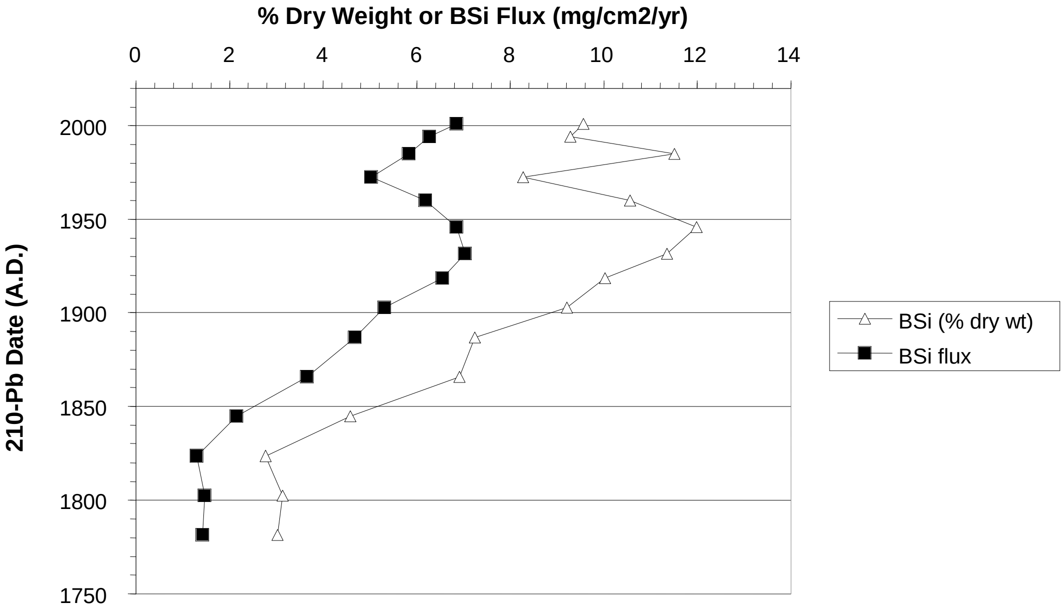


Figure 68. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Grand Sable Lake (PIRO) core.

Beaver Lake: Inventories of ^{210}Pb decreased in Beaver Lake sediments to supported levels below 37 cm (Figure 69). Sediments representing pre-Euro-American settlement were deposited below approximately 30 cm depth (ca. 1870) (Figure 70). Sedimentation rates fluctuated widely in Beaver Lake (Figures 71, 72). Pre-1860s sedimentation rates were about 0.010-0.015 g/cm^2/yr but increased from the 1860s through the1890s to levels closer to 0.020 g/cm^2/yr (Figure 72). In 1905 a dam was built on the outflow of Beaver Lake that remained in operation for sluicing and spring log driving for 5 to 10 yrs. The dam appeared to have altered sedimentation patterns as rates dropped between 1900 and 1930 to 0.008 g/cm^2/yr before an increase upcore to modern levels of 0.02 g/cm^2/yr (Figure 72). A shift from organic- to inorganic-dominated sediment occurred at about 37 cm depth in the core (Figure 73), that predated initial logging in the area (1880s). Sediments above this depth were about 50% dry weight inorganics, 40 to 45% organics, and 4 to 6% carbonates (Figure 73). Flux of sediment constituents reflected the large variability in sedimentation rates with peaks in deposition in the 1880s and at the core top (Figure 74). BSi content in the core initially decreased to about 5% dry weight in 1900 and then increased to 8% by the 1960s (Figure 75). Since the 1960s, BSi has varied from 7 to 10%.

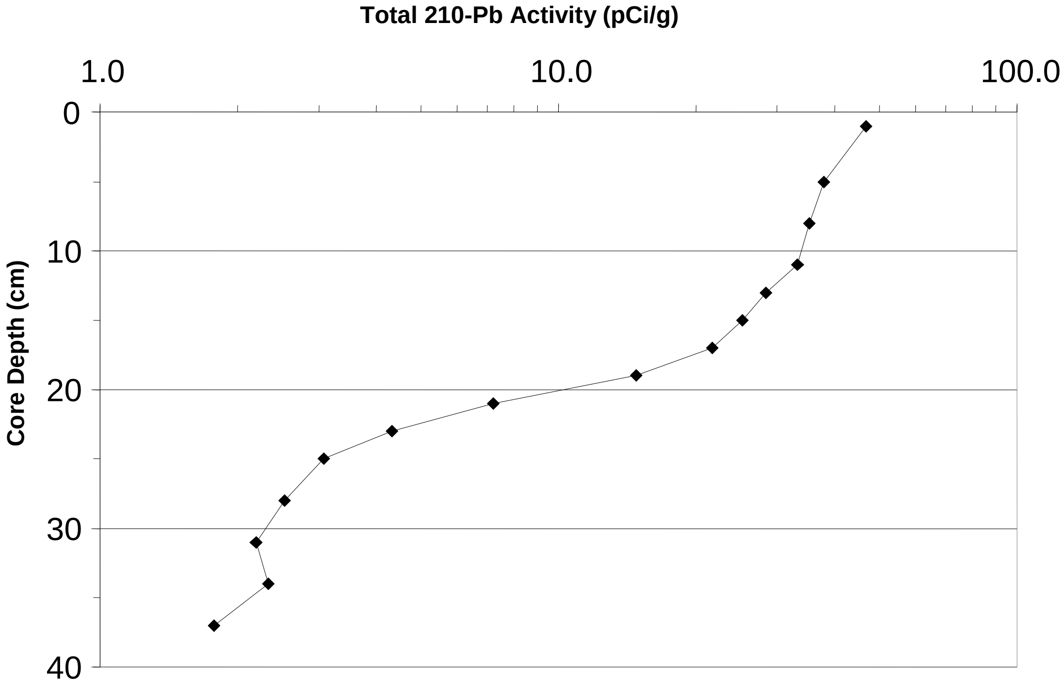


Figure 69. Total 210-Pb activity plotted against core depth (cm), Beaver Lake (PIRO).

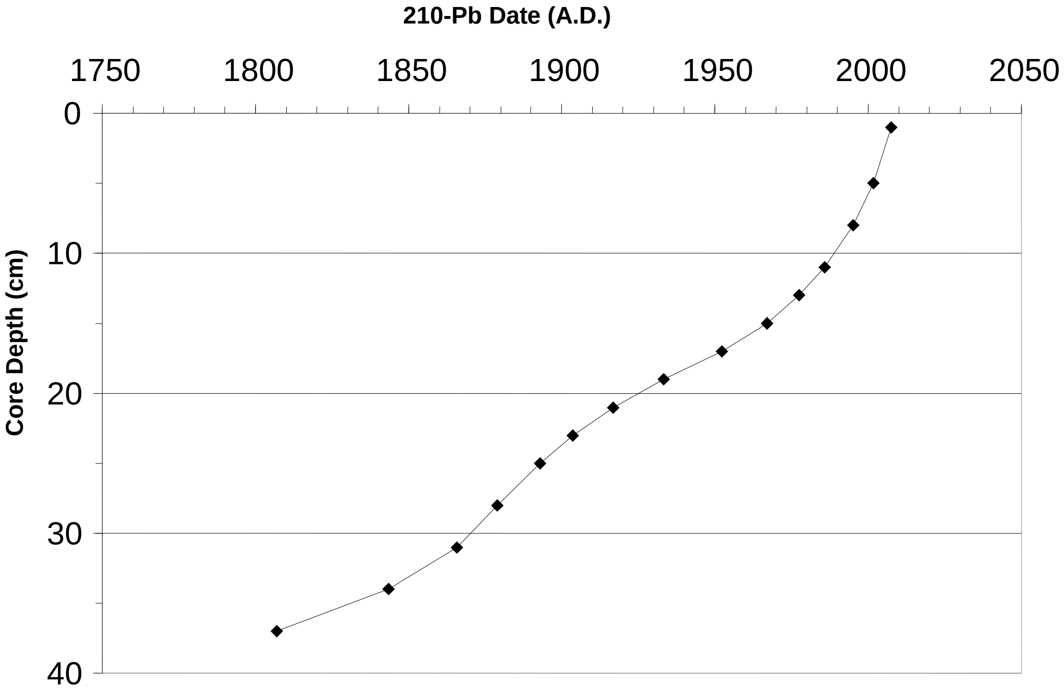


Figure 70. Resulting 210-Pb dating model for Beaver Lake (PIRO) core.

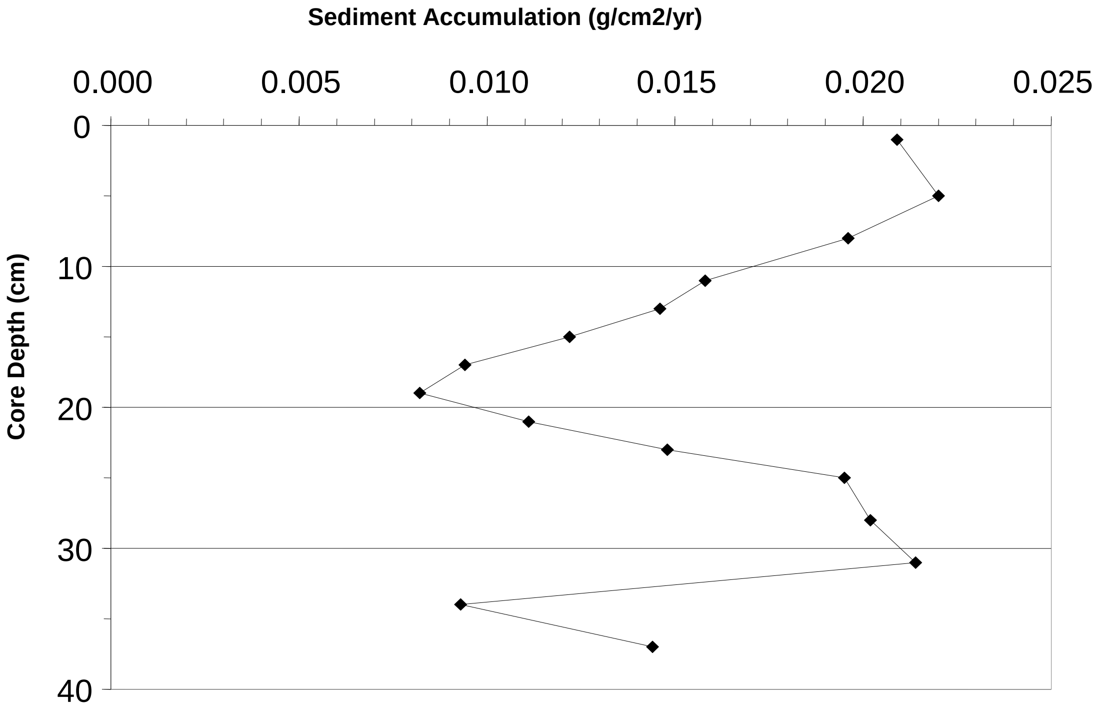


Figure 71. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Beaver Lake (PIRO).

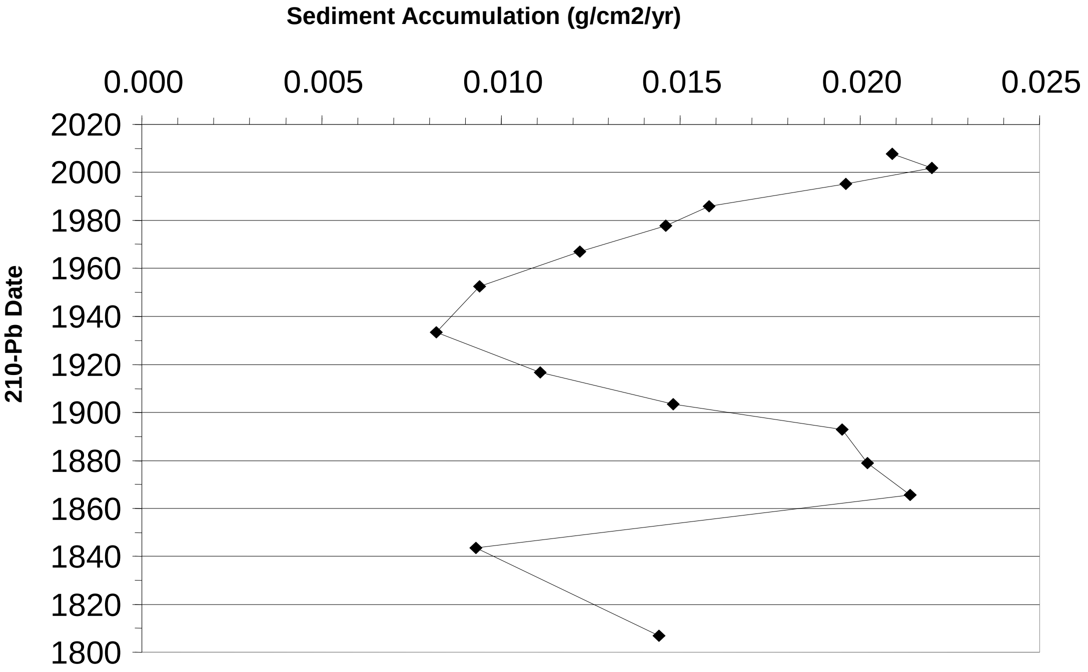


Figure 72. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Beaver Lake (PIRO) core.

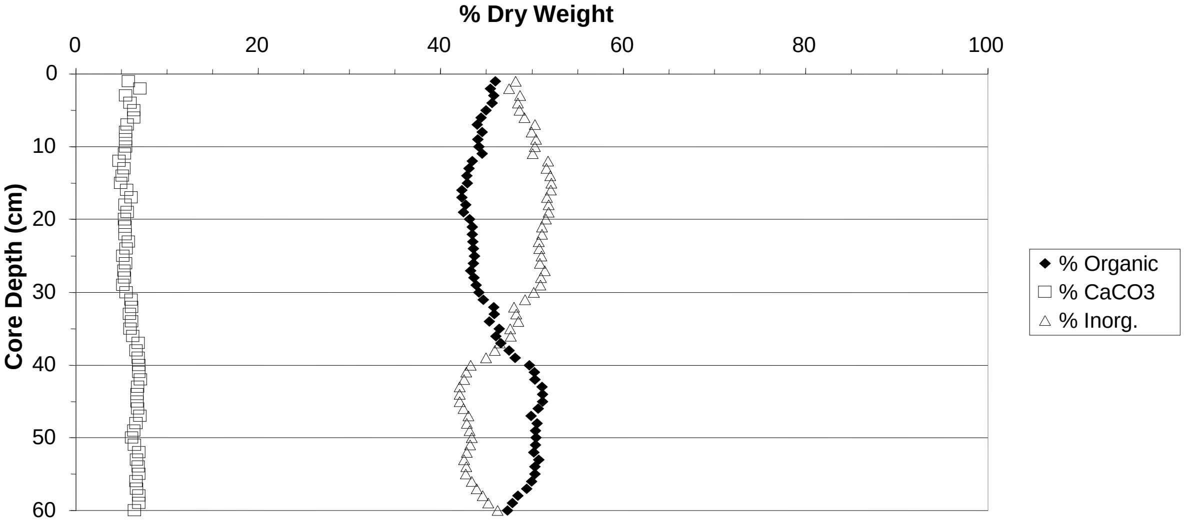


Figure 73. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Beaver Lake (PIRO) core.

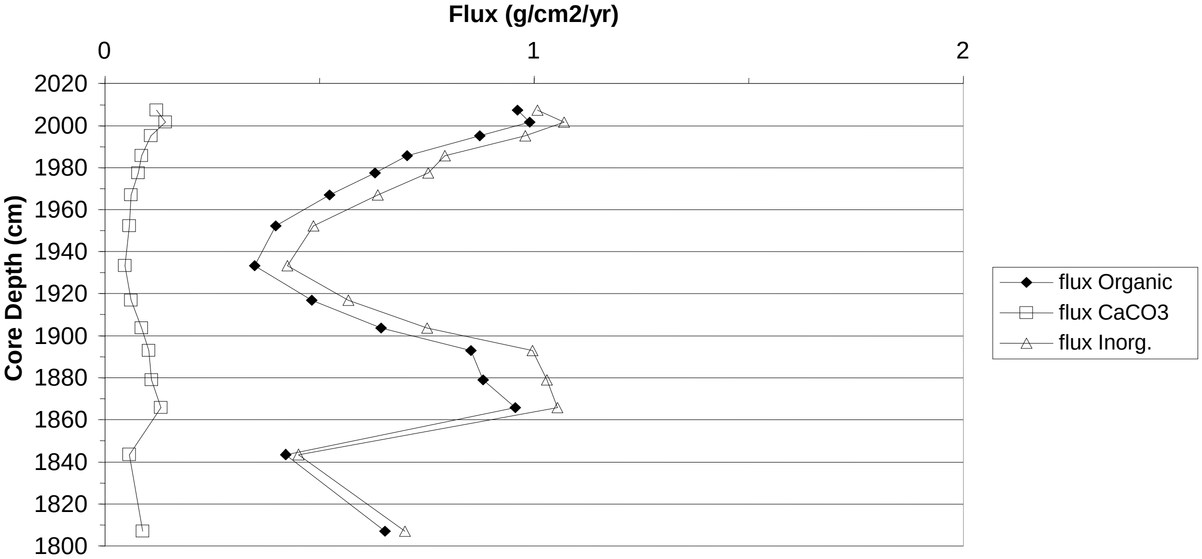


Figure 74. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Beaver Lake (PIRO) core.

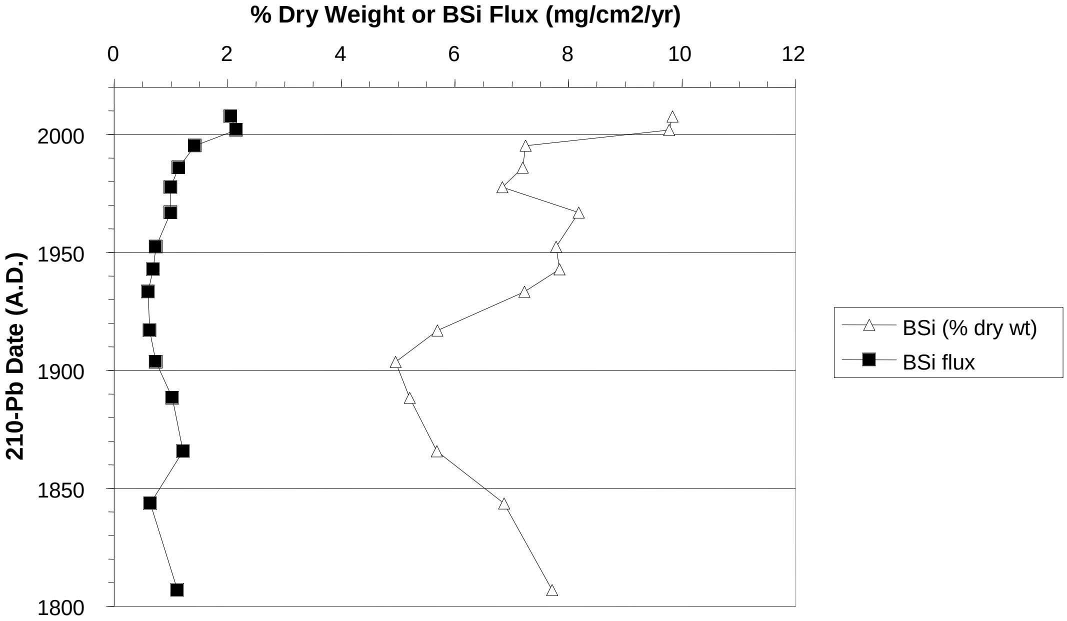


Figure 75. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Beaver Lake (PIRO) core.

Downcore Diatom Communities (stratigraphy, cluster, ordinations)

Grand Sable Lake: Diatom communities were analyzed in 15 levels from Grand Sable Lake covering a period from 1782 to 2001 (Figures 76, 77). A total of 289 diatom species was encountered in the core. Sediments are dominated by *Aulacoseira ambigua* and *A. subarctica*, *Cyclotella* (*Discostella*) *pseudostelligera*, *Fragilaria crotonensis*, and *Asterionella formosa*. A detrended correspondence analysis (DCA) and constrained cluster analysis of downcore diatom assemblages indentified three historical assemblage zones in the recent history of Grand Sable Lake that are separated by periods of larger community change: Zone 1 (1782-1887), Zone 2 (1903-1960), and Zone 3 (1973-2001). Zone 1 was characterized by abundant *Aulacoseira ambigua* and *A. subarctica,* peak abundance of *Cyclotella* (*Discostella*) *pseudostelligera*, and abundance of *Staurosirella pinnata*. Zone 2 was characterized by peaks in abundance of *Aulacoseira ambigua* and *A. subarctica*, decreased abundance of *Cyclotella* (*Discostella*) *pseudostelligera*, continued abundance of *Staurosirella pinnata*, and low abundance of *Asterionella formosa*. Zone 3 (1973-2001) contained slightly lower abundances of *Aulacoseira ambigua* and *A. subarctica*, a peak in abundance of *Fragilaria crotonensis*, *Asterionella formosa*, and *Achnanthidium minutissimum*, and decreased abundance of *Staurosirella pinnata* (Figure 78).

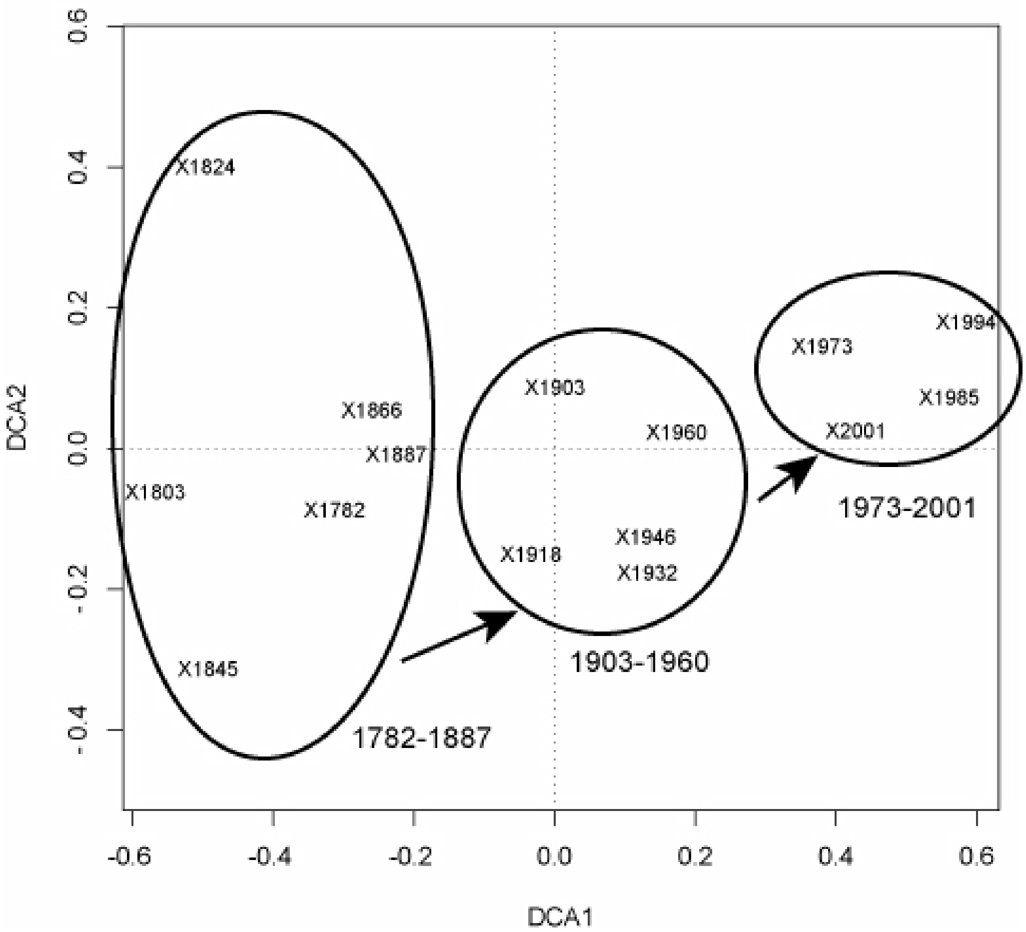


Figure 76. DCA of downcore diatom assemblages from Grand Sable Lake core (PIRO, 1782-2001); axes 1 and 2 loadings plotted for core depths-dates.

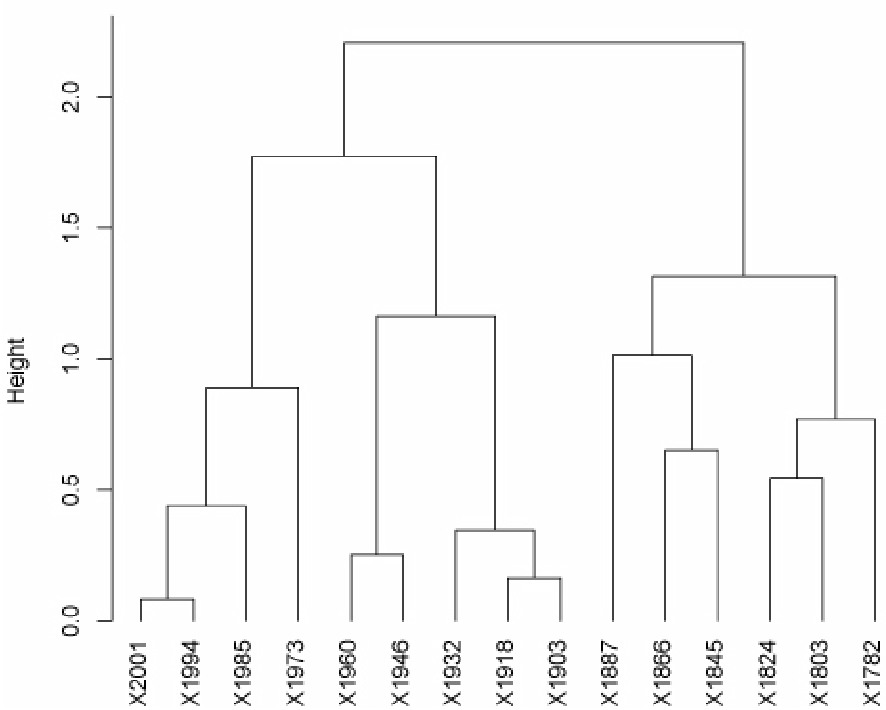


Figure 77. Constrained cluster analysis of downcore diatom assemblages from Grand Sable Lake core (PIRO, 1782-2001).

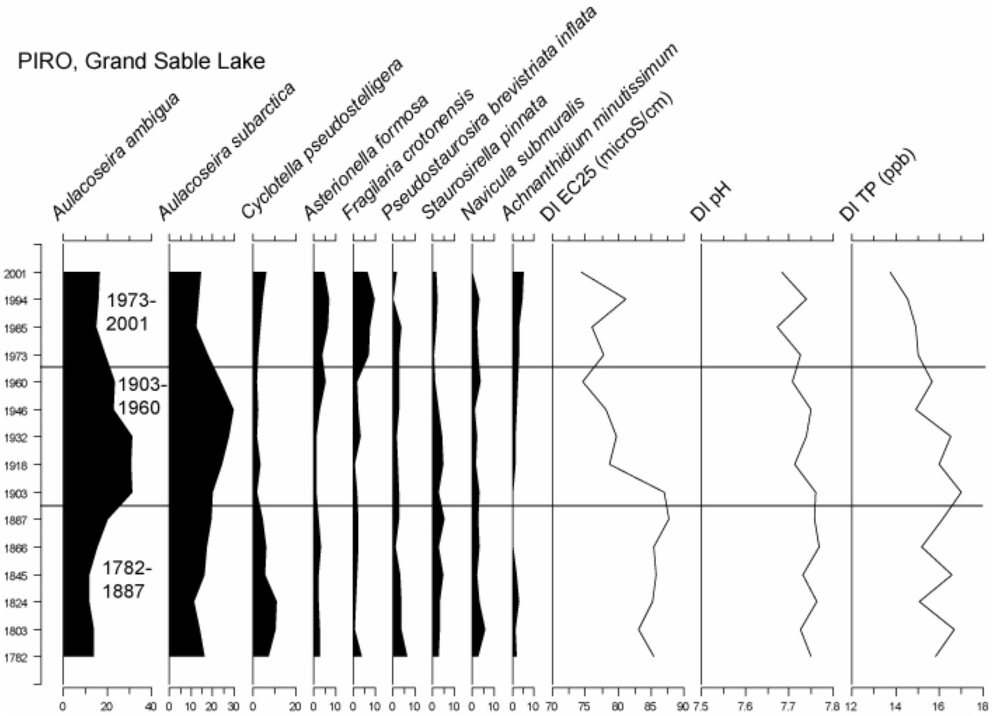


Figure 78. Stratigraphic diagram of relative abundance of dominant diatoms in Grand Sable Lake core (PIRO, 1782-2001) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Beaver Lake: The samples analyzed from Beaver Lake included sediments deposited from 1807 to 2008. Three biostratigraphic zones were evident in the core based on DCA and constrained cluster analysis: Zone 1 (1807-1884), Zone 2 (1904-1978), and Zone 3 (1986-2008) (Figures 79, 80). The three most common diatoms in Beaver Lake sediments were planktonic *Aulacoseira ambigua* and benthics *Staurosirella pinnata* and *Staurosira construens* v. *venter* (Figure 81). The oldest sediments in the Beaver Lake core (Zone 1) were characterized by low abundance of *A. ambigua* and peaks in abundance of *Staurosirella pinnata* and *Staurosira construens* v. *venter*, *Pseudostaurosira brevistriata*, and several forms of *Navicula frugalis*. Zone 2 sediments were defined by the abrupt increase in *A. ambigua* and *A. italica* and the decline in benthic taxa common in Zone 1 sediments. The onset of this zone corresponded to the construction of a dam at the outflow of Beaver Lake (Loope 1993) that obviously changed the ecology of the lake. Zone 3 sediments exhibited further shifts in the planktonic diatom community of Beaver Lake with the appearance or increase in abundance of *Cyclotella comensis*, *C*. sp. *mich-like,* and *Asterionella formosa* concomitant with decreased abundance of the *Aulacoseira* taxa (Figure 81).

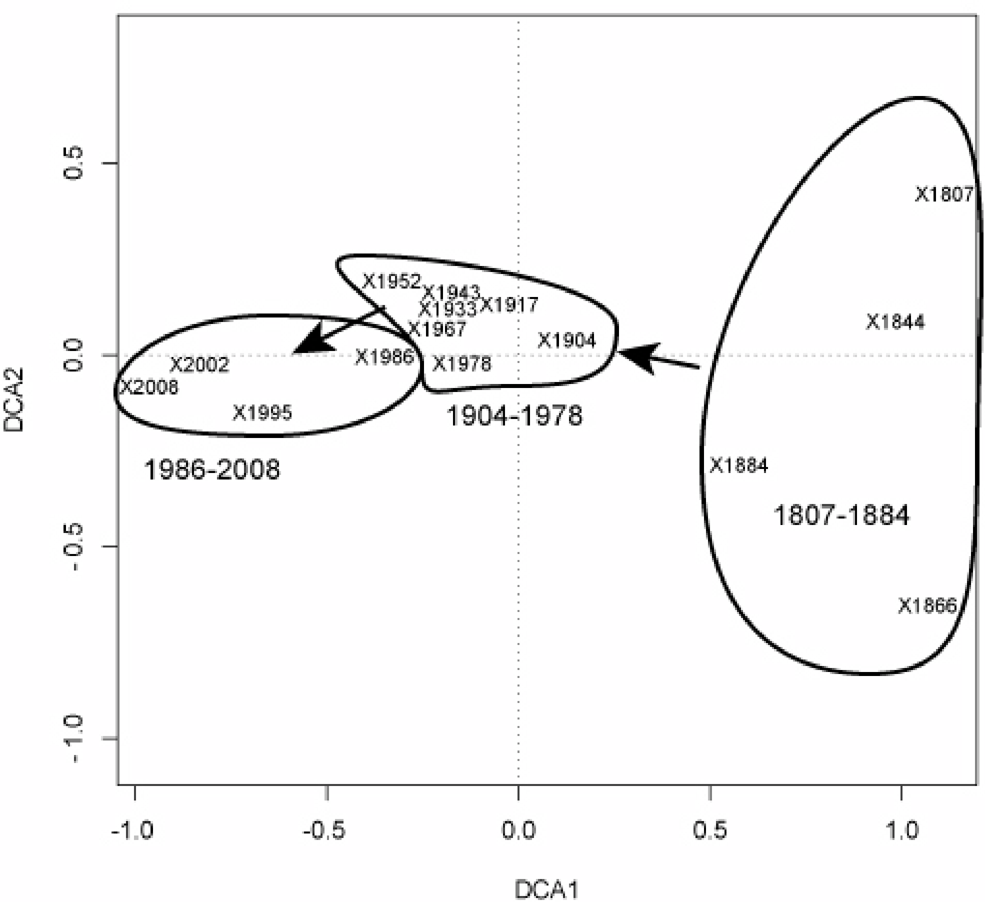


Figure 79. DCA of downcore diatom assemblages from Beaver Lake core (PIRO, 1807-2008); axes 1 and 2 loadings plotted for core depths-dates.

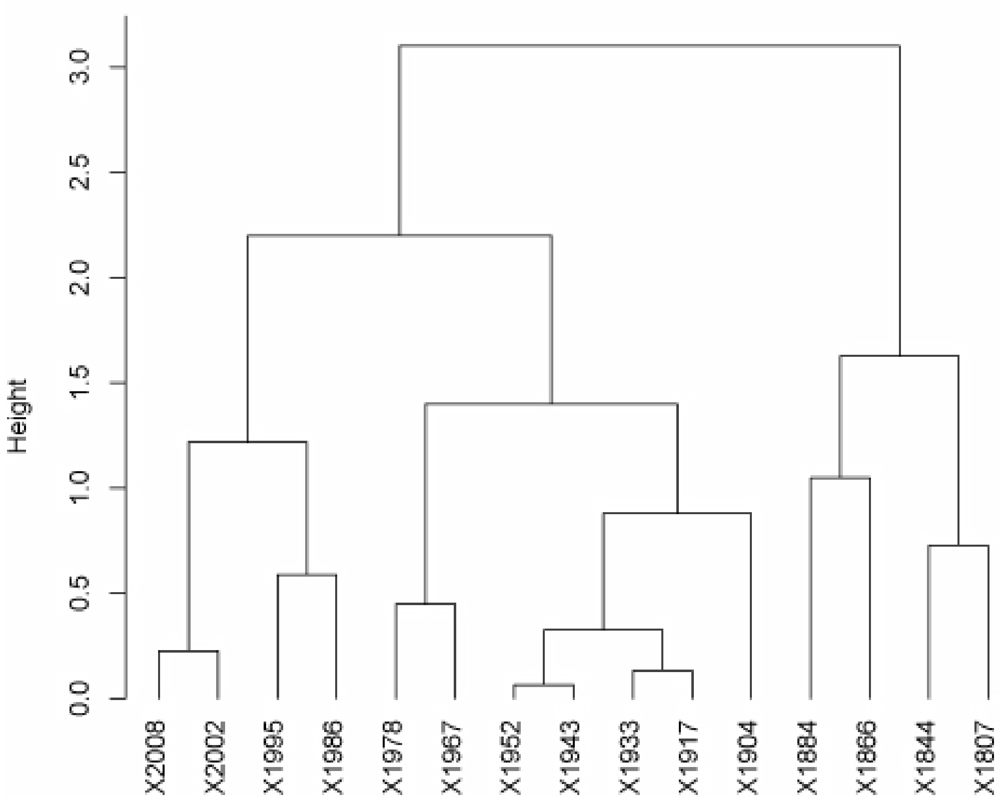


Figure 80. Constrained cluster analysis of downcore diatom assemblages from Beaver Lake core (PIRO, 1807-2008).

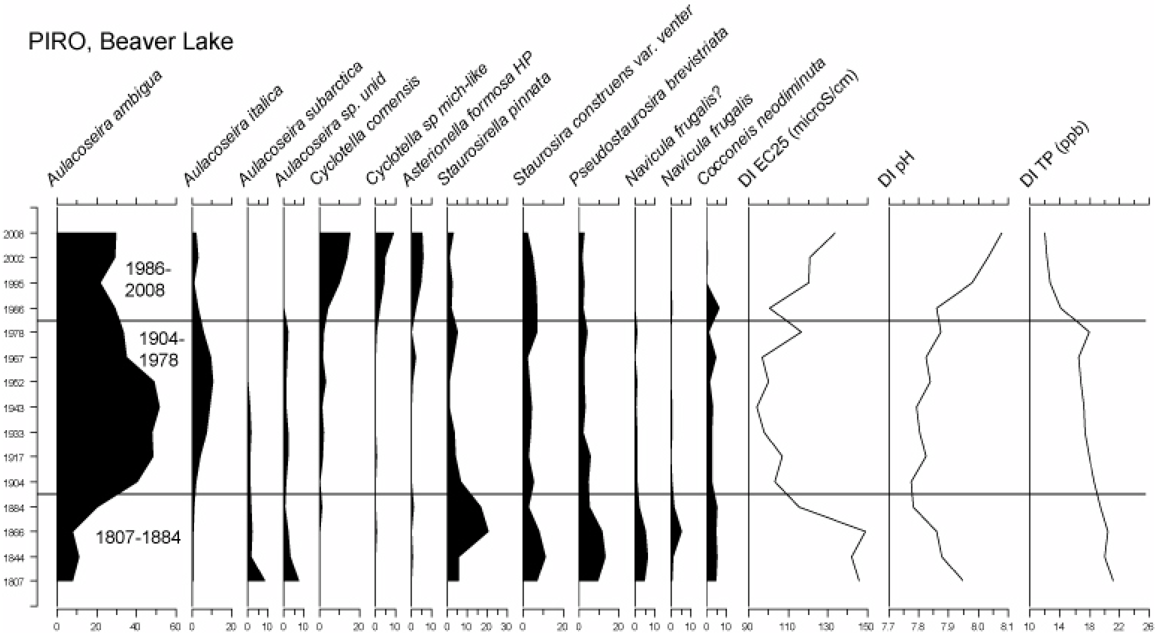


Figure 81. Stratigraphic diagram of relative abundance of dominant diatoms in Beaver Lake core (PIRO, 1807-2008) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Environmental Reconstructions

Grand Sable Lake: The GLKN surface sediment diatom calibration set was used to explore changes in historical conductivity, pH and total phosphorus of Grand Sable Lake (Figure 78). Although all three parameters showed a general upcore decreasing trend, none of the changes were considered significant because they did not exceed the model variation. Historical diatom-inferred TP values were centered around 15 ppb, pH about 7.7, and conductivity from 75-87 µS/cm.

Beaver Lake: The diatom communities in Beaver Lake sediments were used to estimate historical EC25, pH, and TP. Diatom-inferred changes in TP and pH showed minor trends. Diatom-inferred TP underwent a significant decrease in the last 200 years of Beaver Lake's history (Figure 81). Diatom-inferred EC25 showed a significant decrease at the transition between Zone 1 and Zone 2 sediments, which corresponded to the construction of a logging dam at the lake's outflow (Loope 1993). Lower reconstructed EC25 values were maintained throughout Zone 2 (1904-1978) sediments before increasing slightly in Zone 3 sediments. A passive plot of the Beaver Lake core on a CCA of the GLKN calibration set showed how damming led to a decrease in conductivity and the trends in pH and TP (Figure 82).

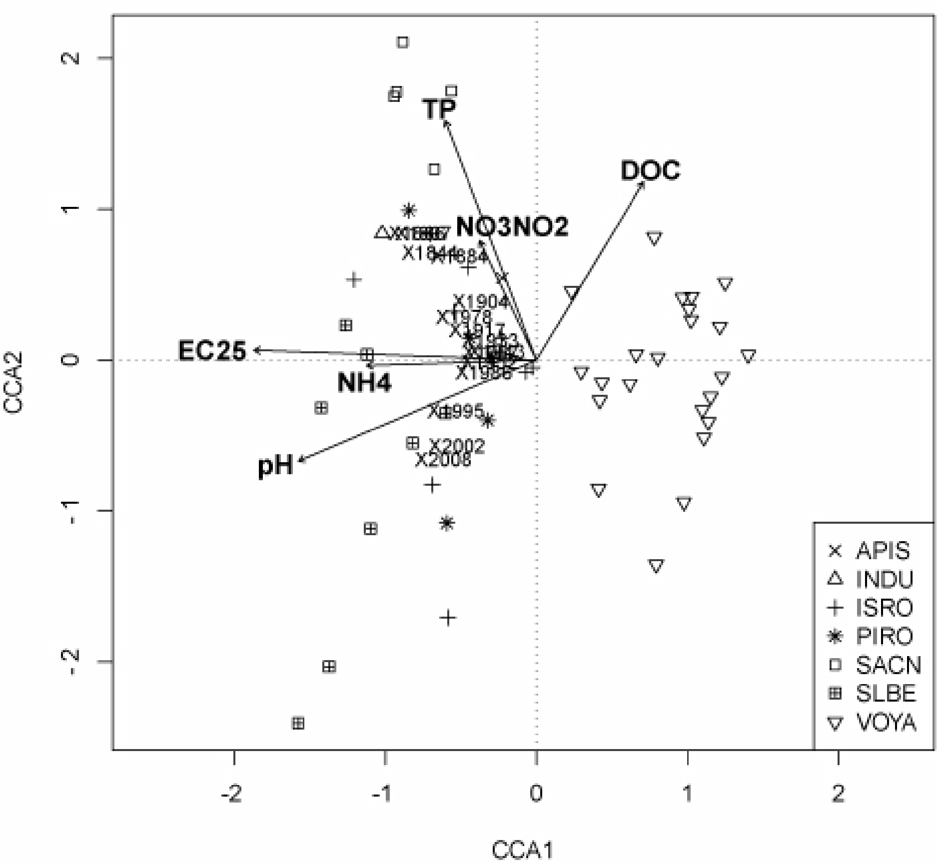


Figure 82. Diatom assemblages from the Beaver Lake core (PIRO, 1807-2008) passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance.

Relation to Land Use/History

Land use changes that have likely impacted PIRO included initial Euro-American settlement in Grand Marais in the early 1860s, the opening of the first sawmill in Grand Marais in 1879, and extensive logging in the late 1800s and early 1900s (Table 3; Lora Loope, pers. comm.). The logging boom was followed by major wildfires and some drought during the 1910s-1930s. Cottage development soon followed as Grand Sable Lake had many seasonal cabins built in the 1930s-1950s. Pictured Rocks National Lakeshore was established in 1966 and shortly thereafter over 30 cottages were removed from the eastern shore of Grand Sable Lake (Table 3).

Beaver Lake at PIRO played a significant role in the logging history of the region. Logging was common in the Upper Peninsula after the 1880s, and the journals of C. H. Hall record initial logging near Beaver Lake in 1893 (Hall 1883-1912). Manipulation of waterways was a key strategy for accessing new stands and moving cut trees to mills. In 1905 a dam was constructed at the outflow of Beaver Lake that effectively raised the water level by about 5 feet. Although the dam was only used for five to ten years for logging, its impact on lake level lasted until the 1960s (Loope 1993).

Park Summary

The first shift in diatom communities in Grand Sable Lake corresponded to a regional wide-scale logging period in the late 1800s and could be seen as a change in the planktonic diatom community (Figures 76-78). Of further interest was the ecological shift noted in diatom assemblages between 1960 and the mid-1970s, which corresponded closely to the establishment of PIRO. During this time, changes were minimal in land use recorded in the park, yet a clear shift occurred in the diatom community of Grand Sable Lake. As noted in other GLKN sediment cores (this study, Kling 2005), this time frame of ecological change was increasingly identified in sediment records from "unimpacted" areas of north central United States and Canada (Rühland et al. 2008). Common to many of these records was an increase in abundance of small centric diatoms (Fritz et al. 1993, Smol et al. 2005) as noted in Grand Sable Lake (and Beaver Lake, see below). One of the strongest correlates of this 1970s shift in diatom communities was climate records that identified a mid-1970s inflection associated with records of global warming; similar timing and community shifts were reported from other GLKN parks (Serieyssol et al. 2009) and in boreal regions (Rühland et al. 2008).

The major change in the Beaver Lake core occurred between Zone 1 and 2 sediments around the turn of the 20th century (Figures 79-81) when the dam was built to facilitate logging operations around Beaver Lake. The increase in lake level shifted the ecology to dominance of planktonic *Aulacoseira ambigua*, decreased sediment accumulation rates for several decades, and lowered diatom-inferred conductivity, resulting in increased BSi content of the sediments. Loope (1993) reported that the dam remained effective at modifying lake levels until the 1960s. As noted above, diatom changes in Zone 3 sediments may provide a further example of widespread climate-linked changes in northern lakes that were characterized by increased abundance of small centric diatoms (Rühland et al. 2008).

Long Sediment Cores (APIS)

Core Collection

Two lagoons on islands at Apostle Islands National Lakeshore were targeted for long core sampling (Table 6). Michigan Lagoon on Michigan Island was sampled in July 2007; however, the lagoon proved difficult to core and concerns with the depositional environment stopped additional analyses on the 73 cm core we recovered. In contrast, a 73 cm core that appeared to record the full history of Outer Lagoon (basal sediments are sand) was recovered in July 2007.

Core Dating, Loss-on-ignition and Geochemistry

Outer Lagoon: The inventory of ^{210}Pb in the Outer Lagoon core consistently decreased to supported levels at 53 cm depth (Figure 83). A depth of 50 cm in Outer Lagoon sediments corresponded to approximately 1880 AD (Figure 84). Sedimentation rates generally increased upcore with a notable shift above 30 cm depth (ca 1970) (Figures 85, 86). Although the core was 73 cm long, the bottom 10 cm of core were sand, suggesting we had captured a full record of sedimentation accumulated during the lagoon's most recent isolation from Lake Superior. The lowest basal sediments with any organic content were from 61 cm and dated at approximately 1773 AD. Loss-on-ignition analysis revealed the entire lagoon history as inorganic sediments that went from 100% dry weight at 63 cm to about 45% at the core top. Mirroring this trend was an increase in organics from 0% dry weight at 63 cm to just more than 50% at the core top (Figure 87). Carbonates also increased upcore from 0% at 63 cm to about 5% above 30 cm (Figure 87). When converted to flux, organics in particular showed a strong upcore increase in accumulation rates, whereas inorganic flux was more variable (Figure 88). BSi content showed a general increasing trend from less than 10% dry weight at the core base to more than 20% near the core top (Figure 89). When treated as flux, BSi accumulation rates increased upcore from 2 to 11 mg/cm^2/yr, with modest increases after the 1970s (Figure 89).

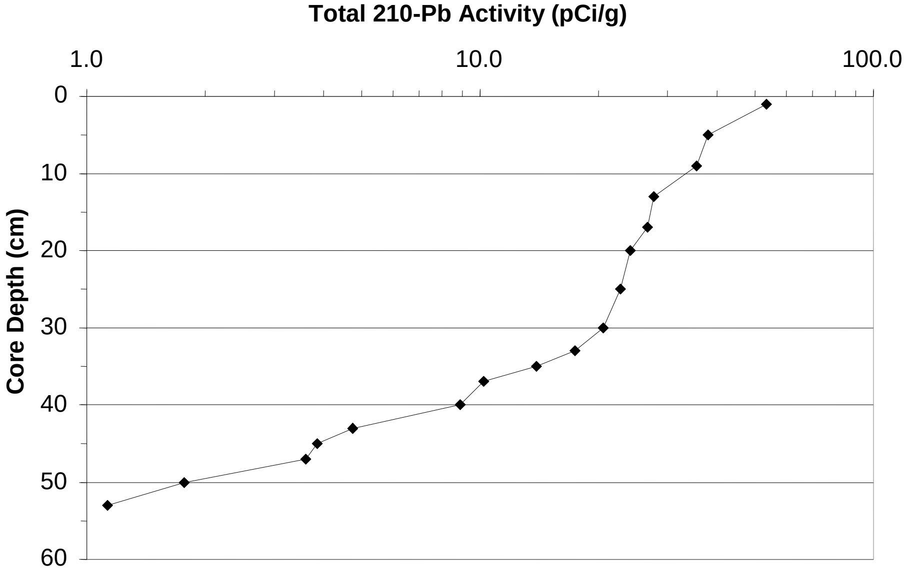


Figure 83. Total 210-Pb activity plotted against core depth (cm), Outer Lagoon (APIS).

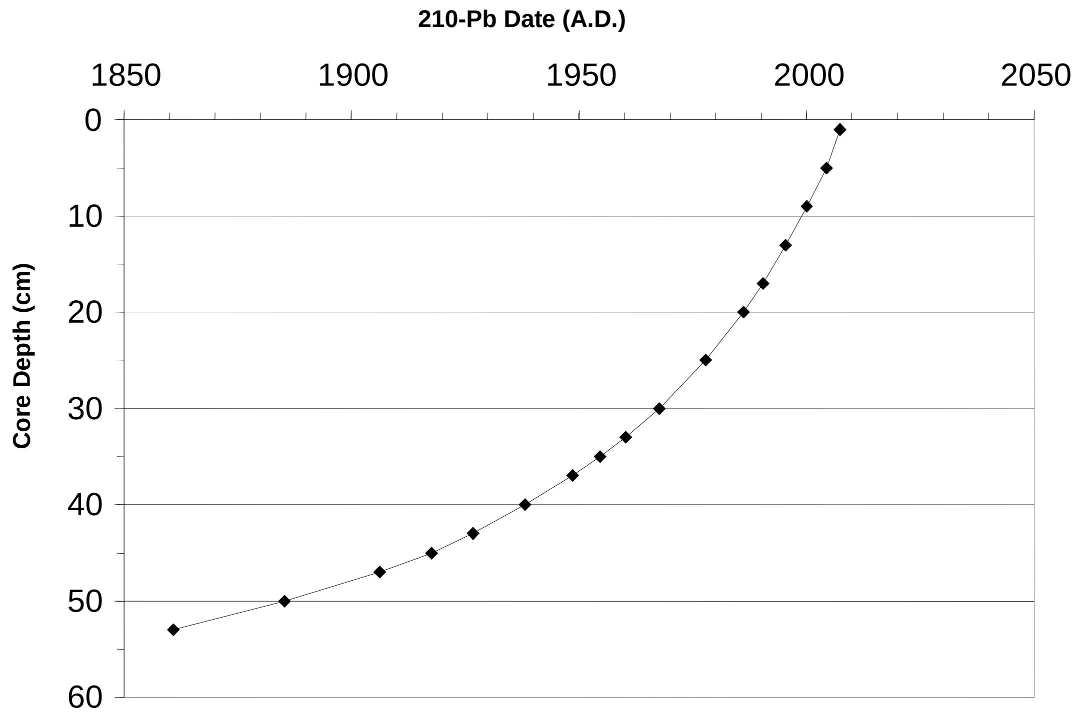


Figure 84. Resulting 210-Pb dating model for Outer Lagoon (APIS) core.

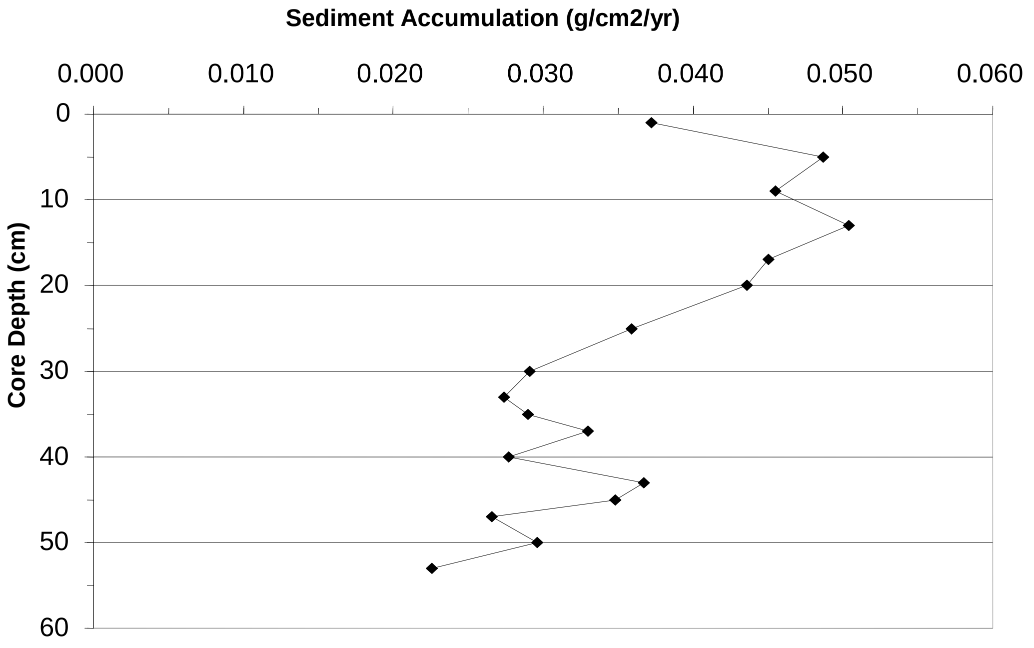


Figure 85. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Outer Lagoon (APIS).

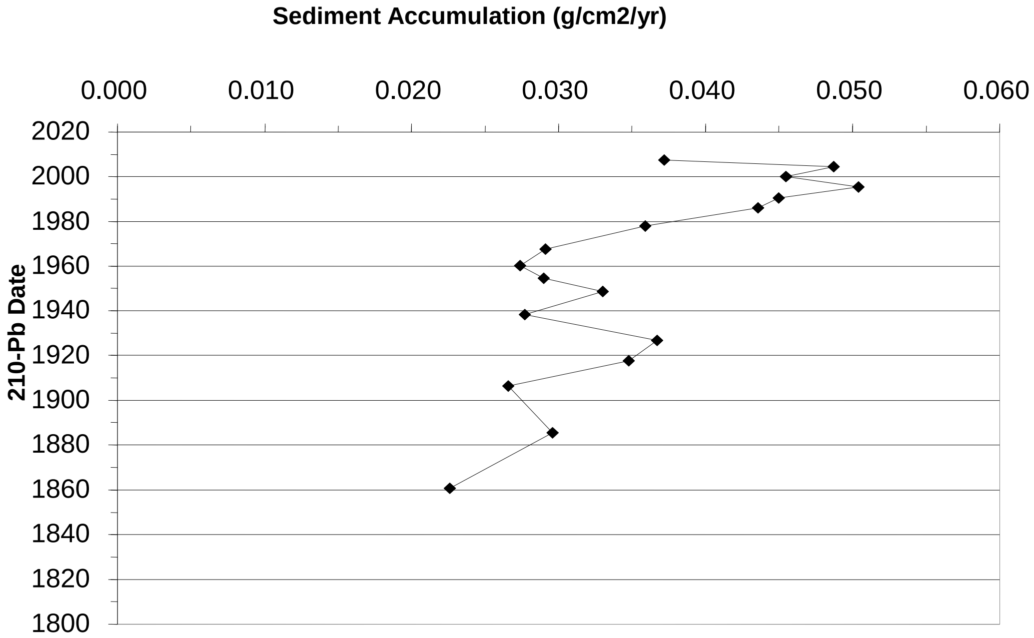


Figure 86. Sediment accumulation rates (g/cm^2/yr) by date (A.D.), Outer Lagoon (APIS) core.

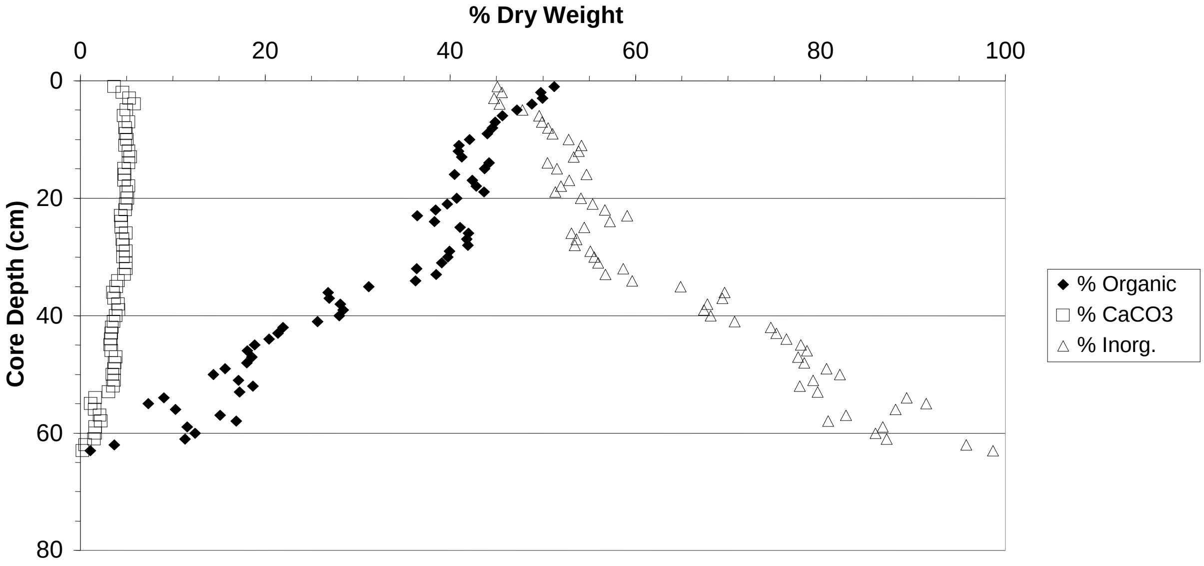


Figure 87. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Outer Lagoon (APIS) core.

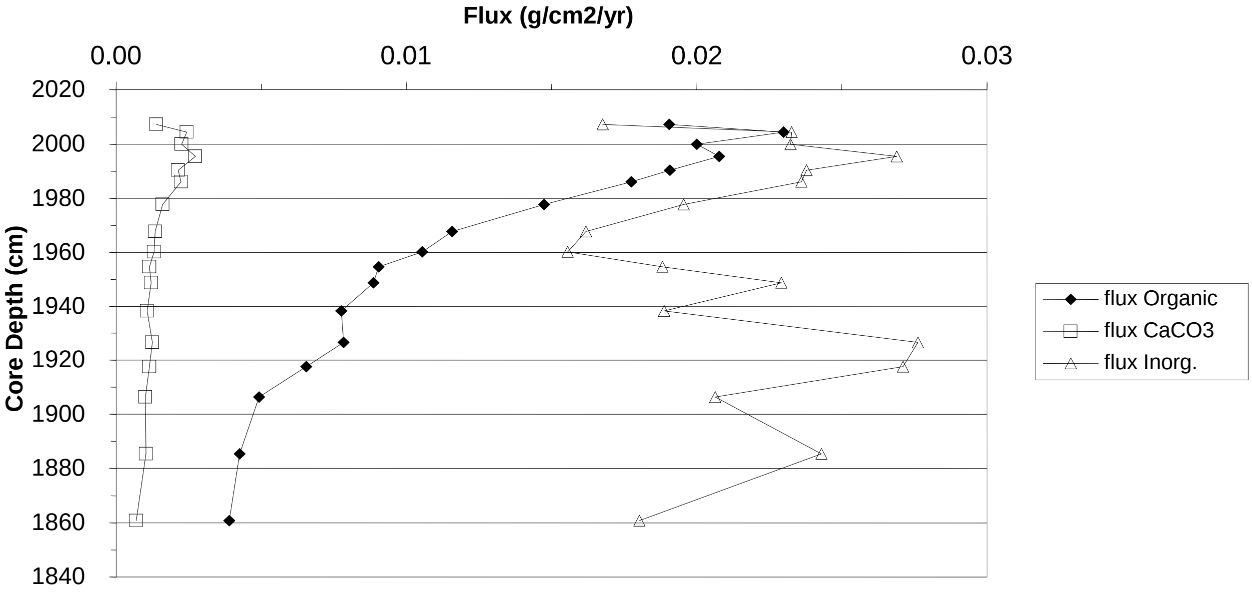


Figure 88. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Outer Lagoon (APIS) core.

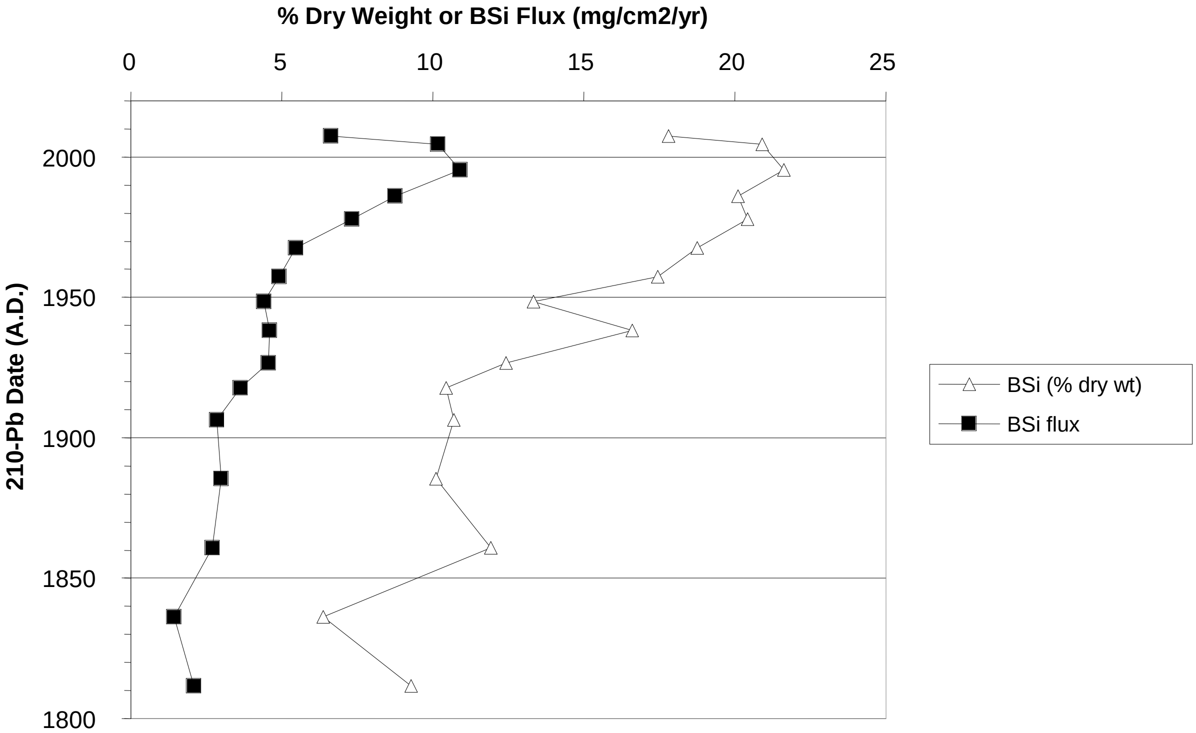


Figure 89. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Outer Lagoon (APIS) core.

Downcore Diatom Communities (stratigraphy, cluster, ordinations)

Outer Lagoon: Diatom communities were analyzed in the Outer Lagoon core from sediments dated from 1836 to 2007. Given the shallow nature of the lagoon, the diatom community was dominated by benthic and small attached forms including *Brachysira*, *Stauroforma*, *Psammothidium*, and *Semiorbis* that indicated soft, slightly acidic waters. A DCA and constrained cluster analysis resolved three primary biostratigraphic zones in the core: Zone 1 (1836-1938), Zone 2 (1949-1995), and Zone 3 (2005-2007), with some potential subgroupings within Zone 1 (Figures 90, 91). Zone 1 sediments were characterized by highest abundances of *Brachysira neoexilis*, *Stauroforma exiguiformis* and *Achnanthidium minutissimum* (Figure 92). A secondary break in Zone 1 was between samples dated 1885 to 1906 and moved into higher abundances of *Stauroforma exiguiformis* and *Psammothidium altaicum*. Zone 2 sediments showed lower abundances of the Zone 1 taxa and increased abundance of *Pseudostaurosira microstriata*, *Brachysira styriaca*, *Nitzschia perminuta*, and the first appearance of *Semiorbis hemicyclus*. The two most upper samples constituted Zone 3 sediments and were characterized by decreased abundance of *Brachysira styriaca* and increased abundance of *Psammothidium altaicum* and *Semiorbis hemicyclus* (Figure 92).

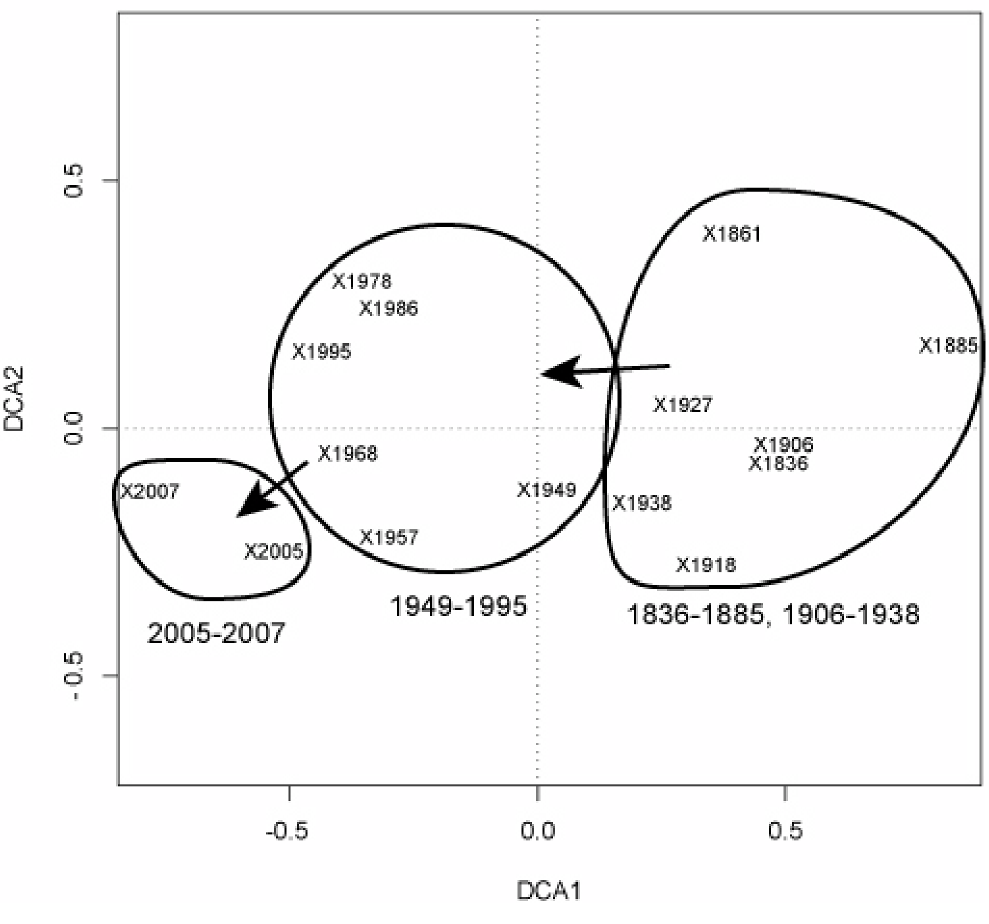


Figure 90. DCA of downcore diatom assemblages from Outer Lagoon core (APIS, 1836-2007); axes 1 and 2 loadings plotted for core depths-dates.

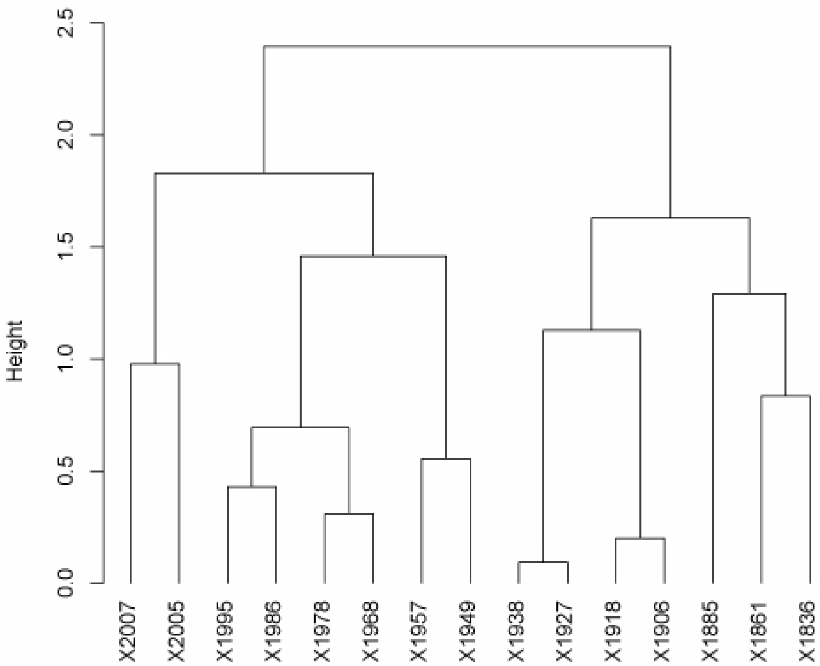


Figure 91. Constrained cluster analysis of downcore diatom assemblages from Outer Lagoon core (APIS, 1836-2007).

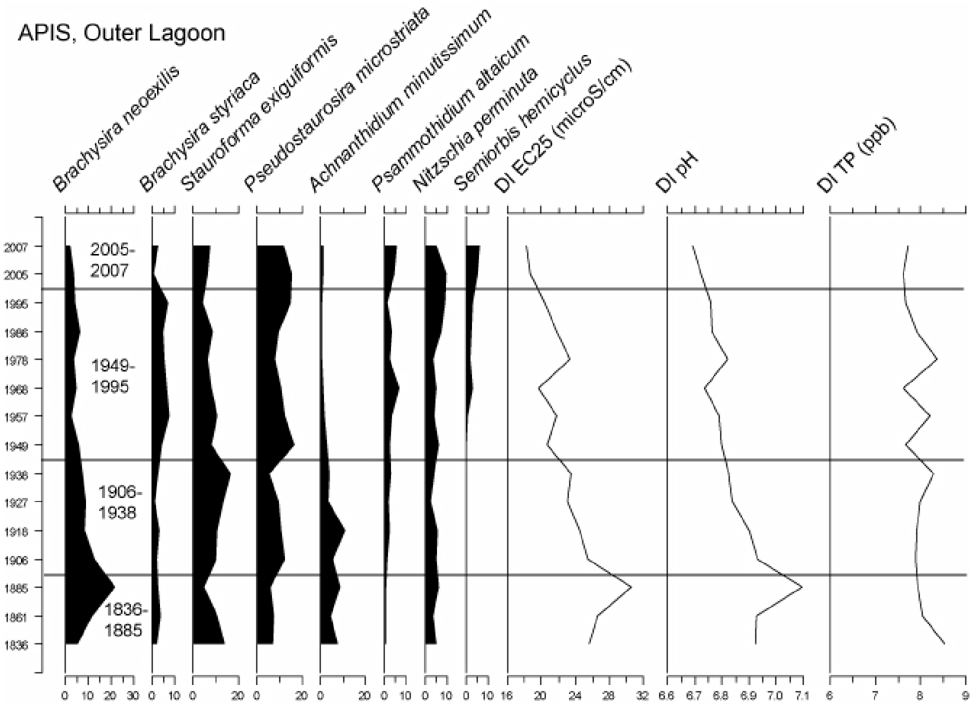


Figure 92. Stratigraphic diagram of relative abundance of dominant diatoms in Outer Lagoon core (APIS, 1836-2007) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Environmental Reconstructions

Outer Lagoon: The GLKN diatom calibration set was applied to the downcore diatom assemblages in Outer Lagoon to reconstruct historical conductivity, pH, and total phosphorus (Figure 92). Results of this analysis must be weighed carefully given that the Outer Lagoon surface sediment sample was considered an outlier for species assemblage and removed from the species-environment dataset during the development of transfer functions. During the last 180 years of Outer Lagoon history changes were not significant in any of the diatom-inferred water quality parameters; however, trends were slight in the reconstructed pH and conductivity. The pH showed a trend toward lower values upcore from core bottom values near 7.0 to core top values of 6.7. Conductivity showed a similar trend toward lower values upcore from basal levels of 26 to 30 µS/cm to core top values of 18 µS/cm.

Relation to Land Use/History

Twenty-two islands located in Lake Superior off shore of Bayfield Peninsula constitute the Apostle Islands. All but Madeline Island are part of the Apostle Islands National Lakeshore, which was established by Congress in 1970. Busch (2008) provided a very complete historical resource study of the Apostle Islands. Original inhabitants of APIS were native peoples who maintained subsistence fishing and hunting camps. "Discovered" by the French in the 1600s, the first Euro-American activity in the region centered around transportation and support of the fur trade that was active until the 1840s. By the 1800s, commercial fishing had also begun around the islands and by the latter half of the 19th century logging began in earnest. The first cut on the islands targeted white pine, but by the early 20th century that species was depleted and logging operations shifted to others. Some farming operations became established on the larger islands. Collapse of the whitefish fishery and few remaining exploitable timber resources by the 1950s shifted the economic focus of the islands toward tourism, and that led to efforts to preserve the natural beauty of the region and eventually to the establishment of Apostle Islands National Lakeshore in 1970.

Historical land use changes specific to Outer Island were summarized by Peggy Burkman (APIS, Biologist, pers. comm.). She noted that Outer Island was not clearcut; the southern half of the island (Outer Lagoon is located on the southern end of the island) was logged fairly heavily but the northern half was less impacted as evidenced by a 270 acre stand of old growth hemlock west of the lighthouse. Where logging occurred in the north there were no post-lumbering fires, whereas in the southern half there were fires following logging. The modern distribution and abundance of Canada yew provided some indication of past lumbering pressure. Percent cover of yew in the north was consistently in the 41 to 50% or 71 to 80% categories, whereas the south part of the island had more areas of 0-20% cover and more variability in the cover types represented.

Park Summary

Based on dating of the Outer Lagoon sediment core and a basal layer of sand, the lagoon was most recently isolated from Lake Superior in the 1770s, although connections to Lake Superior were formed (sometimes purposely) and maintained throughout the years (P. Burkman, APIS, Biologist, pers. comm.). One such channel was maintained at the north end of Outer Lagoon to allow northern pike access to the lagoon (Julie Van Stappen, APIS, pers. comm.). From a biological and limnological standpoint, the changes in Outer Lagoon appeared to be strongly directed toward increased acidity and decreased conductivity of the lagoon as its connection to Lake Superior weakened and hydrological inputs from precipitation and surrounding bogs increased. The unique ontogenetic sequence of this lagoon likely dominated many biological shifts identified in the core including increased upcore abundance of acid indicators such as *Semiorbis hemicyclus*. Minor biostratigraphic changes between 1885 and 1906 possibly reflected response to logging in the area; however, more typical geochemical responses and sedimentation increases at other GLKN sites were not evident. The greatest shift in the diatom flora of Outer Lagoon occurred between 1938 and 1949 and was defined by the first appearance of *Semiorbis hemicyclus* and decline of *Achnanthidium minutissimum* and *Brachysira neoexilis*, and possibly represented a threshold that was crossed in lagoon ontogeny. A final biological change between 1995 and 2005 may be a response to climate, although the shallow Outer Lagoon did not show any of the more typical community shifts in cyclotelloid, *Aulacoseira*, or small fragilarioid diatoms we saw in many of the other GLKN lakes.

Long Sediment Cores (ISRO)

Core Collection

Long sediment cores were recovered from three lakes at Isle Royale National Park in August 2007: Harvey Lake (117 cm), Ahmik Lake (110 cm), and Richie Lake (118 cm) (Table 6).

Core Dating, Loss-on-ignition and Geochemistry

Harvey Lake: Total ^{210}Pb activity was relatively constant in the top 13 cm of the Harvey Lake core before declining to supported levels below 25 cm depth (Figure 93). Sediments deposited below approximately 20 cm depth represented pre-Euro-American settlement (ca. 1875) (Figure 94). Sedimentation rates in Harvey Lake fluctuated a bit before Euro-American settlement, and dropped slightly between 1900 and 1925 before a steady increase upcore to rates in the uppermost sediments that were 2.5 times greater than pre-Euro-American settlement (Figures 95, 96). This shift in sedimentation corresponded to a shift in sediment chemistry towards greater organics and lower inorganic dry weight percent (Figure 97). However, when converted to flux, accumulation of organics and inorganics increased since the 1920s (Figure 98). The BSi trend was similar to weight percent of inorganics with a shift from pre-Euro-American levels of BSi of 18 to 20% dry weight before 1910 to BSi levels of 6 to 8% in the last 50 years (Figure 99). Flux of BSi remained relatively constant throughout the core at between 1 to 2 mg/cm^2/yr (Figure 99).

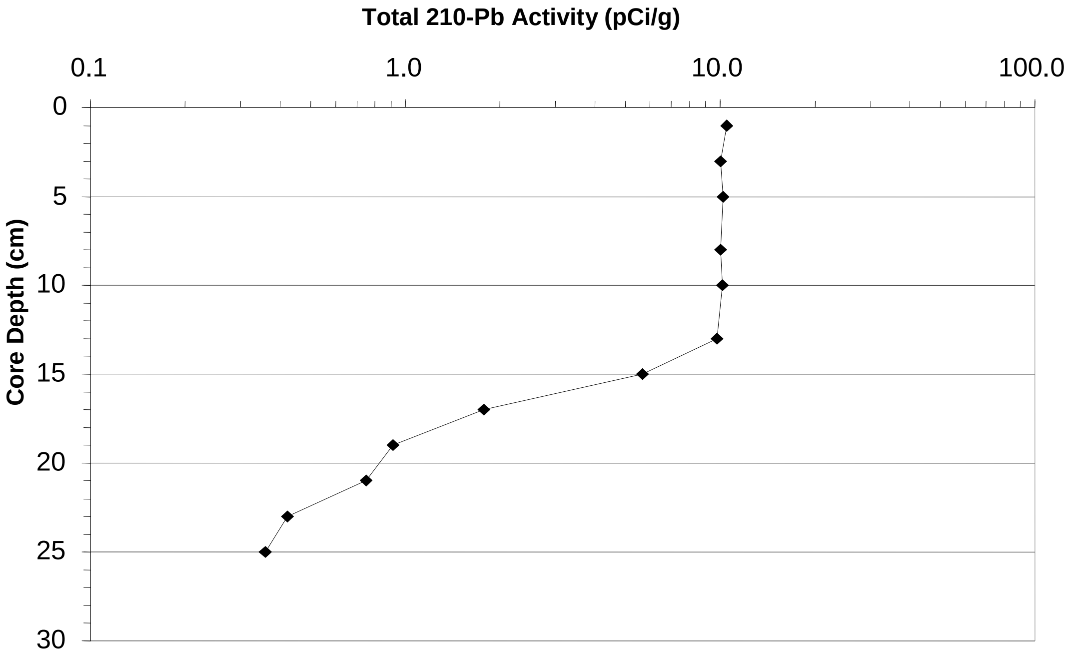


Figure 93. Total 210-Pb activity plotted against core depth (cm), Harvey Lake (ISRO).

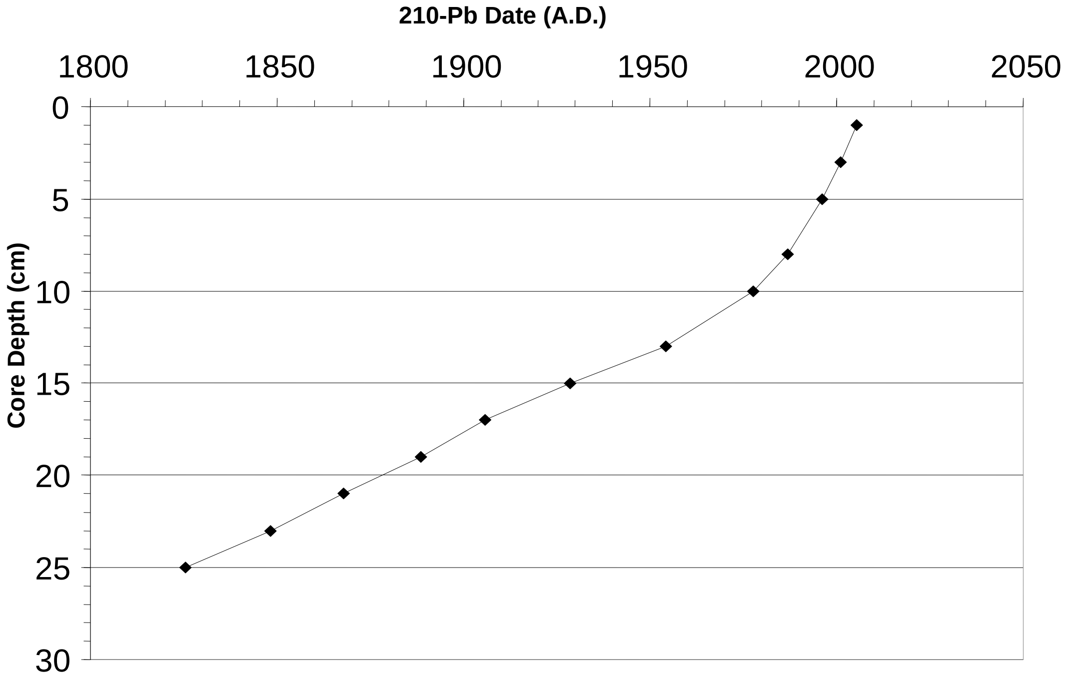


Figure 94. Resulting 210-Pb dating model for Harvey Lake (ISRO) core.

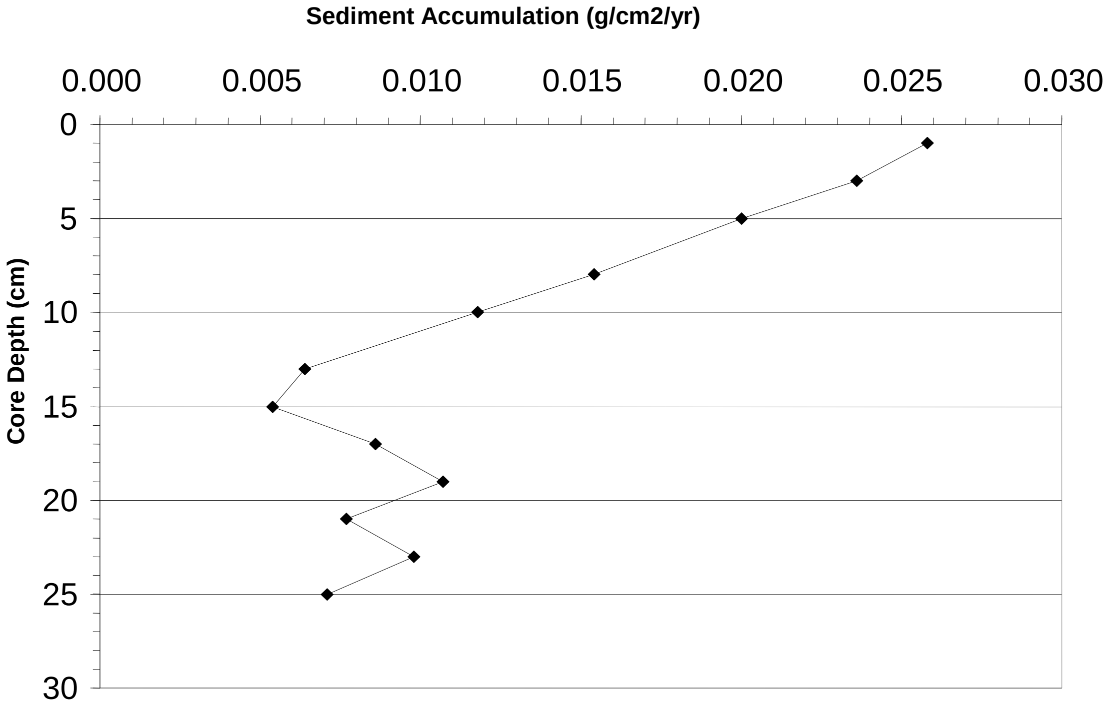


Figure 95. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Harvey Lake (ISRO).

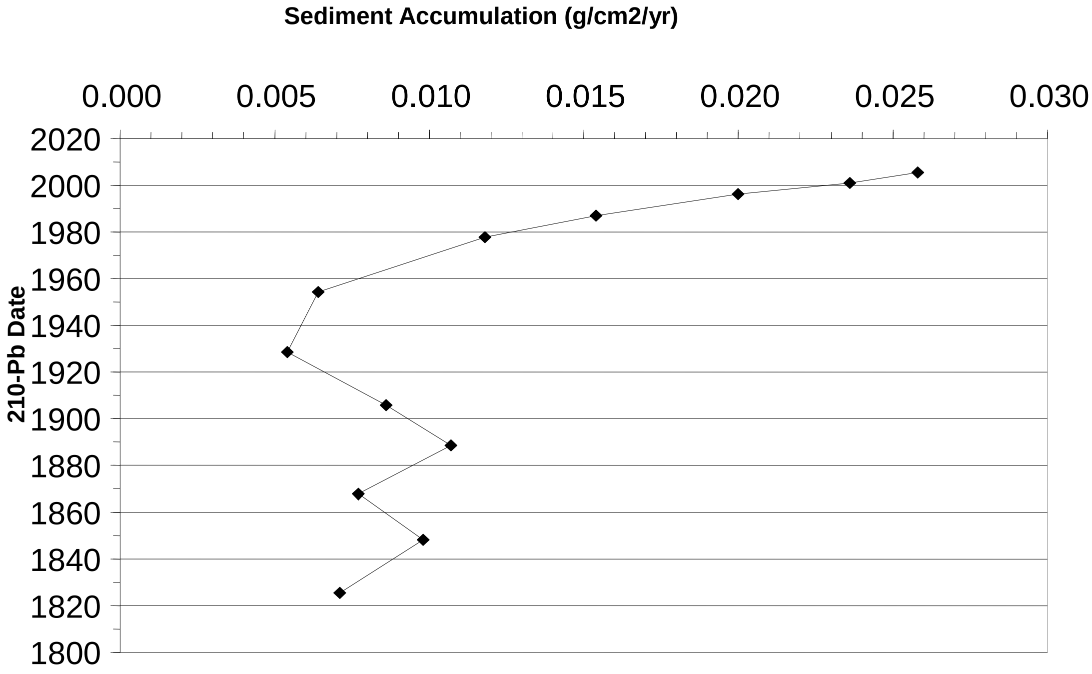


Figure 96. Sediment accumulation rates (g/cm^2/yr) by date (A.D.) for Harvey Lake (ISRO) core.

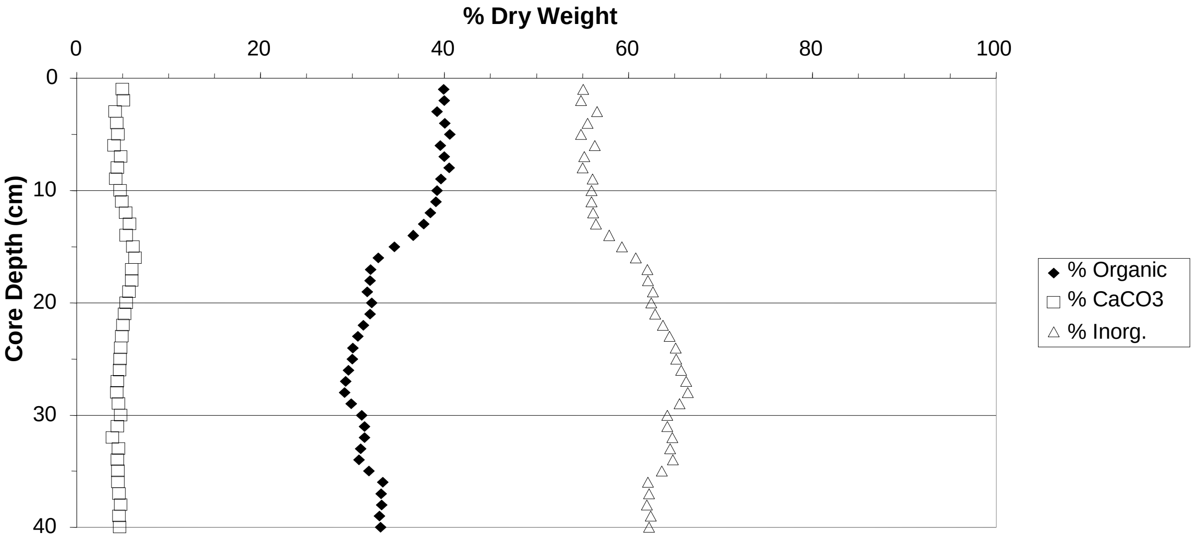


Figure 97. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Harvey Lake (ISRO) core.

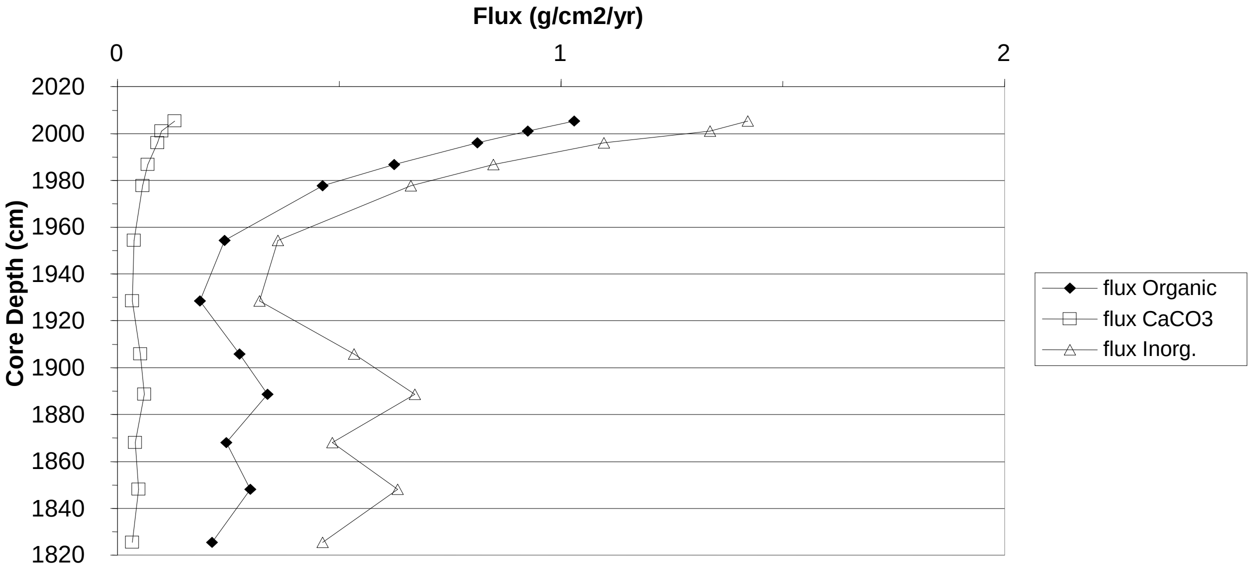


Figure 98. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Harvey Lake (ISRO) core.

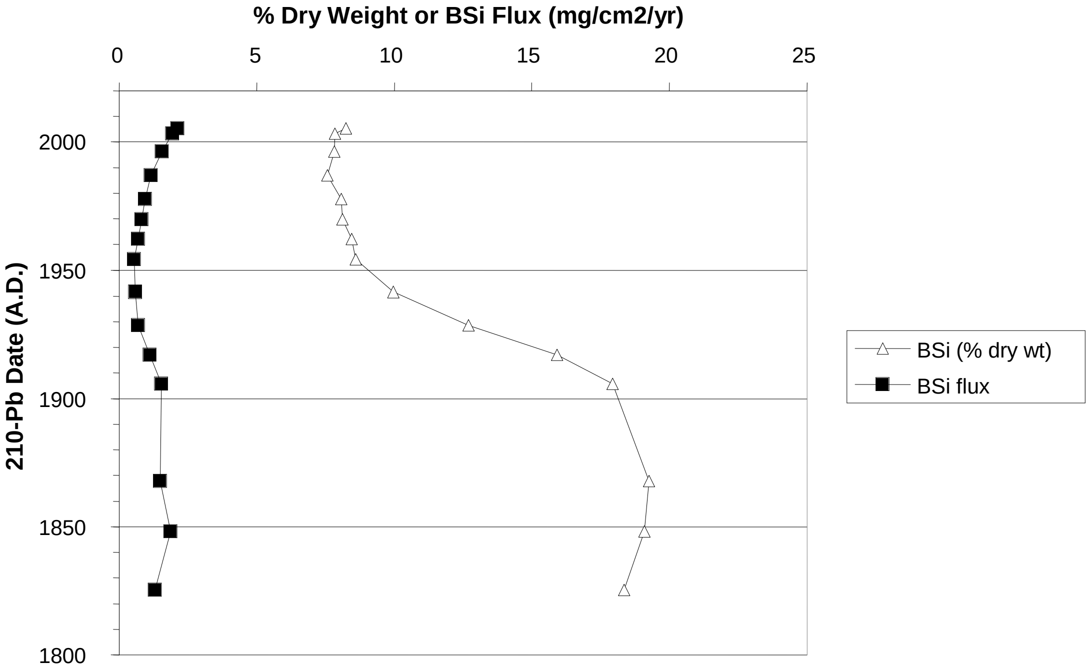


Figure 99. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Harvey Lake (ISRO) core.

Ahmik Lake: The total inventory of ^{210}Pb in Ahmik Lake declined to supported levels below 60 cm depth in the core (Figure 100). Sediments deposited before about 1880 A.D. were present below 50 cm depth (Figure 101). Sedimentation rates in Ahmik Lake increased between the 1920s and 1960s by a factor of about 1.5 (Figures 102, 103). Although slightly variable, sedimentation rates from 1960 to the present varied around 0.04-0.06 g/cm^2/yr (Figure 103). Sediment composition remained very constant in Ahmik Lake with carbonates representing 5 to 7% dry weight, organics between 40 and 50%, and inorganics between 50 and 55% with some small shifts between 25 and 50 cm depth (Figure 104). In contrast, accumulation rates of sediment constituents all increased upcore, especially after 1920, but remained at relatively constant levels after 1960 (Figure 105). A single large change in dry weight percentage of BSi took place in Ahmik Lake sediments between 1910 and1920 when BSi levels dropped from 25 to 20% dry weight (Figure 106). Apart from a single sample peak in BSi flux accumulation around 1910, BSi generally increased upcore after 1920 and remained at about 8-12 mg/cm^2/yr after 1960 (Figure 106).

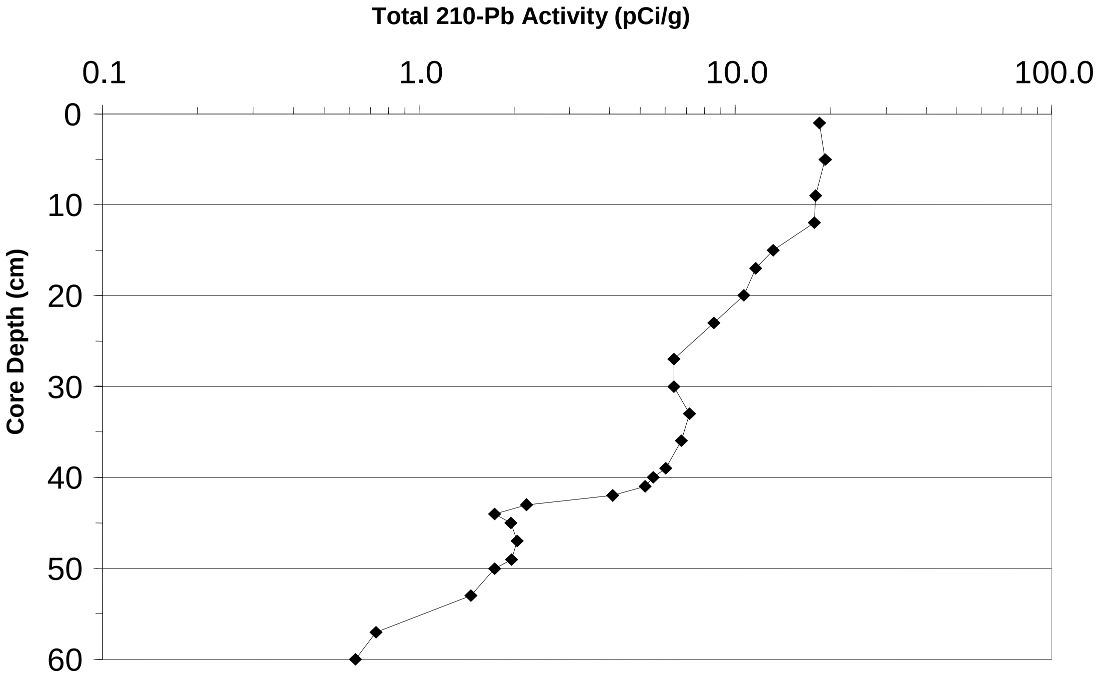


Figure 100. Total 210-Pb activity plotted against core depth (cm), Ahmik Lake (ISRO).

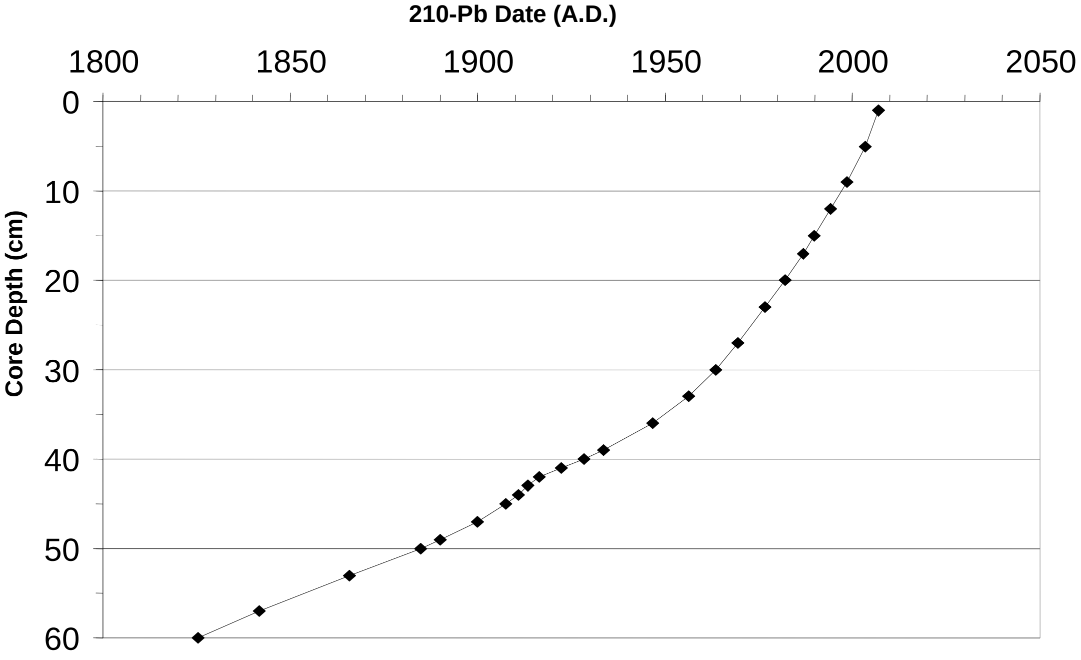


Figure 101. Resulting 210-Pb dating model for Ahmik Lake (ISRO) core.

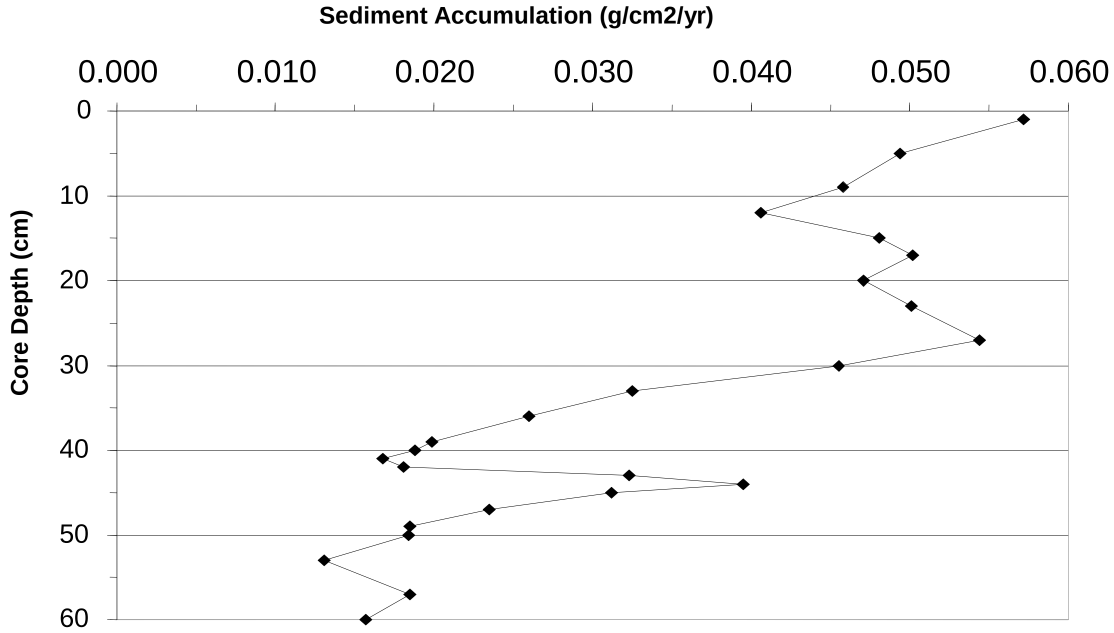


Figure 102. Sediment accumulation rates (g/cm^2/yr) by core depth (cm) Ahmik Lake (ISRO).

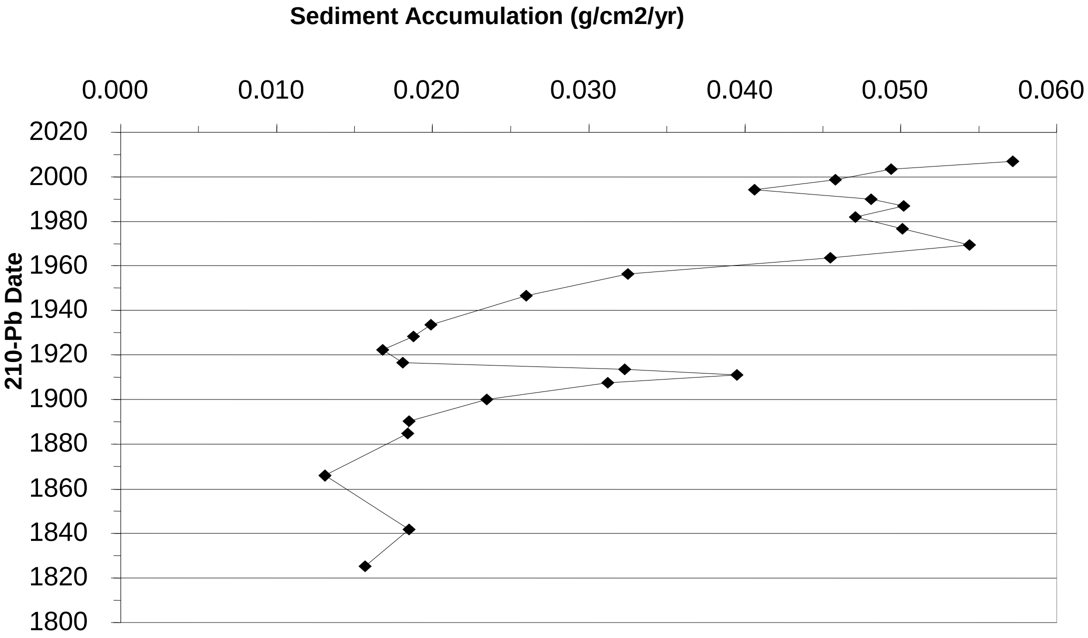


Figure 103. Sediment accumulation rates (g/cm^2/yr) by date (A.D.) for Ahmik Lake (ISRO) core.

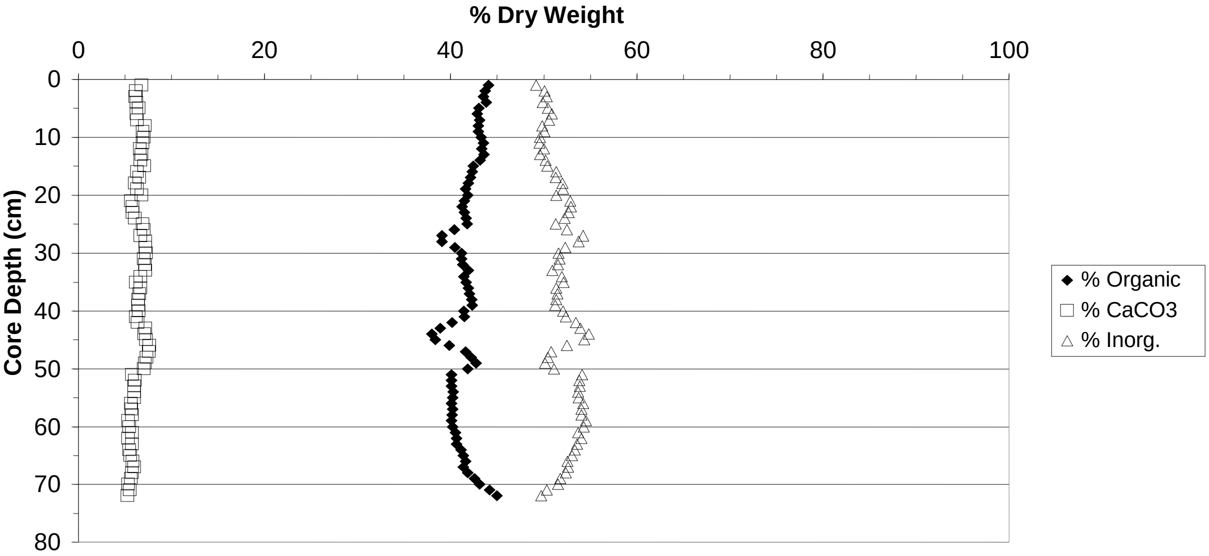


Figure 104. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Ahmik Lake (ISRO) core.

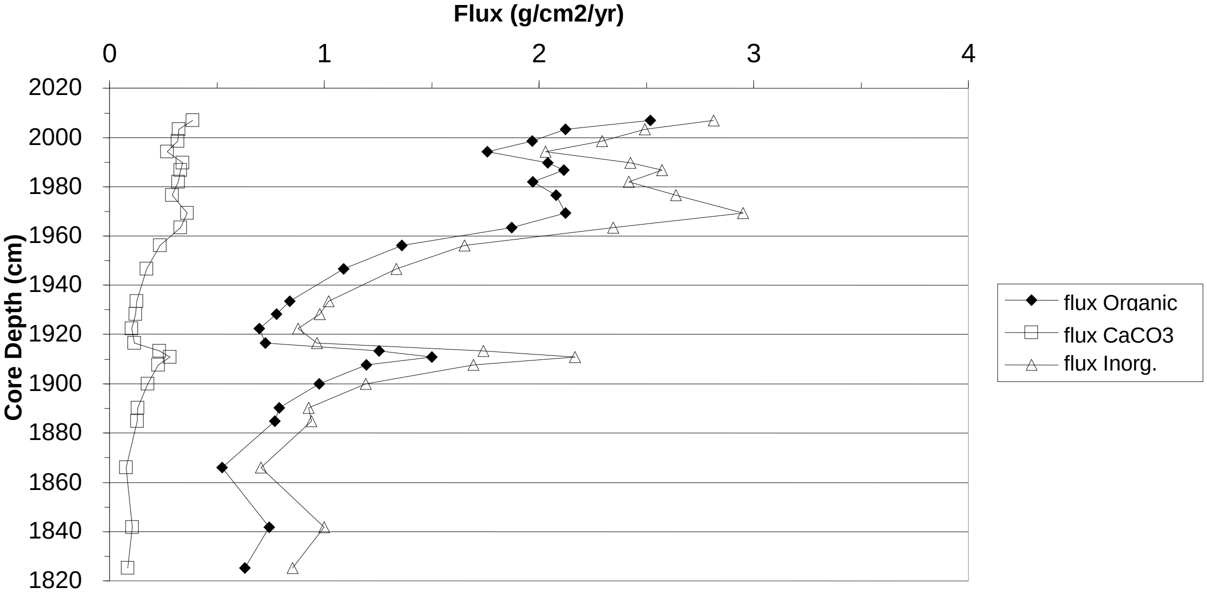


Figure 105. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Ahmik Lake (ISRO) core.

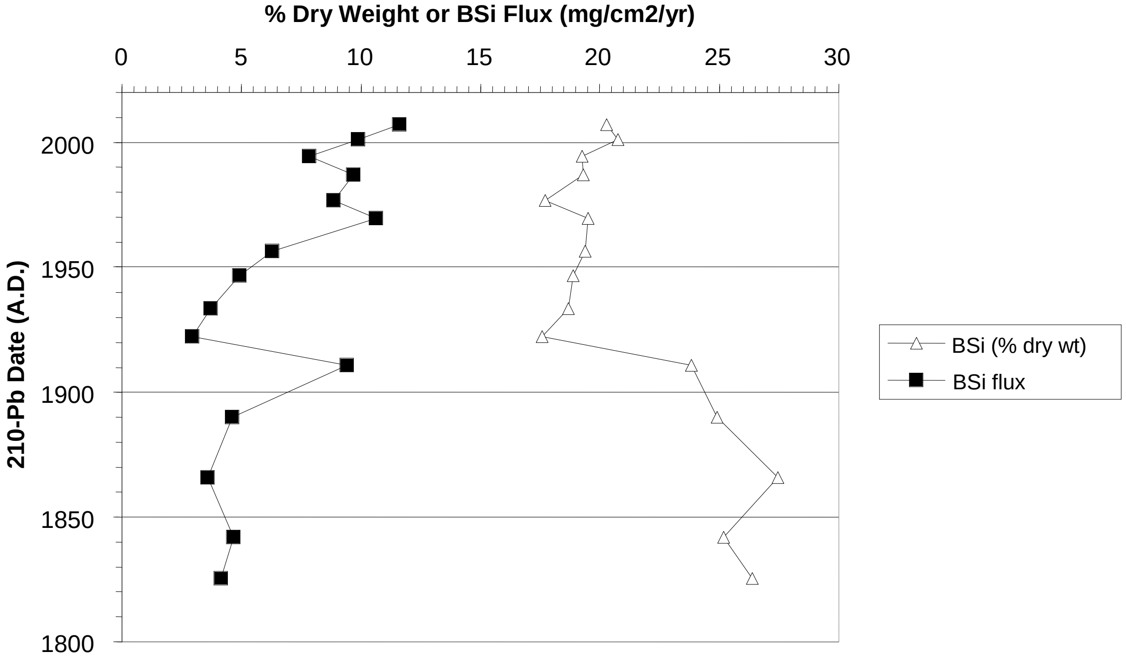


Figure 106. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Ahmik Lake (ISRO) core.

Richie Lake: Total ^{210}Pb inventories declined to supported levels below 26 cm core depth in Richie Lake (Figure 107). Sediments deposited below 20 cm depth are dated from before the 20th century (Figure 108). Sediment accumulation rates showed a general pattern of increase upcore. Pre-1900 sedimentation rates showed little change and were around 0.120 g/cm^2/yr (Figures 109, 110) before an increase to levels of 0.027 g/cm^2/yr by the 1940s (Figure 110). A second period of increased sedimentation was between the 1960s and 1980s before rates drop slightly at the core top. Sediment composition in Richie Lake was dominated by inorganic components that represent between 70 and 80% dry weight except for a few samples near the core top; the amount of inorganics slightly increased near 21 to 22 cm core depth (ca. 1900) (Fig 111). Organics comprised 20% dry weight with a small decrease at 15 to 22 cm depth and slight increases at the core top. Carbonates remained a minor component of the Richie Lake sediments at ca. 5%. Accumulation rates of all sediment constituents tracked changes in bulk sediment accumulation rates with increased accumulation after 1900 to a first peak at 1940 and highest levels upcore in the 1980s-2000s (Figure 112). BSi in Richie Lake was about 18% dry weight before 1900. From 1900 to 2000 BSi dropped to between 12 and 14% dry weight (Figure 113). Accumulation rates of BSi increased upcore from pre-1900 rates of 2 mg/cm^2/yr to approximately 5 mg/cm^2/yr in sediments deposited in the 1980s-2000s.

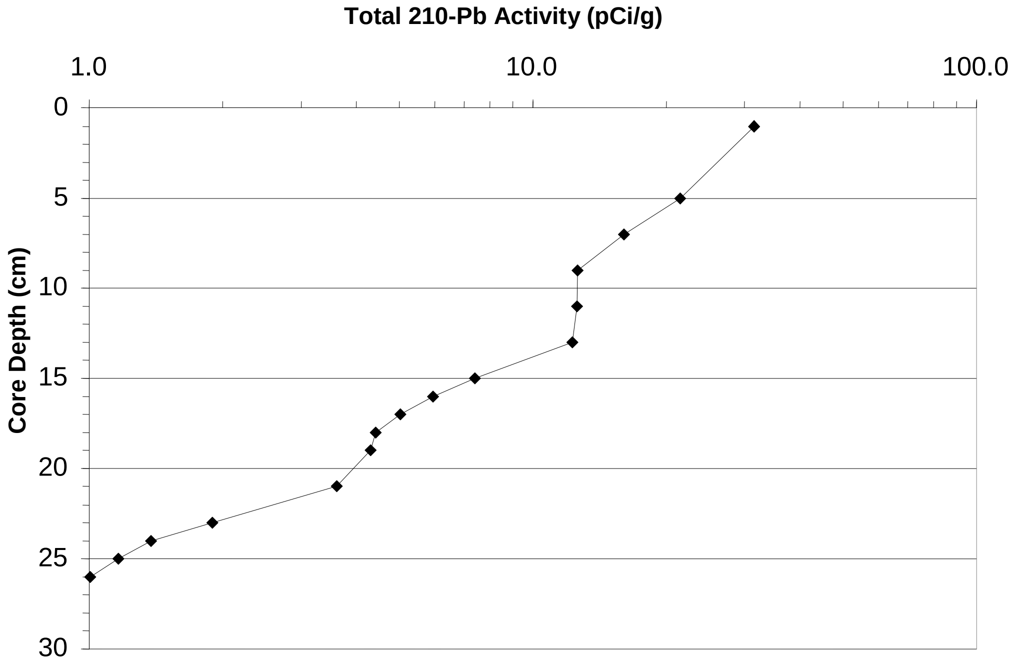


Figure 107. Total 210-Pb activity plotted against core depth (cm), Richie Lake (ISRO).

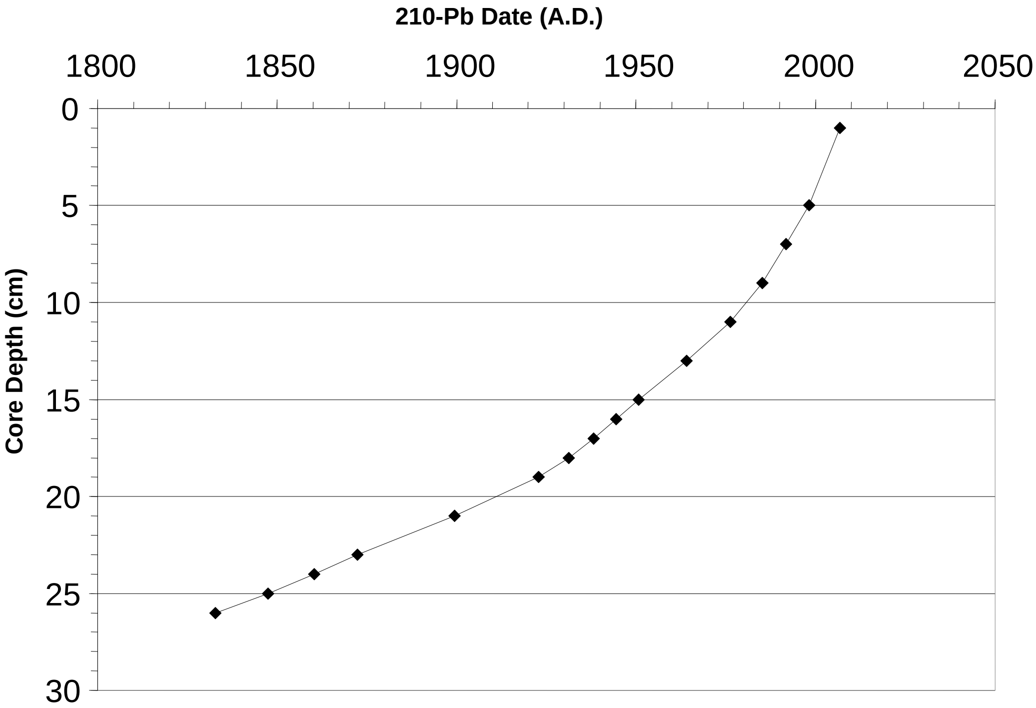


Figure 108. Resulting 210-Pb dating model for Richie Lake (ISRO) core.

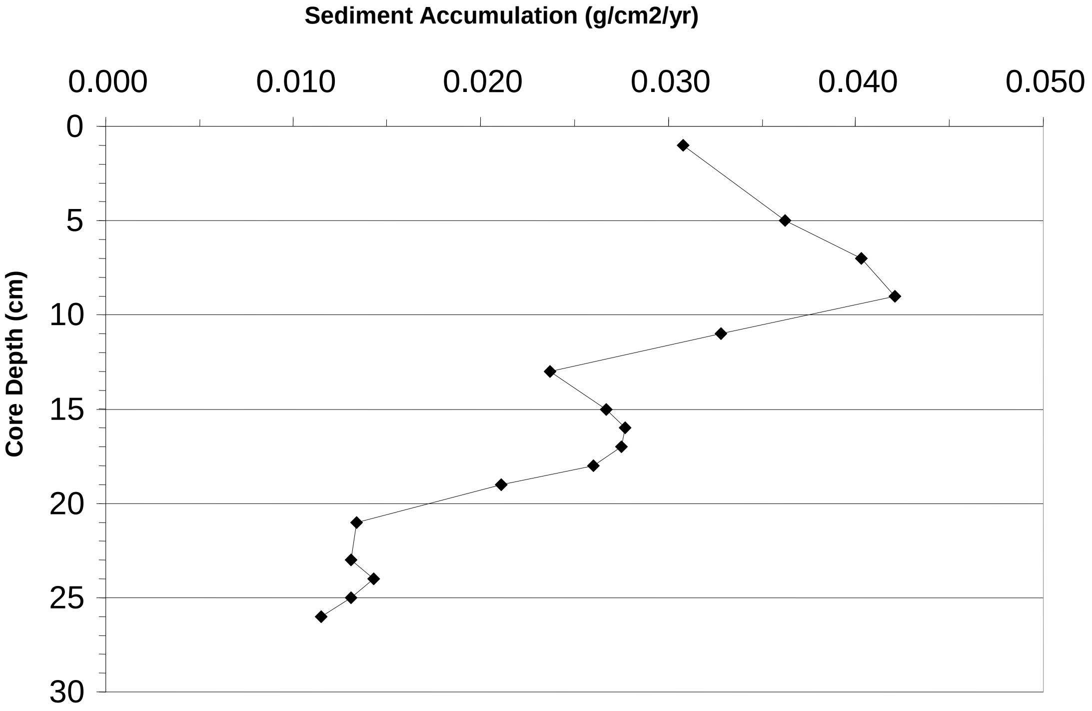


Figure 109. Sediment accumulation rates (g/cm^2/yr) by core depth (cm) for Richie Lake (ISRO).

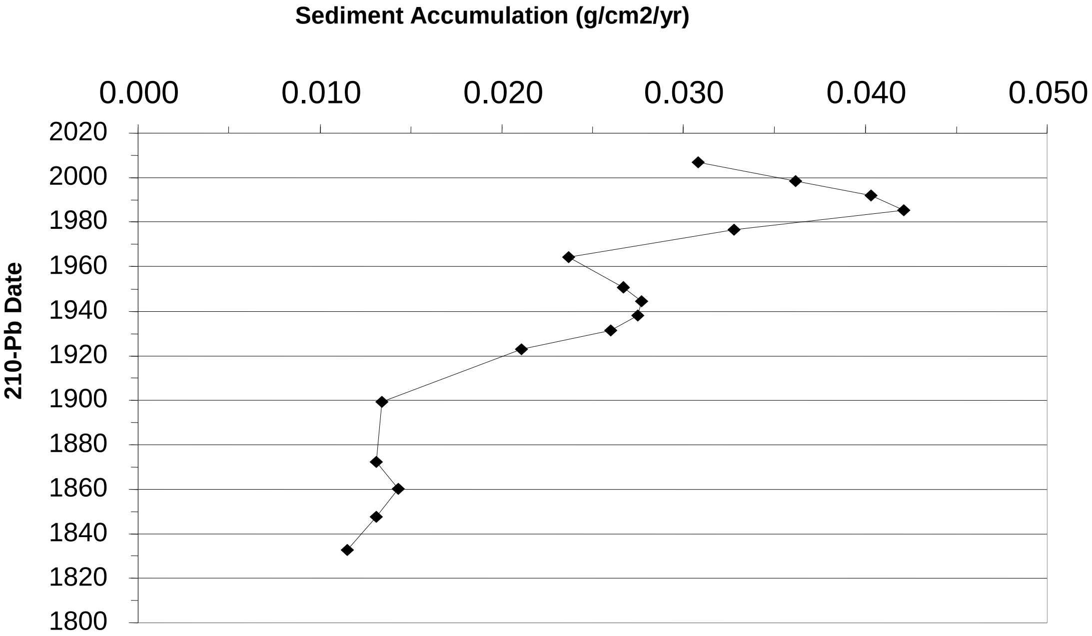


Figure 110. Sediment accumulation rates (g/cm^2/yr) by date (A.D.) for Richie Lake (ISRO) core.

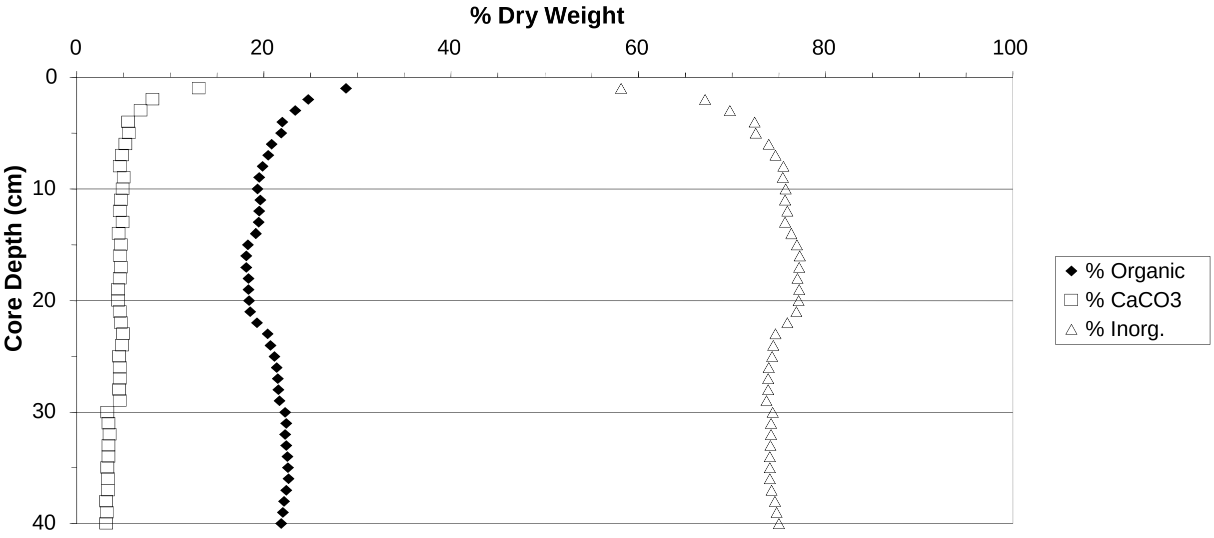


Figure 111. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Richie Lake (ISRO) core.

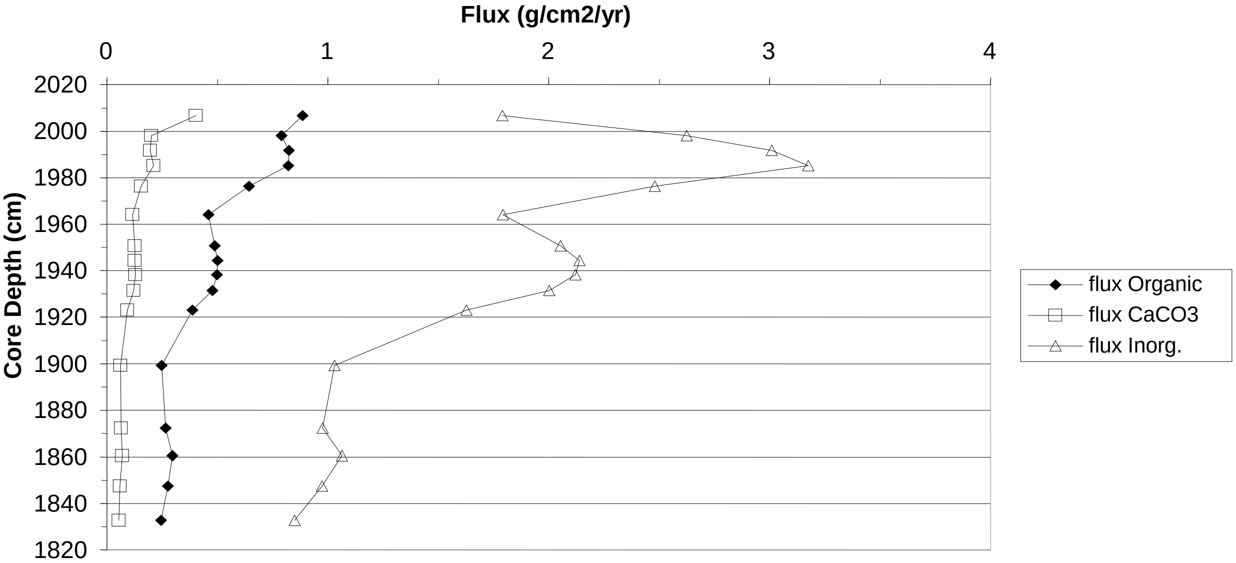


Figure 112. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Richie Lake (ISRO) core.

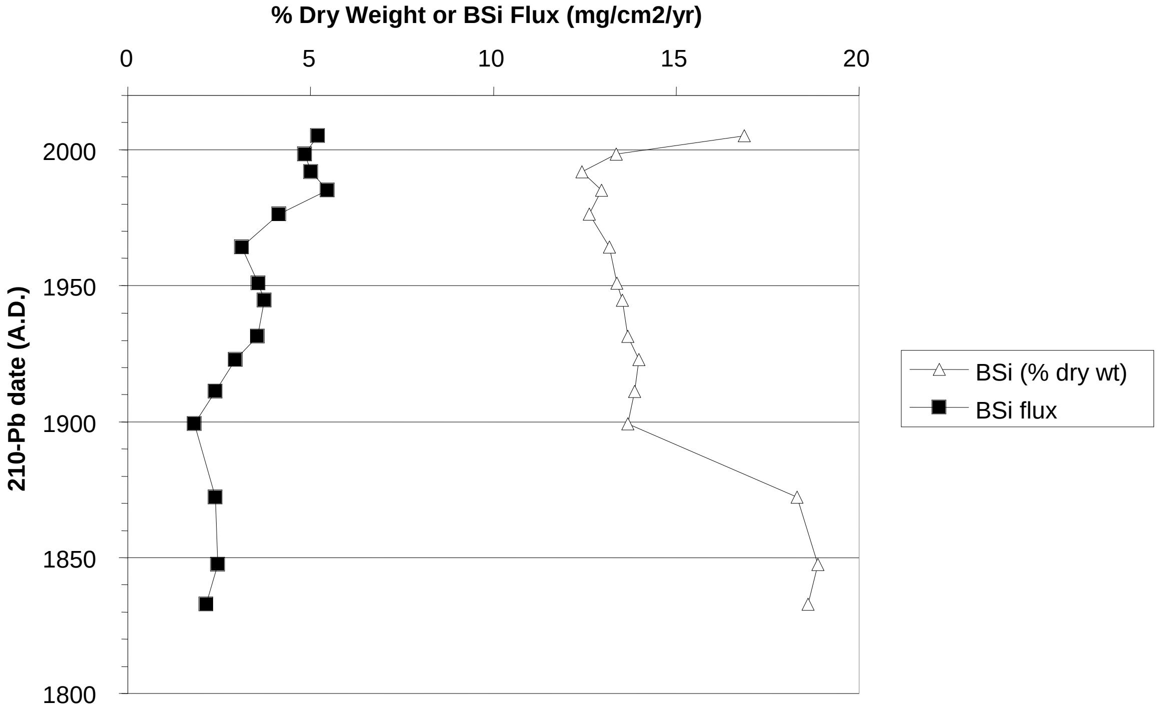


Figure 113. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Richie Lake (ISRO) core.

Downcore Diatom Communities (stratigraphy, cluster, ordinations)

Harvey Lake: Samples dated from 1825 to 2005 were analyzed for diatom remains in the Harvey Lake core. The subfossil diatom community in Harvey Lake was dominated by a benthic or tychoplanktonic araphid diatom flora composed primarily of *Staurosira* and *Staurosirella* species that together made up more than 70% of the diatom community and a nearly non-existent planktonic diatom community. A detrended correspondence analysis and a constrained cluster analysis on the downcore diatom communities identified three biostratigraphic zones: Zone 1 (1825-1917) Zone 2 (1929-1978, and Zone 3 (1987- 2005) (Figures 114, 115). *Staurosira construens*, *S. construens* var. *venter*, and *Staurosirella pinnata* were present in high abundance in all three biostratigraphic zones (Figure 116). Zone 1 sediments were characterized by abundance of *Staurosira elliptica GLEI* and *Pseudostaurosira brevistriata* compared to more recent sediment (Figure 116). Zone 2 sediments captured slightly higher abundance of *Staurosira construens*, and decreased abundance of *Sellaphora vitabunda*, *Staurosira elliptica GLEI* and *Pseudostaurosira brevistriata* compared to Zone 1. The uppermost biostratigraphic Zone 3 was characterized by *Staurosira construens* var. *#2 SWMN*, and loss of *Staurosirella elliptica GLEI* (Figure 116).

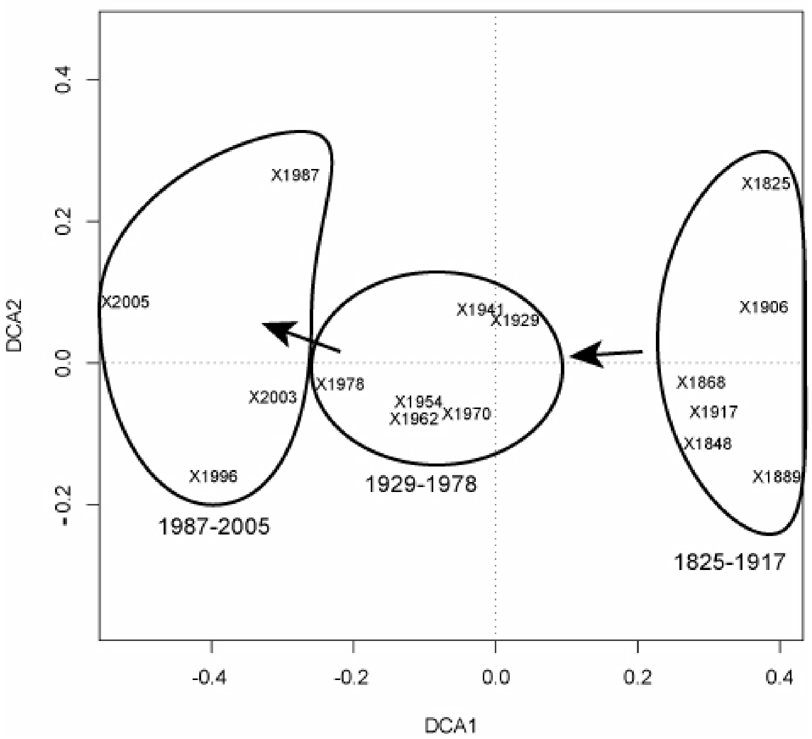


Figure 114. DCA of downcore diatom assemblages from Harvey Lake core (ISRO, 1825-2005); axes 1 and 2 loadings plotted for core depths-dates.

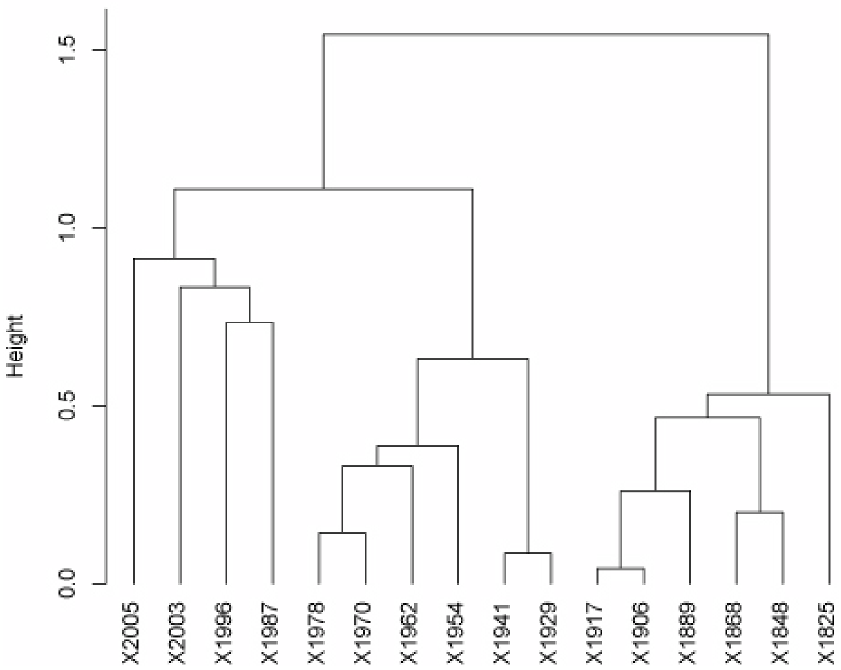


Figure 115. Constrained cluster analysis of downcore diatom assemblages from Harvey Lake core (ISRO, 1825-2005).

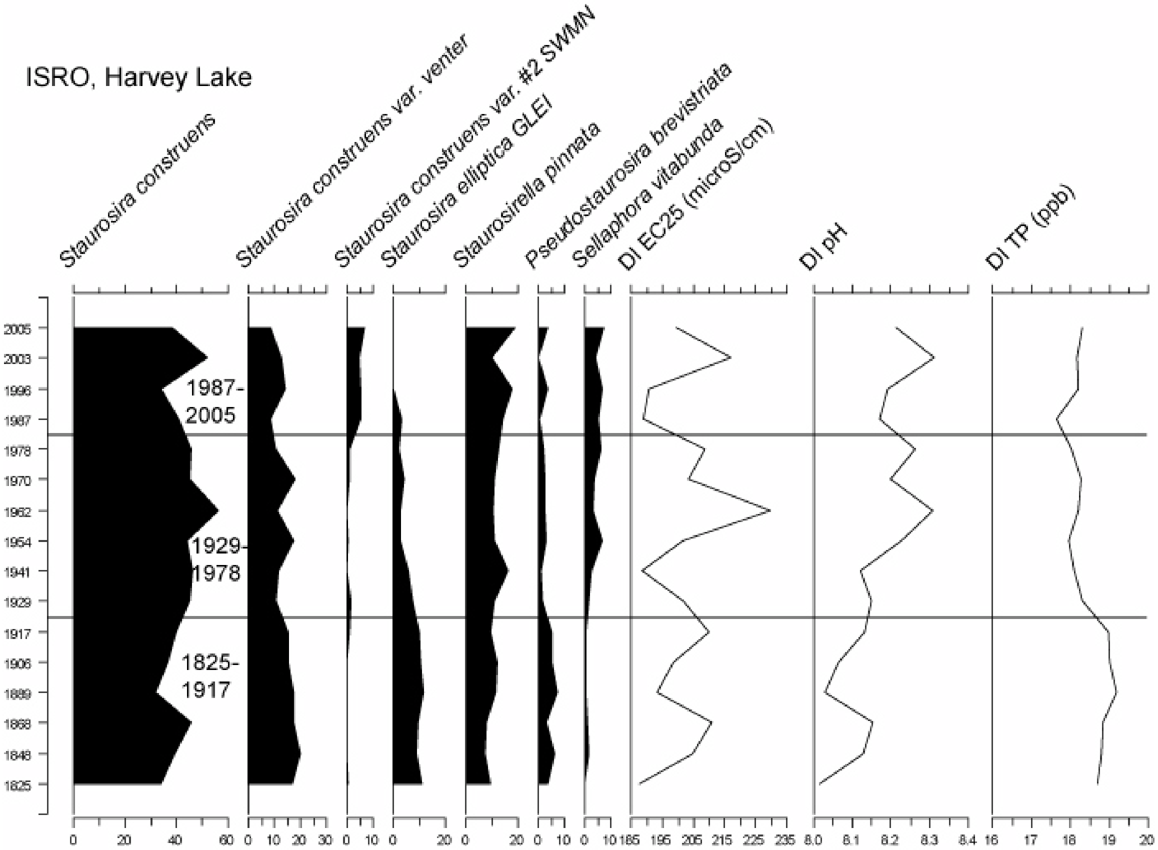


Figure 116. Stratigraphic diagram of relative abundance of dominant diatoms in Harvey Lake core (ISRO, 1825-2005) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Ahmik Lake: Diatoms were analyzed in the sediment core from Ahmik Lake in sections dated from 1825 to 2007. The benthic/tychoplanktonic taxon, *Staurosira construens* var. *venter,* was the dominant taxon throughout the core, a testament to the shallow nature of Ahmik Lake. A DCA and constrained cluster analysis resolved three major zones within the core: Zone 1 (1825-1890), Zone 2 (1911-1947), and Zone 3 (1956-2007) (Figures 117, 118). Zone 3 was secondarily divided between samples dated 1977 and 1987 in the cluster analysis (Figure 118). The pre-Euro-American settlement assemblage from Ahmik Lake (Zone 1) was characterized by very high abundance of *Staurosira construens* var. *venter*; its abundance reached more than 80% at some core depths (Figure 119). Zone 2 sediments contained lower abundance of *Staurosira construens* var. *venter* and increased abundance of other small araphid species such as *Staurosira construens*, *Staurosirella pinnata* and *Pseudostaurosira brevistriata*. Zone 2 sediments also had the first appreciable abundance of planktonic species such as *Aulacoseira ambigua*, *A. subarctica*, and *Discostella stelligera*. Zone 3 sediments had increased abundance of *Staurosira construens*, *Staurosirella pinnata* and *Pseudostaurosira brevistriata* and initially lower abundance of the planktonic forms. The upper sediments in Zone 3 dated from 1987 to 2007 were characterized by the first appearance of *Fragilaria crotonensis*, a diatom more common in mesotrophic to eutrophic lakes (Figure 119).

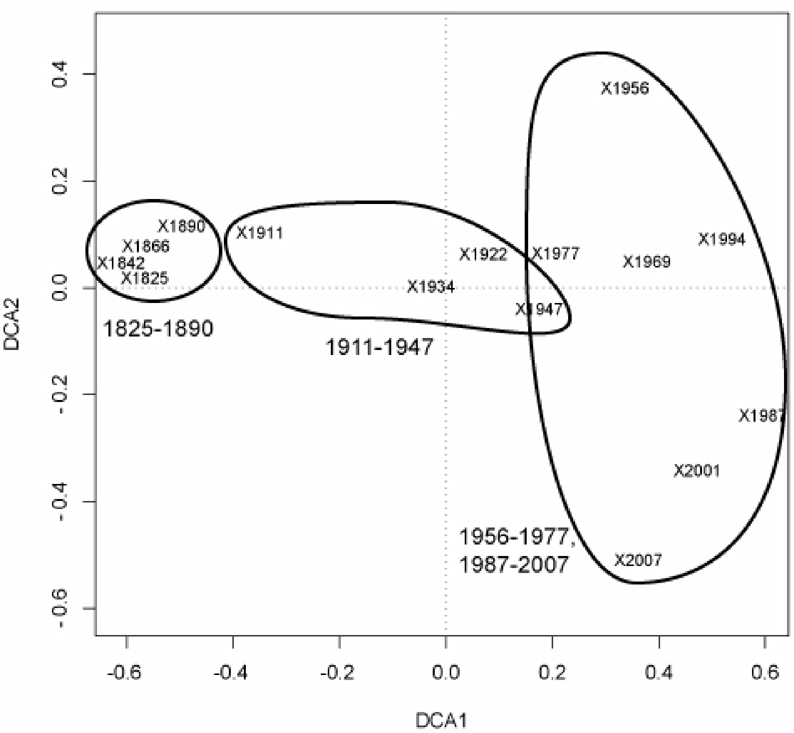


Figure 117. DCA of downcore diatom assemblages from Ahmik Lake core (ISRO, 1825-2007); axes 1 and 2 loadings plotted for core depths-dates.

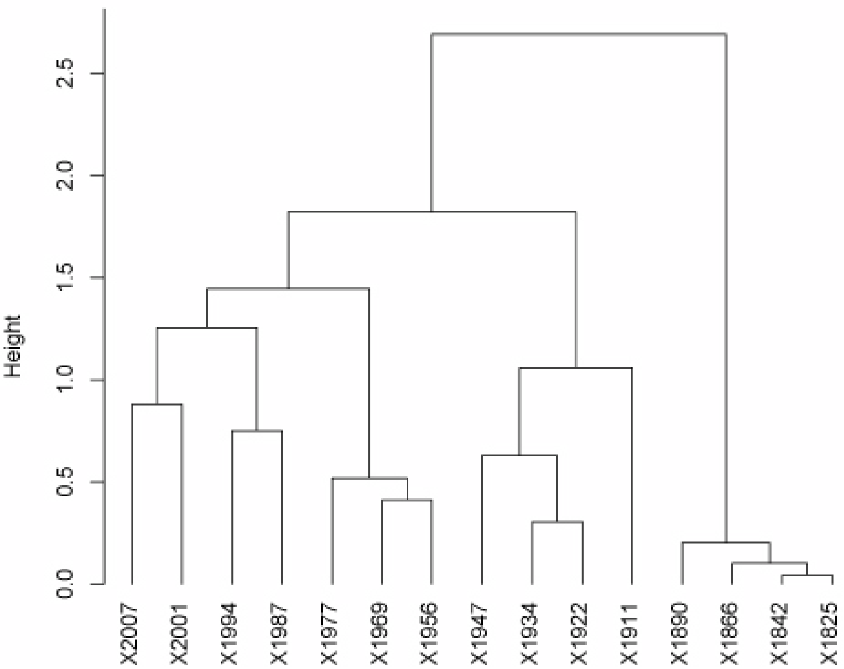


Figure 118. Constrained cluster analysis of downcore diatom assemblages from Ahmik Lake core (ISRO, 1825-2007).

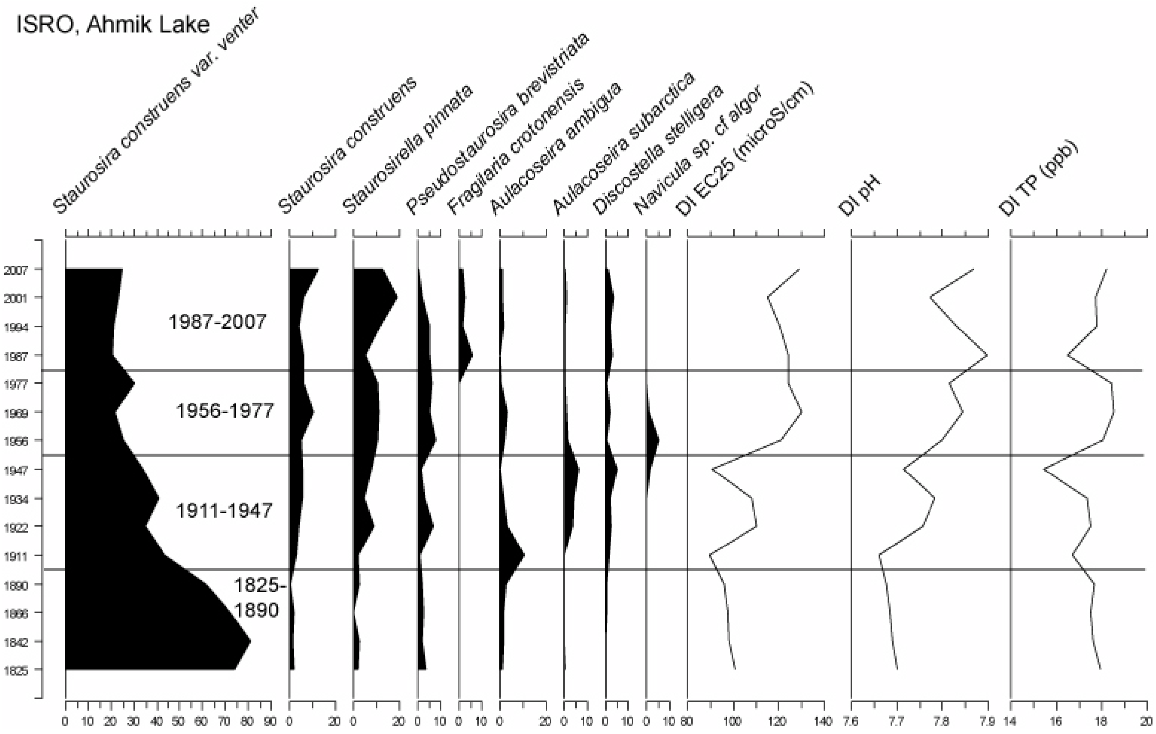


Figure 119. Stratigraphic diagram of relative abundance of dominant diatoms in Ahmik Lake core (ISRO, 1825-2007) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Richie Lake: Richie Lake was the largest lake cored at ISRO and diatom communities were analyzed from sediments dated 1833 to 2005. In contrast to Ahmik and Harvey Lakes, the subfossil diatom community in Richie Lake was dominated by planktonic forms including species from the genera *Aulacoseira*, *Fragilaria*, *Asterionella*, *Tabellaria*, *Discostella*, and *Cyclotella*. A DCA and constrained cluster analysis of diatom communities in the Richie Lake core identified three major biostratigraphic zones; the uppermost sample in the core was a notable outlier (Figures 120, 121). Zone 1 sediments (1833-1872) represented lake conditions prior to Euro-American settlement and were characterized by high abundance of *Aulacoseira ambigua*, *A. subarctica*, and *Discostella stelligera*. Many other planktonic species were in low abundance (Figure 122). Zone 2 sediments captured the lake history from 1899 to 1964 and were identified by decreased abundance of *Aulacoseira ambigua* and increased abundance of *A. granulata* and *A. distans* v. *nivalis*. Zone 3 (1976-1998) sediments had fewer *A. subarctica* and more *A. granulata*, *A. distans, Asterionella formosa*, and *Tabellaria flocculosa* IIIp. The uppermost sample analyzed was dated 2005 and separated from Zone 3 sediments by its unique abundance of *Fragilaria crotonensis*, *Cyclotella michiganiana*, and *Tabellaria flocculosa* III. It is important to note that when Lake Richie was cored in 2007, a large cyanobacterial bloom of *Lyngbya birgei* was occurring (see *Park Summary* below).

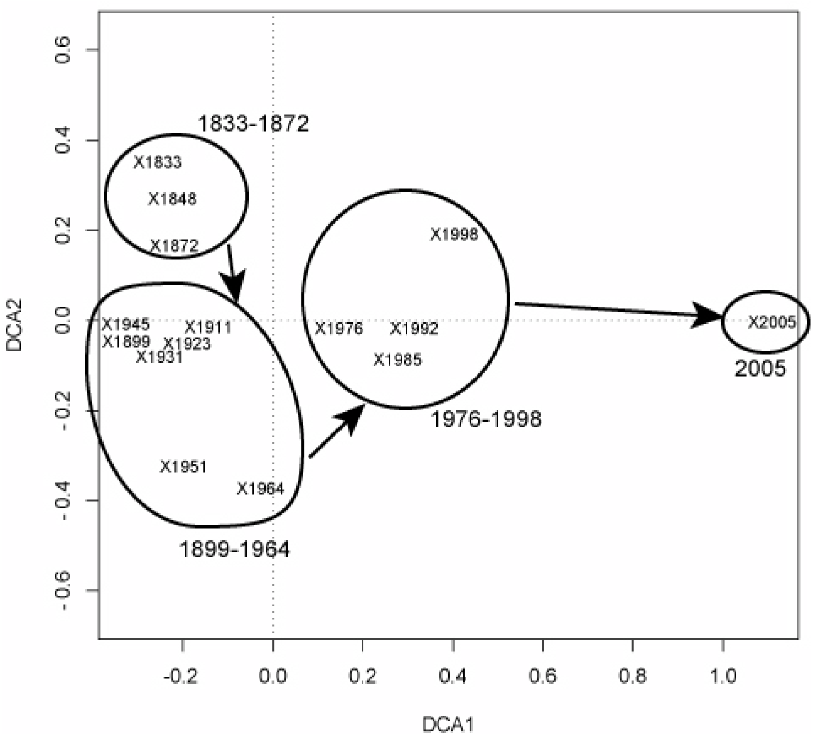


Figure 120. DCA of downcore diatom assemblages from Richie Lake core (ISRO, 1833-2005); axes 1 and 2 loadings plotted for core depths-dates.

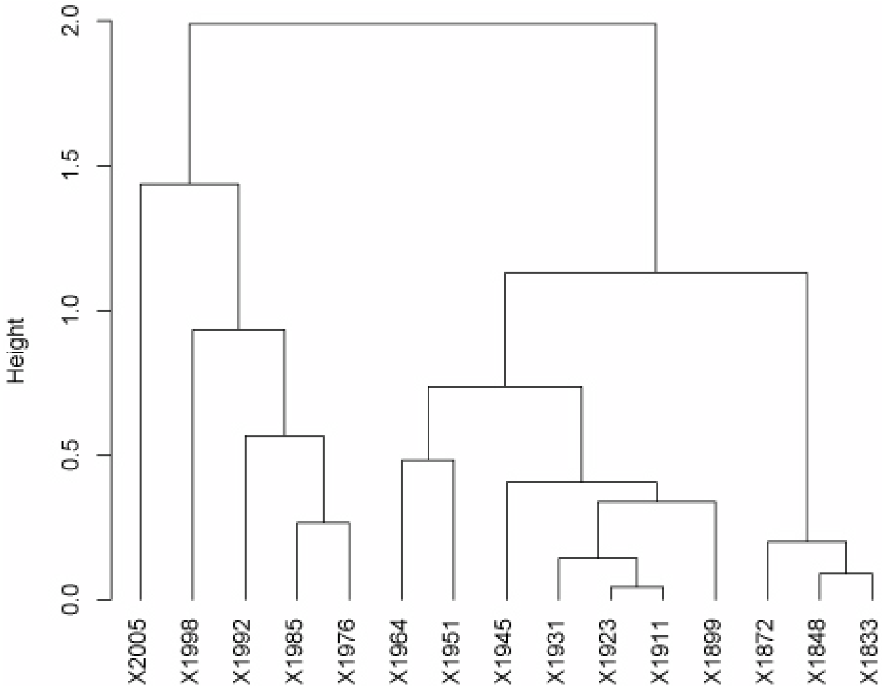


Figure 121. Constrained cluster analysis of downcore diatom assemblages from Richie Lake core (ISRO, 1833-2005).

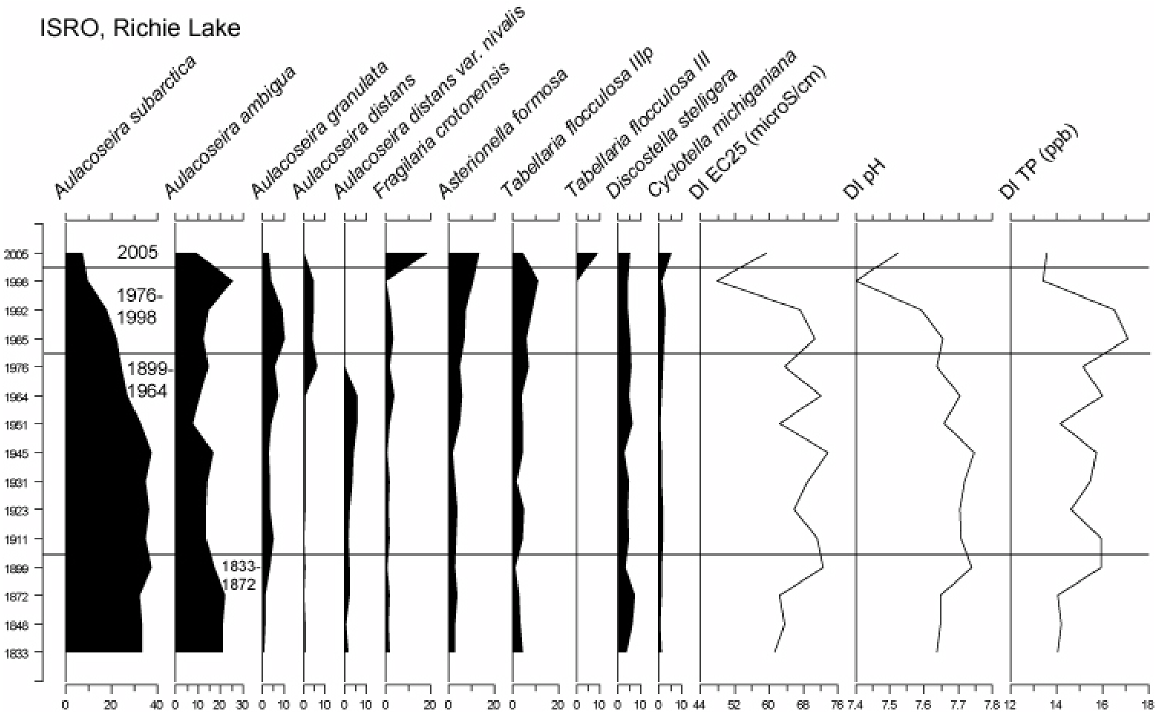


Figure 122. Stratigraphic diagram of relative abundance of dominant diatoms in Richie Lake core (ISRO, 1833-2005) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Environmental Reconstructions

Harvey Lake: Diatom-inferred reconstructions of historical pH, conductivity, and TP were estimated for Harvey Lake from 1825 to 2005. Changes in diatom-inferred water quality parameters in Harvey Lake were considered not significant, because reconstructed values did not exceed model error estimates (Figure 116). Diatom-inferred TP remained at around 18 ppb, pH varied between 8.0 and 8.3, and conductivity only varied from 185-230 µS/ cm.

Ahmik Lake: The GLKN diatom calibration set and transfer functions were applied to downcore diatom communities from Ahmik Lake to reconstruct historical pH, conductivity, and TP. Similar to Harvey Lake, no significant changes were found in historical inferred water quality in Ahmik Lake (Figure 119). Conductivity reconstructed at 90 to 130 µS/cm, diatom-inferred pH ranged from 7.7 to 7.9, and diatom-inferred TP remained around 18 ppb throughout.

Richie Lake: Compared to other GLKN lakes, the ISRO lakes, including Richie Lake, showed very little change in historical water quality as estimated from the subfossil diatom assemblages (Figure 122). Richie Lake showed no significant differences or trends in diatom-inferred pH, conductivity, or TP. Total phosphorus remained between 13 and 17 ppb, pH ranged from 7.7 to 7.4, and conductivity centered around 65 µS/cm during the last 180 years of the lake's history.

Relation to Land Use/History

Shelton (1975), Karamanski et al. (1988), Huber (1983), Stottlemyer et al. (1998), and Cochran (2009) have synthesized the geological, biological, and cultural histories of Isle Royale. Old Copper Culture hunters were the first to arrive on Isle Royale and actively mined native copper deposits until 1500 BC. The later Woodland Peoples continued to exploit Isle Royale's copper extensively; during the Hopewellian period, they provided many Native American cultures with copper from Isle Royale through trade. Oddly, at the time of Euro-American arrival in the Great Lakes region, the mining of copper by native cultures ended on Isle Royale.

European explorers arrived at Lake Superior in the 1600s, and by the 1670s Isle Royale was on maps of the region. Fur trade and safe harborage led the initial interest in Isle Royale, but by the early 1800s the geological and fishery resources were also recognized. By the mid-1800s the first geologic maps of the island attracted prospectors and small companies who began mining operations around the island. Most operations were small and of varying success, and the remote location and logistics of working on Isle Royale, as well as falling copper prices kept profits down. By 1855 most of the mining on Isle Royale had ceased. The Civil War, higher copper prices, and improved Great Lakes transportation reinvigorated mining on Isle Royale in the 1870s. To support the mining operations, large areas of trees were cut and fires were used to expose mineral deposits. By the late 1800s serious mining activity ended on Isle Royale.

The other early use of Isle Royale's resources by Euro-American settlers was commercial fishing. As early as the late 18th century commercial fishing was occurring around Isle Royale. Fishing increased on the island through the 1800s with abundant catches. Permanent fishing camps worked side-by-side with the mining operations and shipped the catch to eager western and eastern markets. Technological improvements in vessels and fishing gear expanded fishing operations and by the late 1800s fish stocks and catch began to decline from overfishing and the beginnings of habitat degradation. Active fishing camps flourished into the 20th century; however, the decline of whitefish, introduction of smelt and lamprey, and establishment of the national park signaled the end of Isle Royale's commercial fishing.

Logging activities on Isle Royale were initially dictated by mining and fishing activity. Miners needed timber for building, mining timbers, and fuel. Fires were often set to expose mineral resources. Fisherman used forest resources for construction of barrels, boats, fishing gear, and structures. However, because of its remote location, much of Isle Royale was spared from commercial logging through the 1920s. With word that Isle Royale would become a national park, logging companies showed interest in the island's forests again. In the mid-late 1930s the Siskiwit Valley was cut for pulpwood; the slash fueled the large 1936 fire on the island.

Tourism began on Isle Royale near the turn of the 20th century, catering in part to sportsmen attracted to trout fishing around Isle Royale. Resorts, often very crude collections of tents and buildings, sprung up near Washington and Rock Harbors but were struggling in the early 1900s. Several upscale clubs tried to become established but the general tourist was treated to a simple retreat. With formation of Isle Royale National Park in 1940, the Park Service gradually purchased all of the resorts and most family homes, and incorporated several into park operations. In recent years, Isle Royale has had a limited number of visitors (10,000 - 24,000 per year), but offers superb backpacking and boating opportunities in the Great Lakes region.

Park Summary

As with other GLKN park lakes, sediment cores from the inland lakes of Isle Royale showed biological and geochemical changes in the last 200 years. Some of the more temporally constrained changes seen at the time of Euro-American settlement in other GLKN park lakes were not as evident on Isle Royale, likely because of Isle Royale's remote location and the more focused post-Euro-American settlement activities along the nearshore regions of the island. For example, increased sedimentation rates, common in other GLKN parks following logging and land clearance activities, were somewhat delayed in the Isle Royale lakes and occurred well into the 20th century (e.g., after the 1950s in Harvey Lake). The first biological changes did not adhere to timing of land use changes associated with mining in the 1840s on Isle Royale, but were delayed until the 1880s (Richie Lake) to the 1920s (Harvey Lake). In Harvey and Ahmik Lakes, the earliest biological changes seen in the cores were more pronounced than changes seen in the latter part of the 20th century. In contrast, changes recorded in sediments deposited between 1964 and 1976 in Richie Lake were more dramatic than changes recorded at the turn of the 20th century.

All three ISRO lakes show a secondary shift in the diatom communities in the latter half of the 20th century while under NPS management. The timing of this shift varied among the lakes: Richie (1964-1976), Harvey (1978-1987) and Ahmik (1947-1956 and 1977-1987). In Richie Lake, abundance increased in *Tabellaria*, *Cyclotella michiganiana*, *Fragilaria crotonensis*, *Aulacoseira granulata*, and *A. distans*, and decreased in *A. subarctica* and *A. distans* v. *nivalis*. In Ahmik Lake *Fragilaria crotonensis* increased as well as *Discostella stelligera*, and several of the small fragilarioid taxa (*Staurosira construens* and *Staurosirella pinnata*). Diatom community changes in Harvey Lake were controlled by the abundance of small fragilarioid species. Post-1970s communities contained greater abundances of *Staurosira construens* var. *#2 SWMN* and loss of *Staurosira elliptica* GLEI. The diatom community changes at ISRO fit some of the patterns identified as responses to climate drivers that were noted in other boreal lakes and in other GLKN parks. For example, shifts toward stronger stratification due to warming led to a decline in the *Aulacoseira* species that thrived during periods of mixing, and increased in taxa such as the small cyclotelloid species (*Discostella* and *Cyclotella* species) and *Fragilaria crotonensis* that adapted to warmer stratified conditions (Rühland et al. 2008).

A special note is deserved regarding Richie Lake and some very recent ecological changes. During our coring trip to the lake in 2007, a very extensive bloom of the cyanobacterium *Lyngbya birgei* was present. The bloom existed throughout the lake and water column, with Secchi disk measurements of ~1 m. Near-surface pH readings exceeded 9.0 (the EPA criterion for freshwater life) likely due to photosynthetic uptake of CO_2, while the senescence of cyanobacteria beneath the photic zone caused anoxic conditions below 5 m depth (Joan Elias, pers. comm.). The bloom was notably thicker along the shore and in the eastern end of the lake where wind and wave action had produced large accumulations of floating, green, flocculent masses. Cyanobacterial accumulations began rotting and the stench was notable. Backpackers avoided the lake due to the unpleasant bloom conditions. The bloom did not reoccur at Richie in 2008 or 2009, although in 2009 a similar but less intense bloom occurred in nearby Sargent Lake. However, during late August 2010, another large cyanobacterial bloom occurred in Richie Lake (sampled and reported by Rick Damstra, NPS Aquatic Ecologist). The bloom was present throughout the lake and visible water column, and was thicker along shore and among macrophyte beds at the lake's eastern shoreline. In contrast to the 2007 bloom in Richie Lake, the 2010 cyanobacterial bloom comprised three blue-green taxa. The primary species was again *Lyngbya birgei*, but two species of *Anabaena* were also present: *Anabaena flos-aquae* and *Anabaena planctonica*.

To put Richie Lake's recent behavior in historical context, we extended the analysis of our 1.2 m long sediment core to include geochemistry, diatoms, carbon and nitrogen isotopes, and fossil pigments. The most recent interval (last decade) was marked by a decrease in heavily silicified diatom species (*Aulacoseira* species; often characteristic of well-mixed lakes) and a corresponding increase in small centric diatoms and other planktonic species such as *Fragilaria crotonensis* and *Tabellaria flocculosa* III. At the same time there was a notable increase in fossil algal pigments of N-fixing and colonial cyanobacteria (aphanizophyll, canthaxanthin, and myxoxanthophyll) coincident with a recent shift toward depleted $\delta^{15}N$ (data not shown), perhaps due to increased atmospheric nitrogen deposition or alternatively to increased N-fixation by cyanobacteria. Regardless, the recent and unprecedented changes in Richie Lake provided yet another example of how lakes in relatively pristine and protected areas showed evidence of ecological change that cannot be readily attributed to land use (Smol et al. 2005, Rühland et al. 2008). It becomes more and more likely that changes in climate had driven these observed ecological changes in lakes.

Long Sediment Cores (VOYA)

Core Collection

Long sediment cores were recovered from three lakes in Voyageurs National Park in August 2006: Ek Lake (135 cm), Peary Lake (88 cm), Cruiser Lake (88 cm) (Table 6). In Cruiser Lake the more easterly basin was cored rather than the westerly basin. The westerly basin was used for WQ analysis and surface sediment collection; unfortunately, the western basin was too deep for rigid drive rod coring techniques used to recover long sediment cores.

Core Dating, Loss-on-ignition and Geochemistry

Ek Lake: Lead-210 inventories decrease rapidly in Ek Lake to supported levels in samples below 23 cm core depth (Figure 123). The Euro-American settlement horizon (1870s) was located at approximately 18-19 cm (Figure 124). Sedimentation rates gradually increased in Ek Lake from the 1900s to present; modern rates were approximately two to three times higher than pre-Euro-American rates (Figures 125, 126). The increase in sedimentation rates coincided with initial logging in the region. Biogeochemical records in Ek Lake were variable. Carbonate was a minor and relatively constant component of the sediments (about 5% by weight; Figure 127), whereas organic and inorganic content changed over time. Pre-Euro-American sediments were approximately 42% and 52% dry weight organic and inorganic content, respectively. However, a shift occurred in the 1950s (10 cm) to greater organic content and lower inorganic content. If treated as flux, all sediment constituents from LOI increased in accumulation rates after 1900 (Figure 128). BSi content decreased over time in Ek Lake sediments from approximately 25% to 22% dry weight (Figure 129). When converted to flux rates, sedimentation of BSi increased from <1 to more than 3 $mg/cm^2/yr$ at the core top. The increased sedimentation rate, organic content and BSi flux may indicate increased 20th century productivity in Ek Lake.

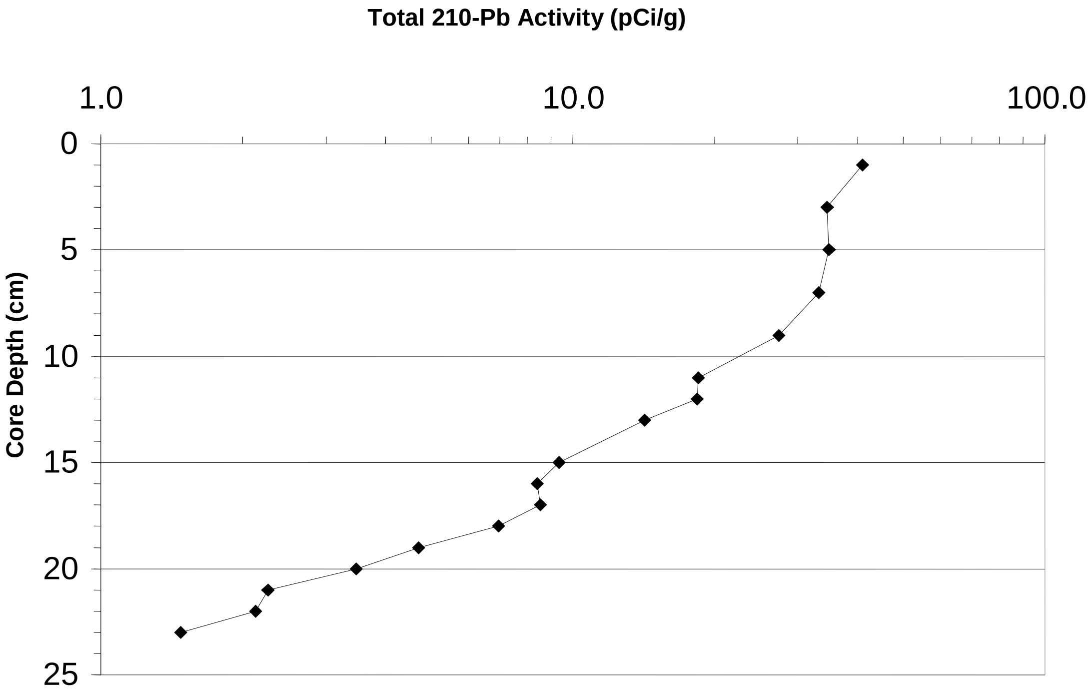


Figure 123. Total 210-Pb activity plotted against core depth (cm), Ek Lake (VOYA).

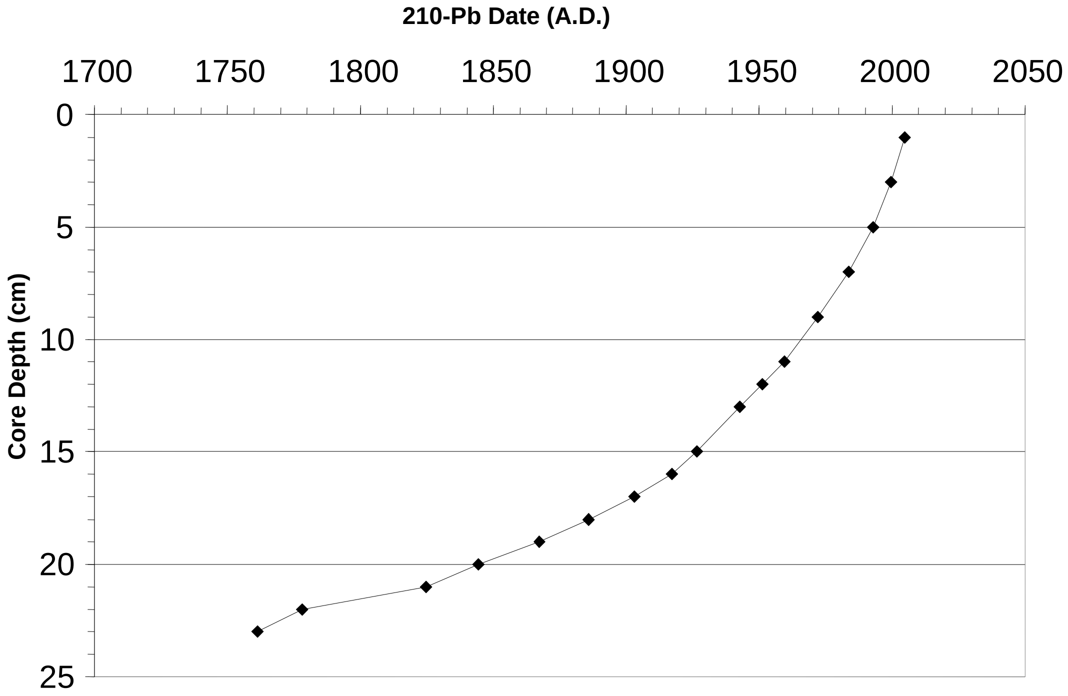


Figure 124. Resulting 210-Pb dating model for Ek Lake (VOYA) core.

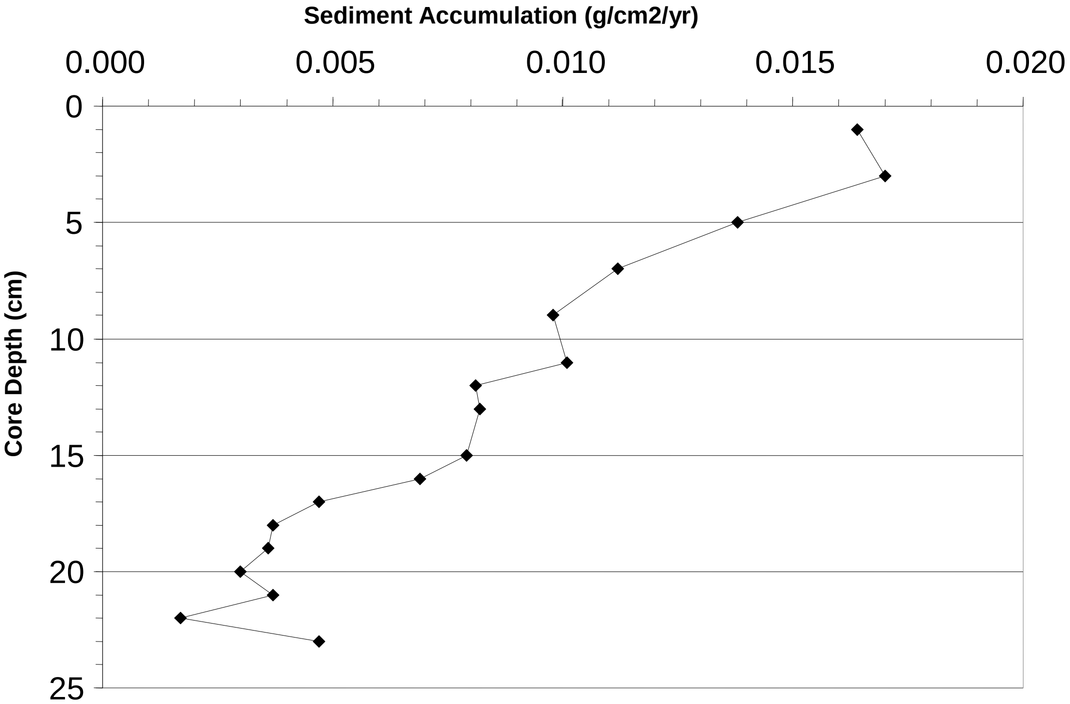


Figure 125. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Ek Lake (VOYA).

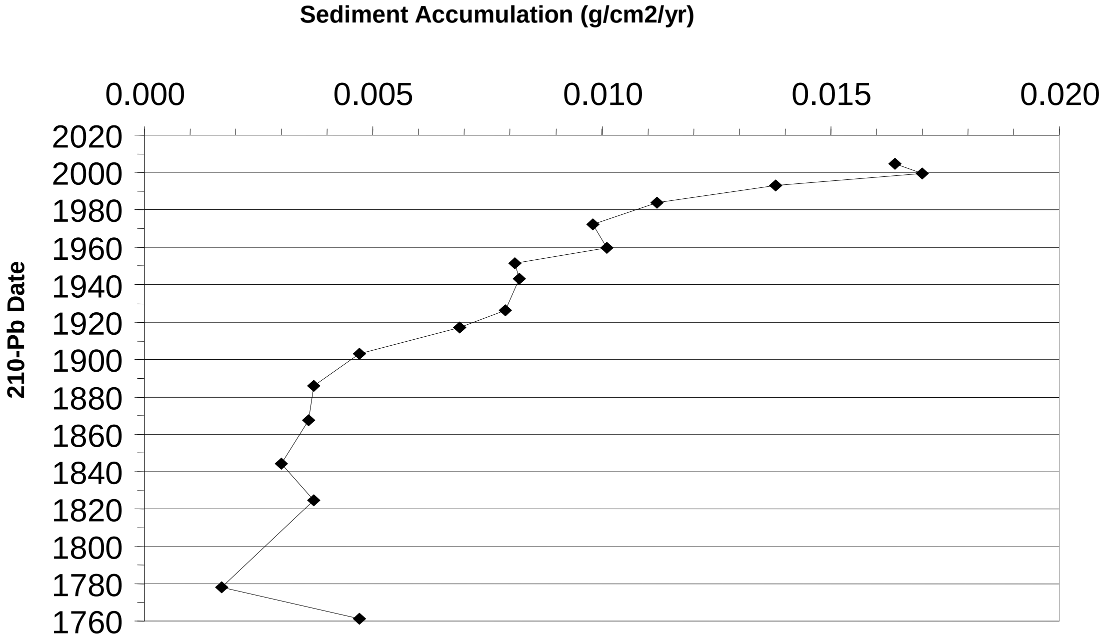


Figure 126. Sediment accumulation rates (g/cm^2/yr) by date (A.D.) for Ek Lake (VOYA) core.

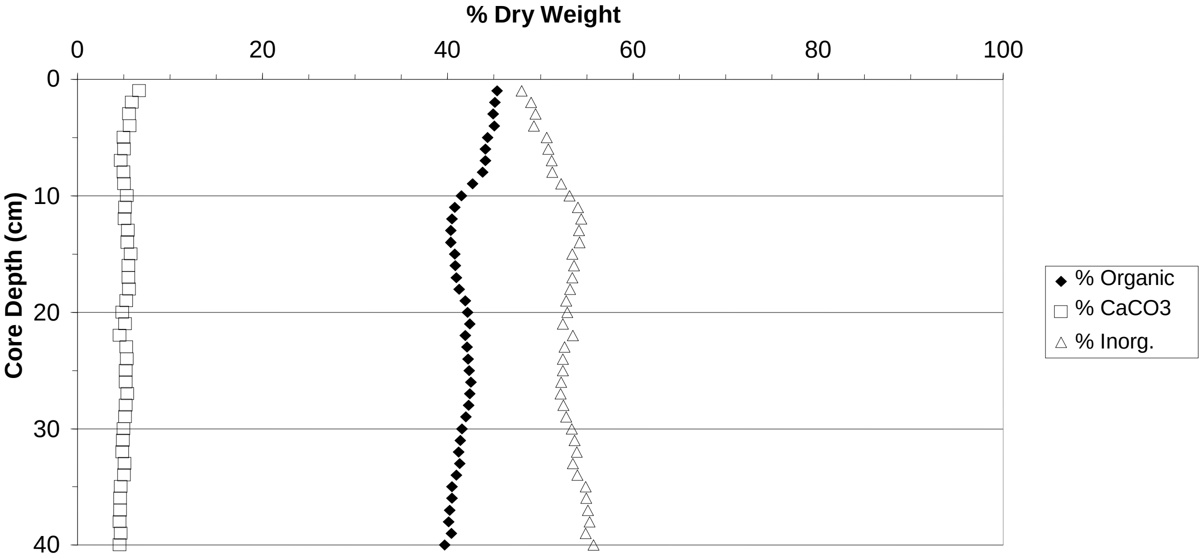


Figure 127. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Ek Lake (VOYA) core.

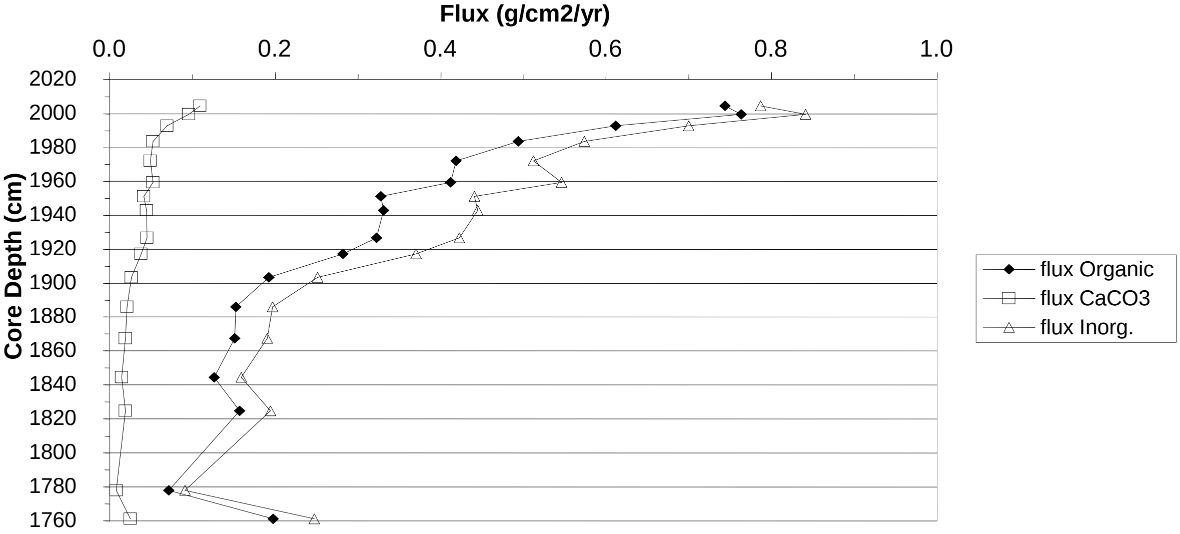


Figure 128. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Ek Lake (SLBE) core.

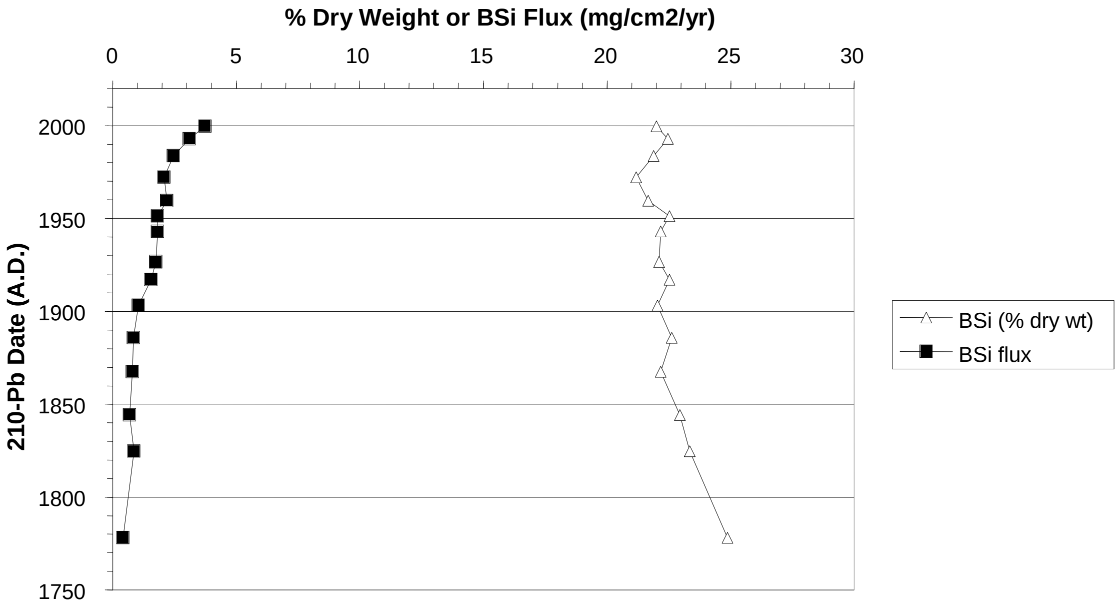


Figure 129. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Ek Lake (VOYA) core.

<u>Peary Lake</u>: The inventory of ^{210}Pb declined monotonically in Peary Lake to supported levels at approximately 15 cm core depth (Figure 130). The Euro-American settlement horizon was located at approximately 12 cm core depth (Figure 131). Sedimentation rates in Peary Lake have varied between 0.008 and 0.018 g/cm^2/yr with a slight peak in the 1960s and 1970s and decreasing sedimentation rates in the most recent decades (Figures 132, 133). Loss-on-ignition analysis of Peary Lake showed that sediments were dominated by >70% dry weight inorganic content that declined after 1950 to 60 to 70% in the uppermost sediments (Figure 134). Organic content mirrored inorganic content with approximately 20% dry weight in the pre-1950 sediments and increased to 25 to30% in the upper core sections (Figure 134). Carbonates remained low throughout the core at <5% except for a small increase in the upper two samples (Figure 134). Flux of organics and inorganics increased after 1910, although accumulation of inorganics decreased after the 1970s (Figure 135). BSi varied from 11 to14% dry weight with decreased values from 1870 to 1970 and a small increase in content in the top few samples (Figure 136). Flux of BSi remained rather constant during the last 200 years at 1-2 mg/cm^2/yr.

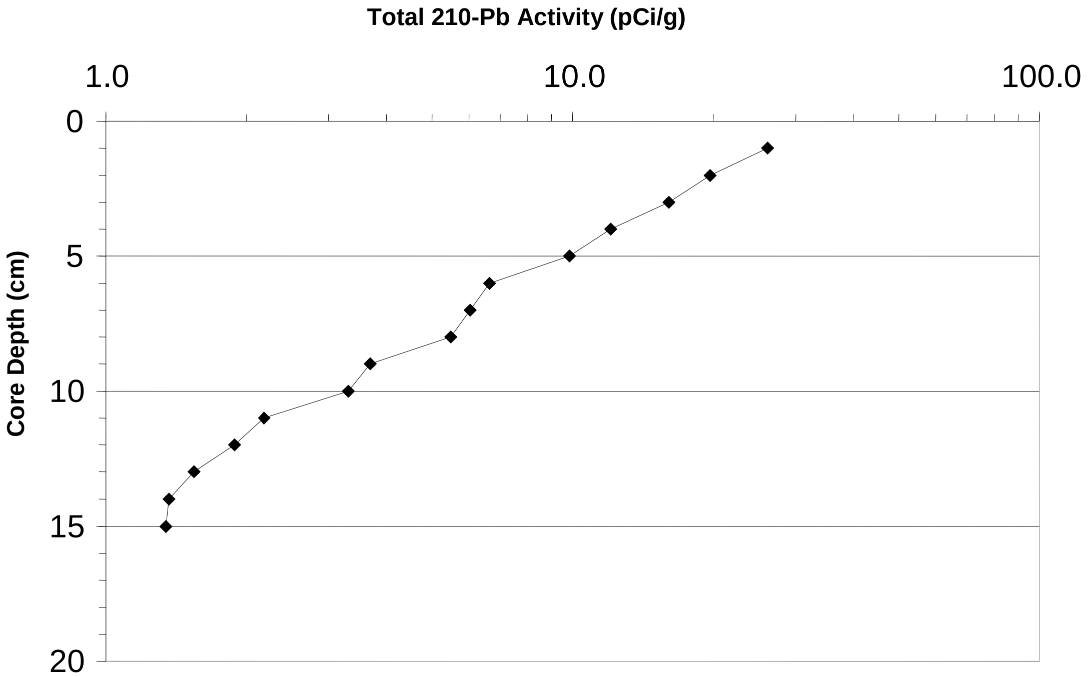


Figure 130. Total 210-Pb activity plotted against core depth (cm), Peary Lake (VOYA).

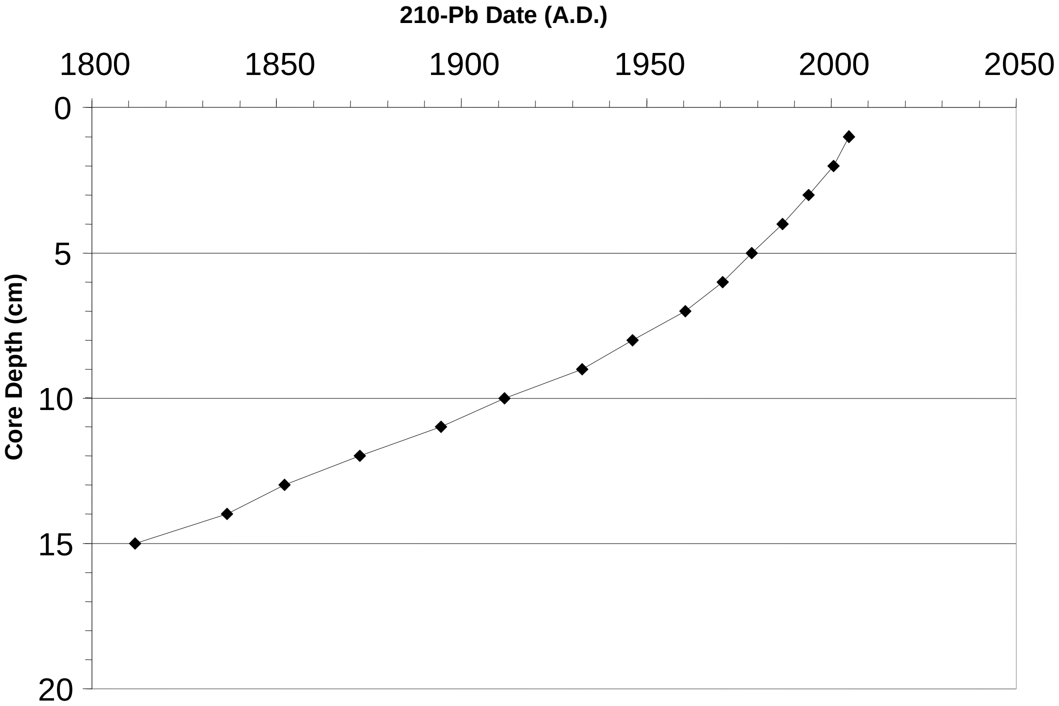


Figure 131. Resulting 210-Pb dating model for Peary Lake (VOYA) core.

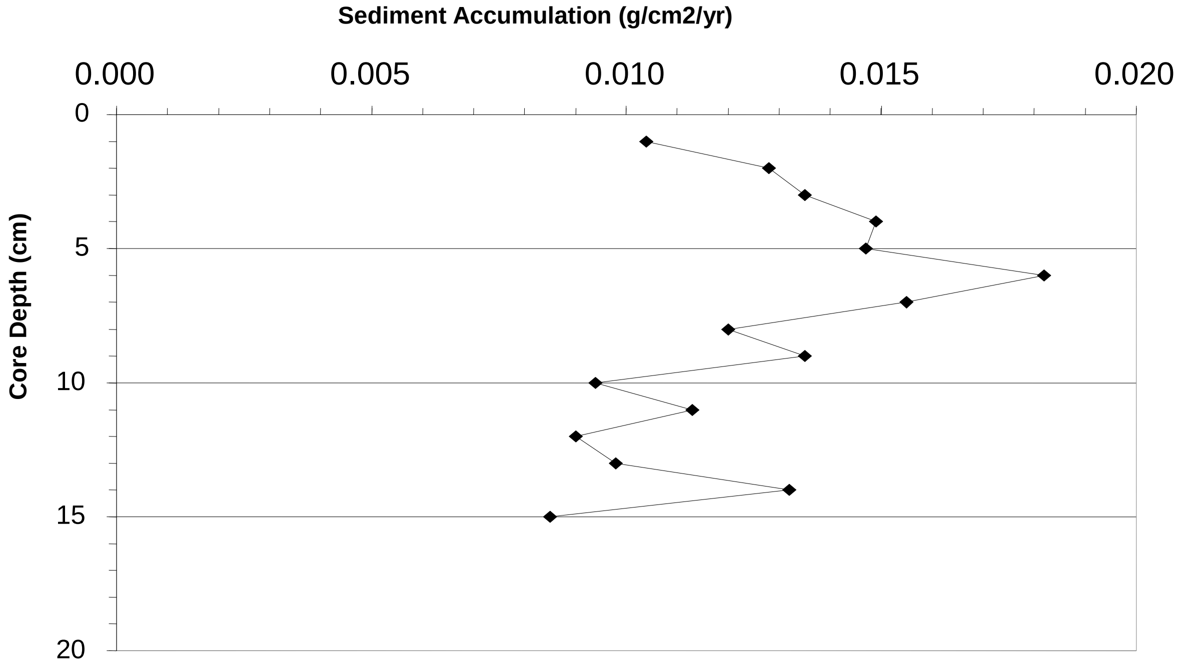


Figure 132. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Peary Lake (VOYA).

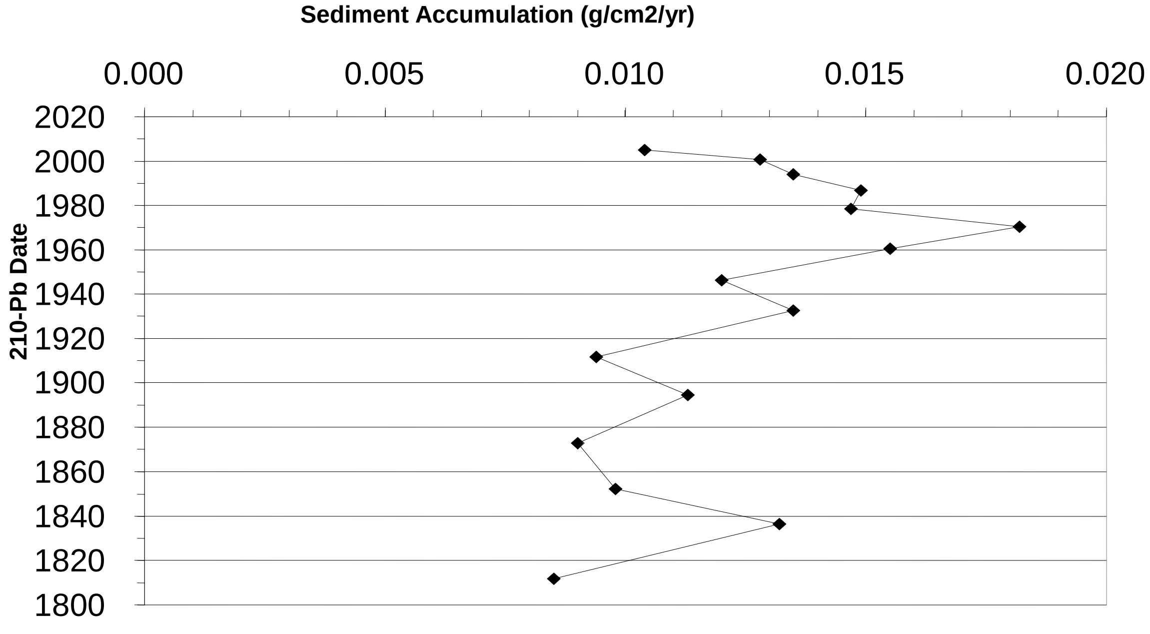


Figure 133. Sediment accumulation rates (g/cm^2/yr) by date (A.D.) for Peary Lake (VOYA) core.

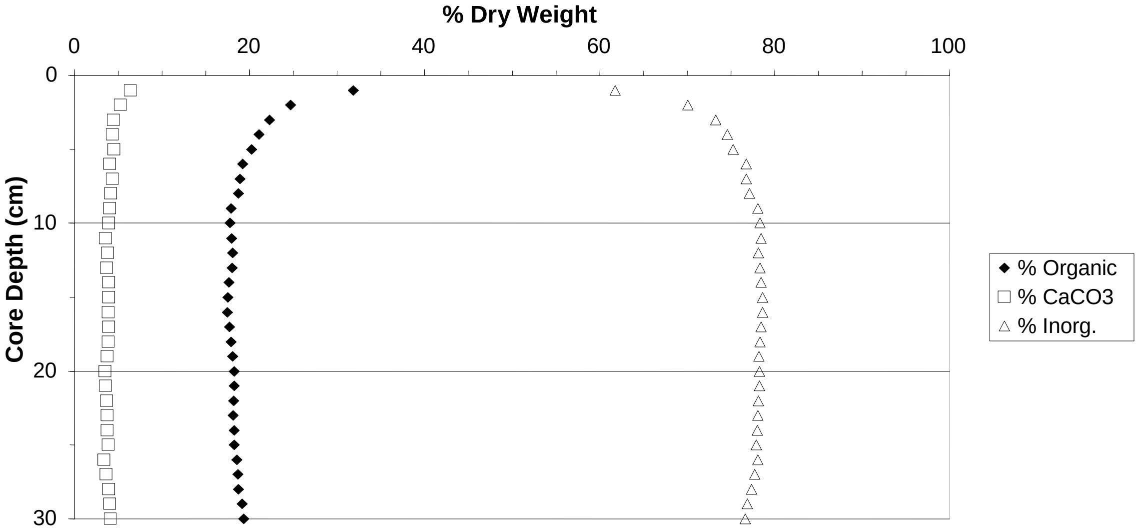


Figure 134. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Peary Lake (VOYA) core.

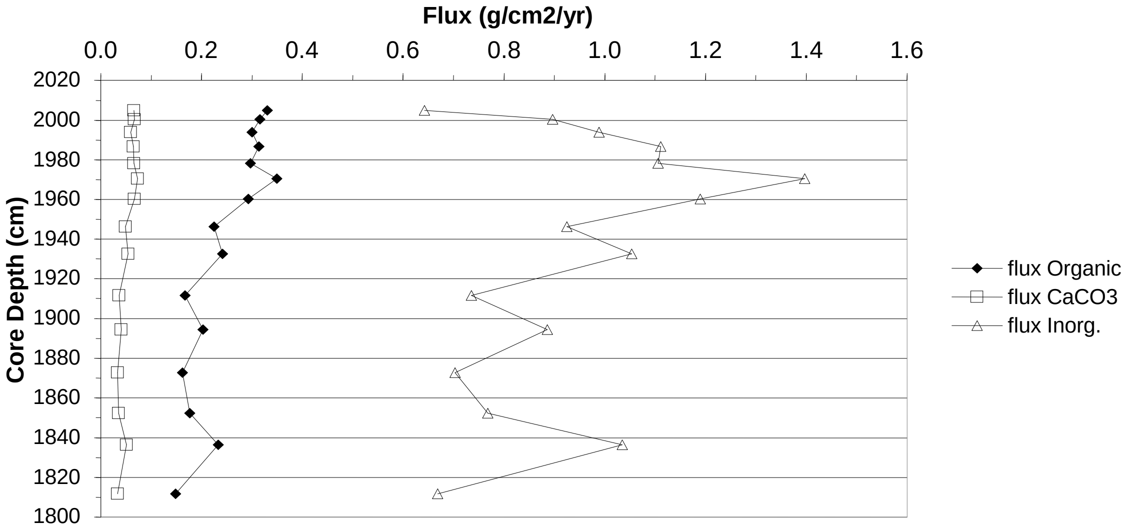


Figure 135. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Peary Lake (VOYA) core.

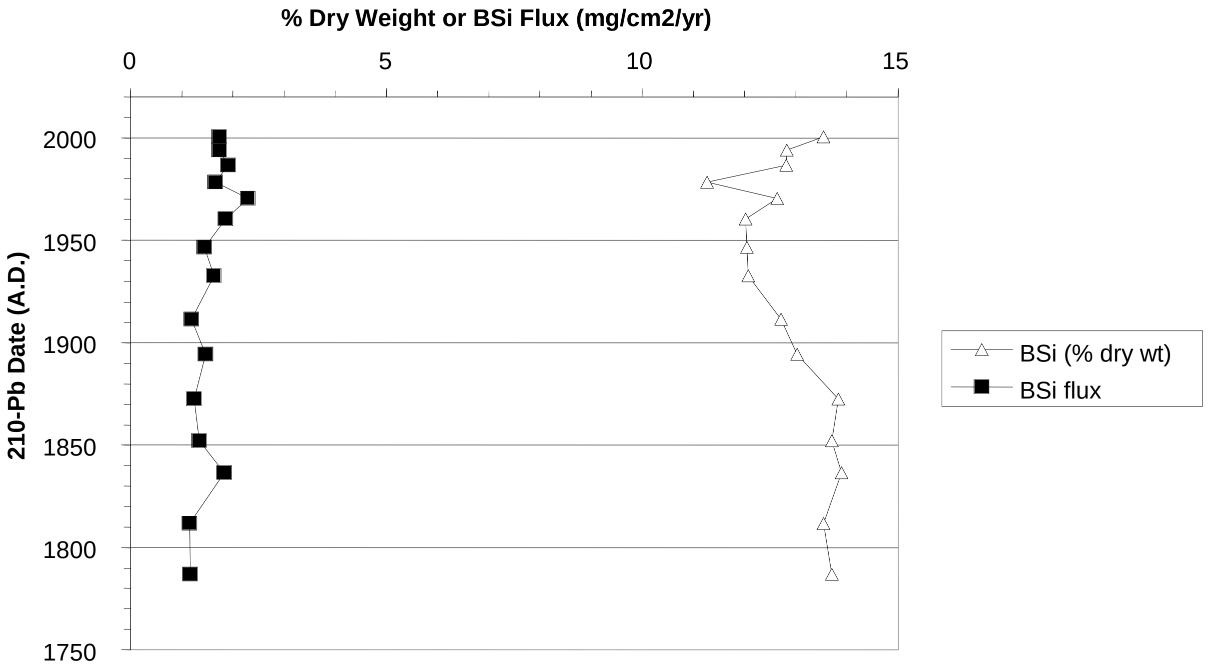


Figure 136. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Peary Lake (VOYA) core.

Cruiser Lake: Cruiser Lake sediments steadily declined in ^{210}Pb inventory and reach supported levels in samples below at 14 cm depth (Figure 137). The Euro-American settlement date (1870s) was at approximately 11 cm core depth (Figure 138). Sedimentation rates increased in Cruiser Lake after 1920 to modern levels that were potentially four- to fivefold higher than background conditions (Figures 139, 140). It is difficult to conceive how sedimentation rates changed and continued to increase in this isolated lake, because logging and fire activity peaked on the peninsula in the early 20th century. Alternatively, the basin where the core was collected was small and steep-sided, thus the potential for a change in sediment focusing existed. Organic, carbonate and inorganic content of the Cruiser Lake core varied little in the last 250 years. Sediments were dominated by inorganic content at about 60% by dry weight, and secondarily by organic content (ca. 30%; Figure 141); inorganic content increased slightly above 10 cm (1880s; Figure 141). As might be expected on the Voyageurs peninsula, carbonate content in the sediments was very low (Figure 141). Accumulation rates of organics, carbonates, and inorganics tracked the increased sedimentation rates after the 1920s (Figure 142). Dry weight percent BSi declined slightly upcore from a long-term average of about 20% to about 18% at the core top (Figure 143). When expressed as flux, BSi deposition increased approximately four-fold between the 1920s and the top of the core, although with the low sedimentation rates in Cruiser Lake, this pattern may simply reflected diagenesis and burial (Figure 143).

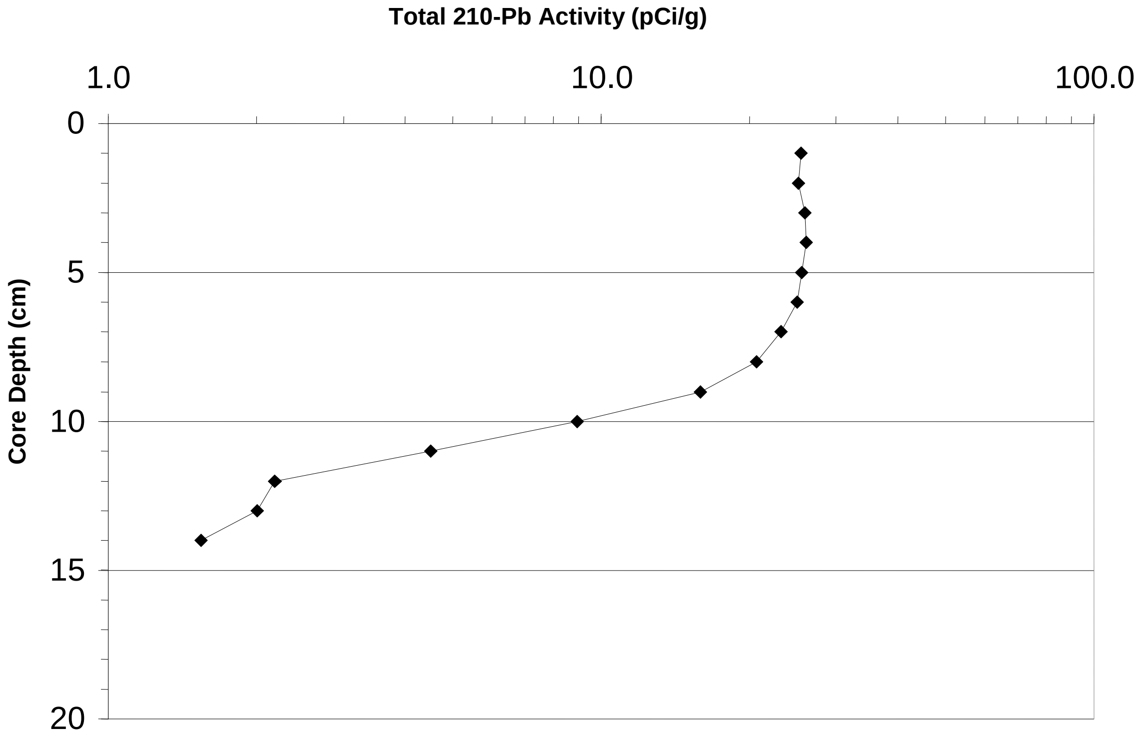


Figure 137. Total 210-Pb activity plotted against core depth (cm), Cruiser Lake (VOYA).

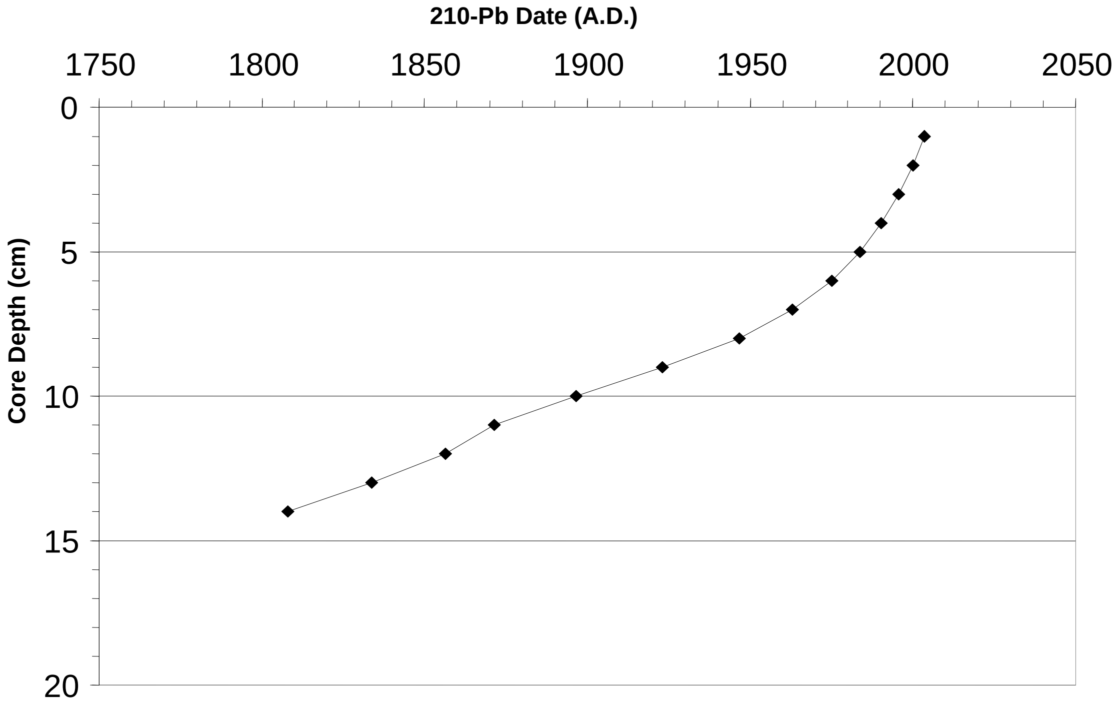


Figure 138. Resulting 210-Pb dating model for Cruiser Lake (VOYA) core.

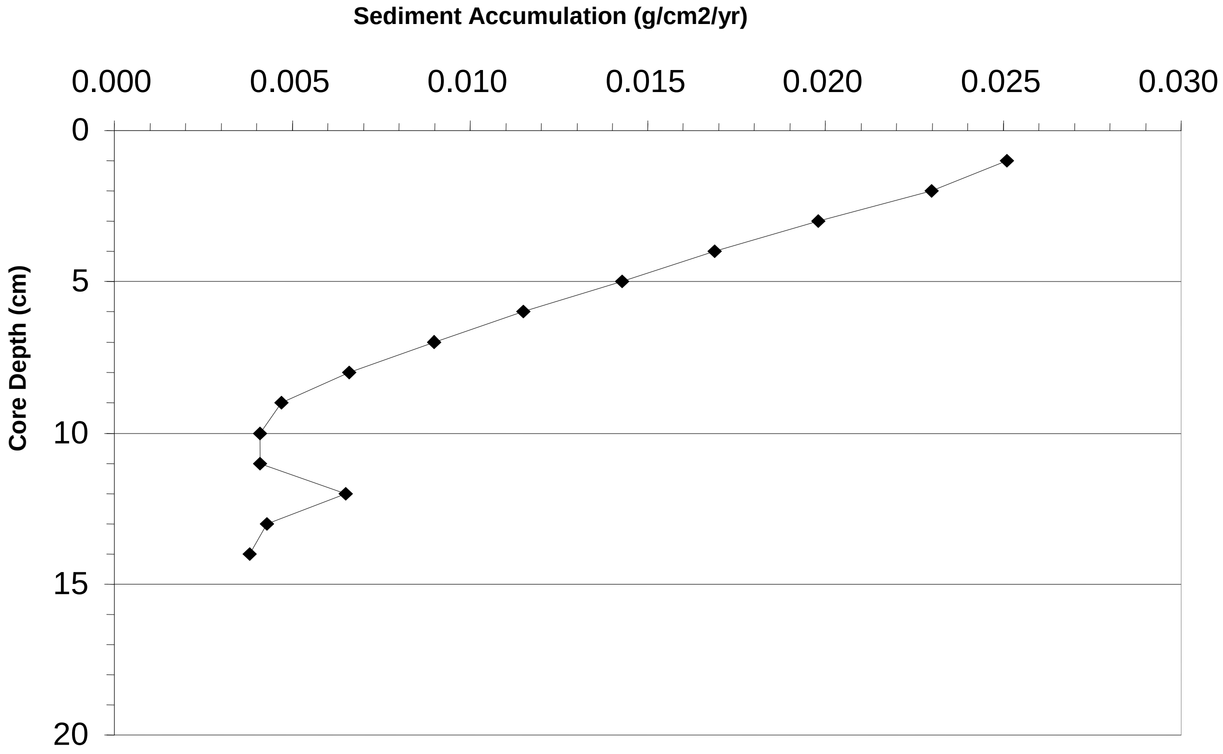


Figure 139. Sediment accumulation rates (g/cm^2/yr) by core depth (cm), Cruiser Lake (VOYA).

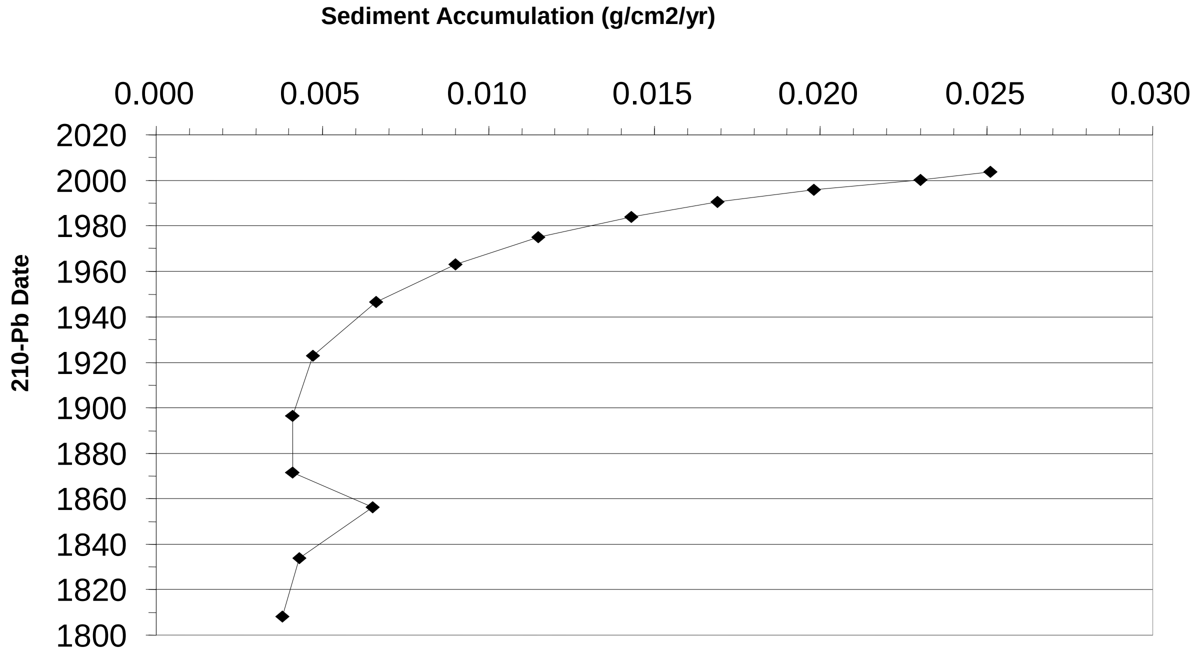


Figure 140. Sediment accumulation rates (g/cm^2/yr) by date (A.D.) for Cruiser Lake (VOYA) core.

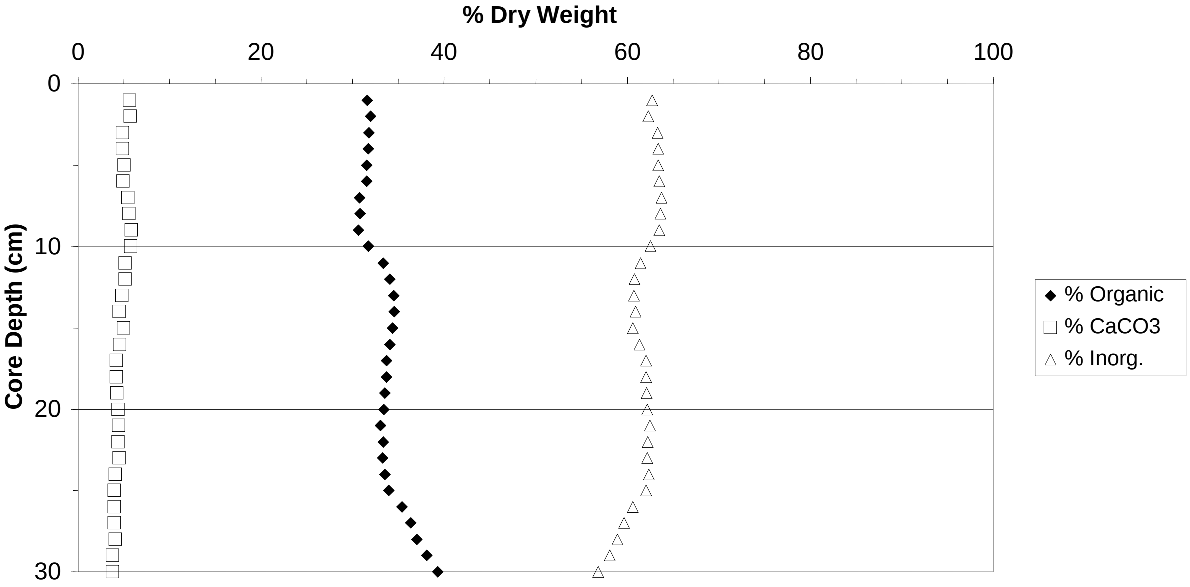


Figure 141. Percent dry weight composition of organics, carbonates, and inorganics versus core depth based on loss on ignition analysis of Cruiser Lake (VOYA) core.

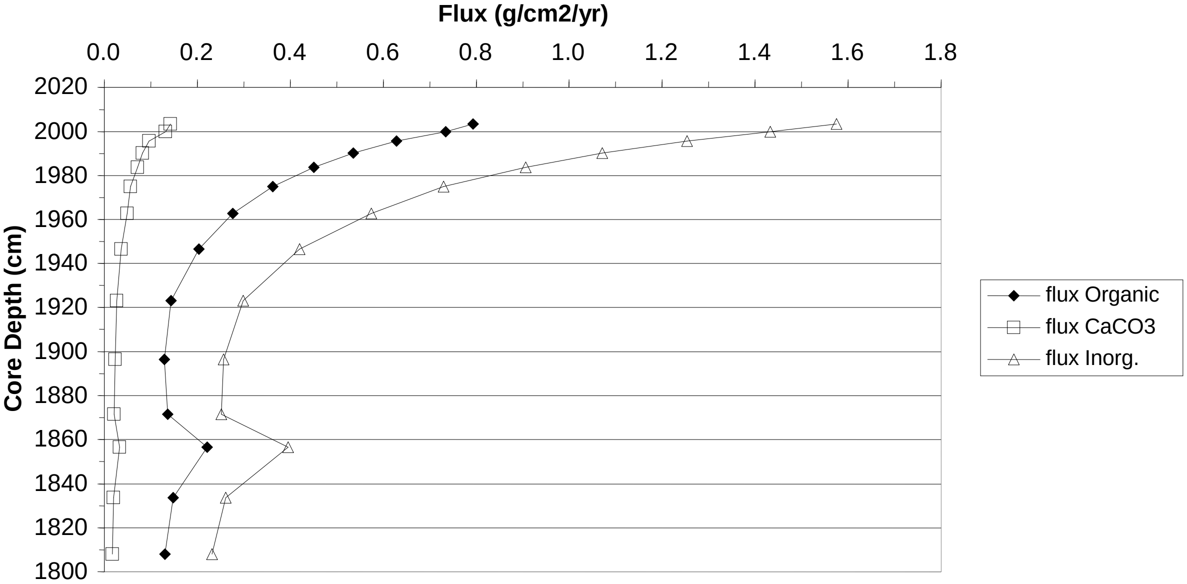


Figure 142. Flux of sediment components (g/cm^2/yr) by date (A.D) in the Cruiser Lake (VOYA) core.

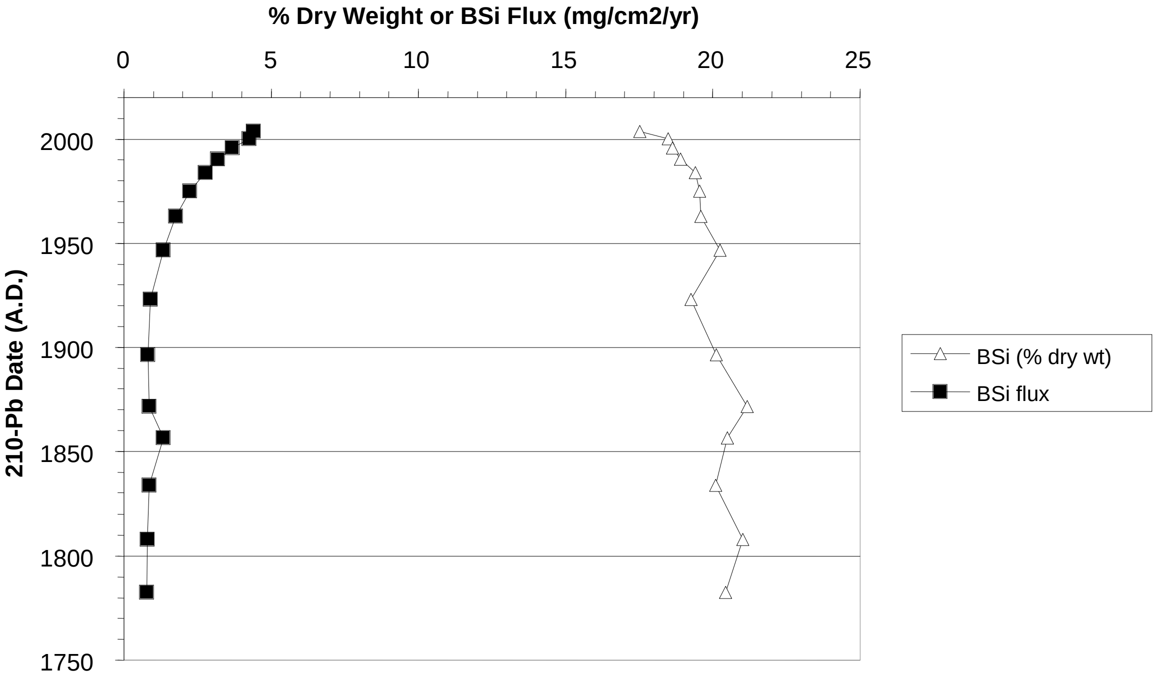


Figure 143. Sediment biogenic silica, dry weight percent and flux (mg/cm^2/yr) by date (A.D.) in the Cruiser Lake (VOYA) core.

Downcore Diatom Communities (stratigraphy, cluster, ordinations)

Ek Lake: Sediments dated from 1778 to 2000 in Ek Lake were analyzed for diatom remains and over 500 taxa were recorded. A detrended correspondence analysis and a constrained cluster analysis of diatom communities in the Ek Lake core separated four biostratigraphic zones: Zone 1 (1778-1844), Zone 2 (1868-1903), Zone 3 (1917-1960), and Zone 4 (1972-2000) (Figures 144, 145). Ten diatom species were present at >5% relative abundance including planktonic and benthic species. Similar to Cruiser Lake, two predominant planktonic species in the core were *Discostella stelligera* and *Asterionella formosa*; *Aulacoseira tenella* and *Eunotia zasuminensis* were other predominant plankters in Ek Lake. Other subdominant species included planktonic species *Aulacoseira ambigua* and *Tabellaria flocculosa* IIIp, and basal records of *Puncticulata radiosa*. The benthic diatom flora in Ek Lake was diverse but dominated by the araphid species *Pseudostaurosira brevistriata*, *Staurosirella pinnata*, and *Staurosira construens* v. *venter* (Figure 146).

Zone 1 represented the community deposited before logging and Euro-American settlement in the region. Benthic species were well-represented in Zone 1. It also was characterized by presence of *Puncticulata radiosa* and lower abundances of *Aulacoseira tenella* and *Discostella stelligera* (Figure 146). Zone 2 had increased abundance of *Discostella stelligera*, *Aulacoseira tenella* and *Eunotia zasuminensis*, and a decline of *Puncticulata radiosa* from the Ek Lake flora. Zone 3 was characterized by continued high abundance of *Discostella stelligera*, *Aulacoseira tenella* and *Eunotia zasuminensis*, and loss of *Puncticulata radiosa* from Ek Lake flora. Other taxa varied little in abundance within this zone. Zone 4 contained slightly higher abundances of

Asterionella formosa and a continued increase in *Discostella stelligera*. In contrast, *Eunotia zasuminensis* decreased in abundance in Zone 4.

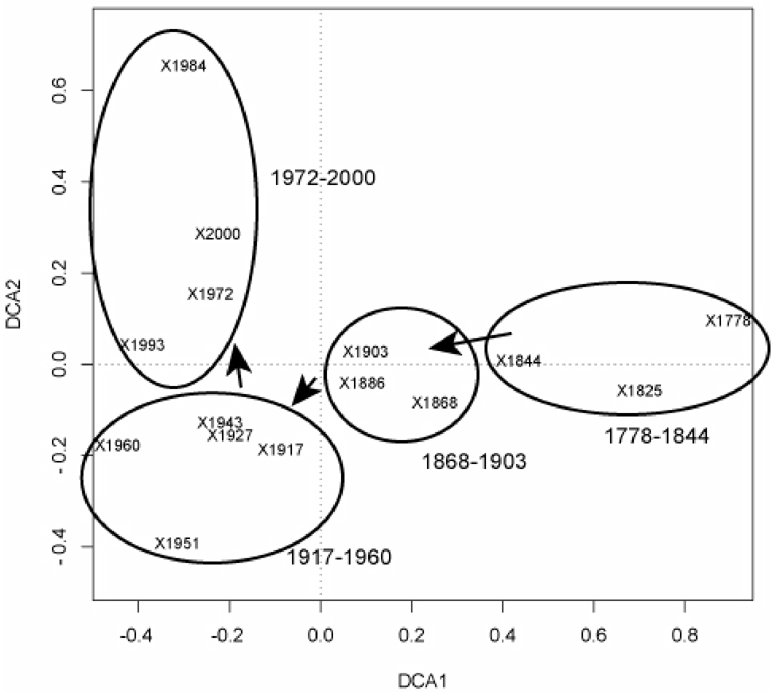


Figure 144. DCA of downcore diatom assemblages from Ek Lake core (VOYA, 1778-2000); axes 1 and 2 loadings plotted for core depths-dates.

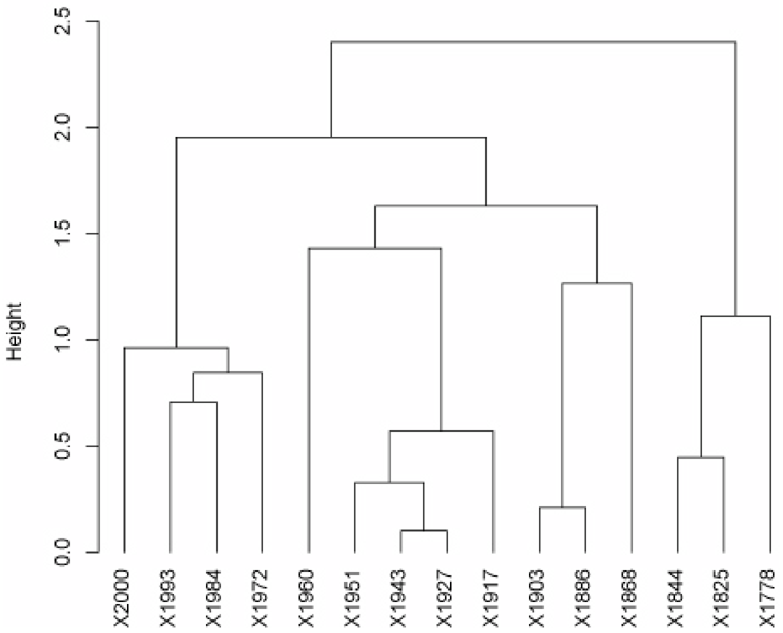


Figure 145. Constrained cluster analysis of downcore diatom assemblages from Ek Lake core (VOYA, 1778-2000).

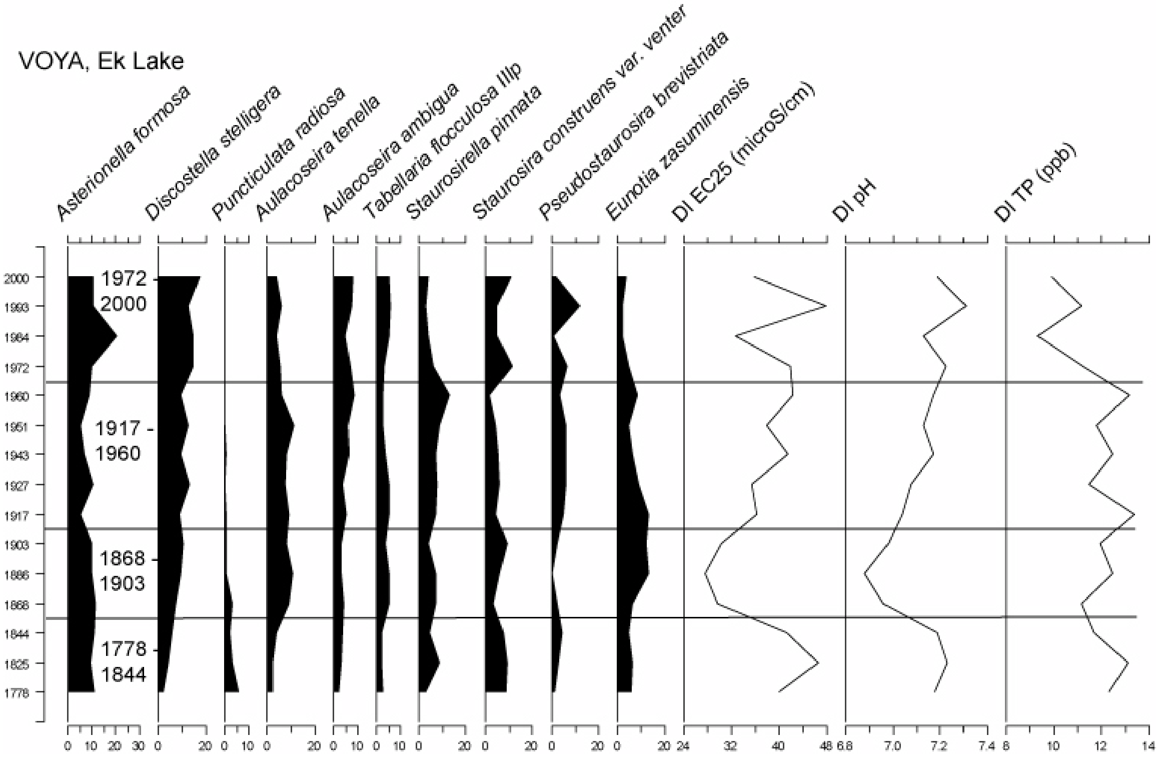


Figure 146. Stratigraphic diagram of relative abundance of dominant diatoms in Ek Lake core (VOYA, 1778-2000) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Peary Lake: Fifteen sediment samples from the Peary Lake core spanned from 1786 to 2001. A detrended correspondence analysis and constrained cluster analysis of the historical diatom communities in Peary Lake identified three biostratigraphic zones: Zone 1 (1786-1873), Zone 2 (1895-1946), and Zone 3 (1960-2001) (Figures 147, 148). More than 500 diatom taxa were found in the core with only seven diatom species at >5% relative abundance downcore (Figure 149). The sediment assemblage was primarily planktonic and included *Aulacoseira tenella*, *Discostella stelligera*, *Asterionella formosa*, and *Eunotia zasuminensis*. *Aulacoseira ambigua* was in greater abundance downcore, whereas *Tabellaria flocculosa* IIIp had higher abundance upcore. The only benthic taxon that was found at >5% abundance was *Staurosira construens* v. *venter*; it was more abundant upcore (Figure 149).

Zone 1, similar to other VOYA lakes, preserved an assemblage characteristic of pre-Euro-American settlement conditions. In Peary Lake this zone was characterized by high abundance of *Aulacoseira ambigua* and slightly lower abundance of *A. tenella* (Figure 149). Other common plankters were generally found at similar abundances throughout the core, except for *Tabellaria flocculosa* IIIp, which was nearly absent in Zone 1. Zone 1 was also relatively low in abundance of benthic species. Zone 2 comprises only four samples in the Peary Lake core. The samples seemed to be transitional between Zones 1 and 3 with initial increases in *Tabellaria flocculosa* IIIp and *Staurosira construens* v. *venter*. Zone 2 also indicated the start of a decline in abundance of *A. ambigua*, and a peak in abundance of *A. tenella*. Zone 3 sediments continued to decrease in abundance of *Aulacoseira ambigua* offset by increased abundance of *Tabellaria flocculosa* IIIp and *Staurosira construens* v. *venter*. The other planktonic species were relatively consistent abundances in Zone 3.

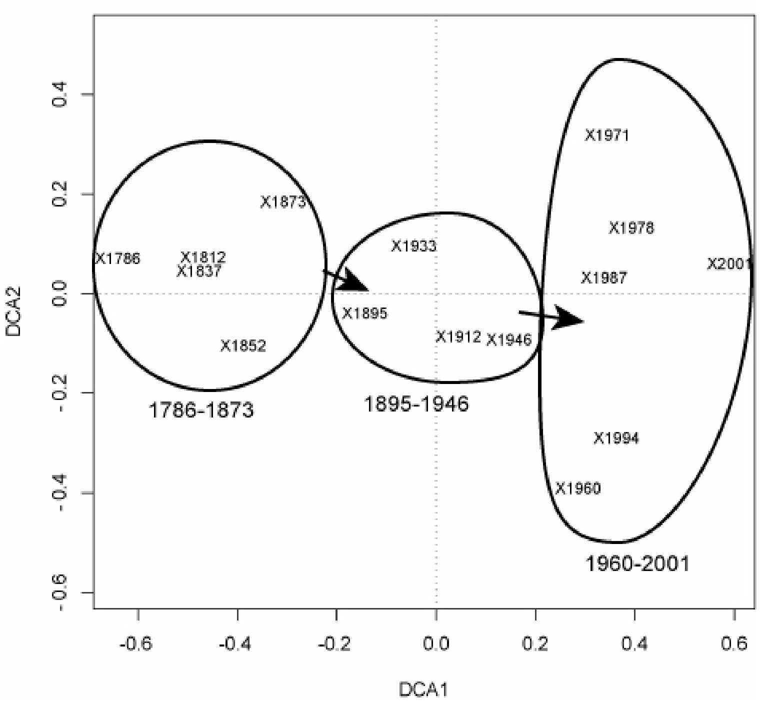


Figure 147. DCA of downcore diatom assemblages from Peary Lake core (VOYA, 1786-2001); axes 1 and 2 loadings plotted for core depths-dates.

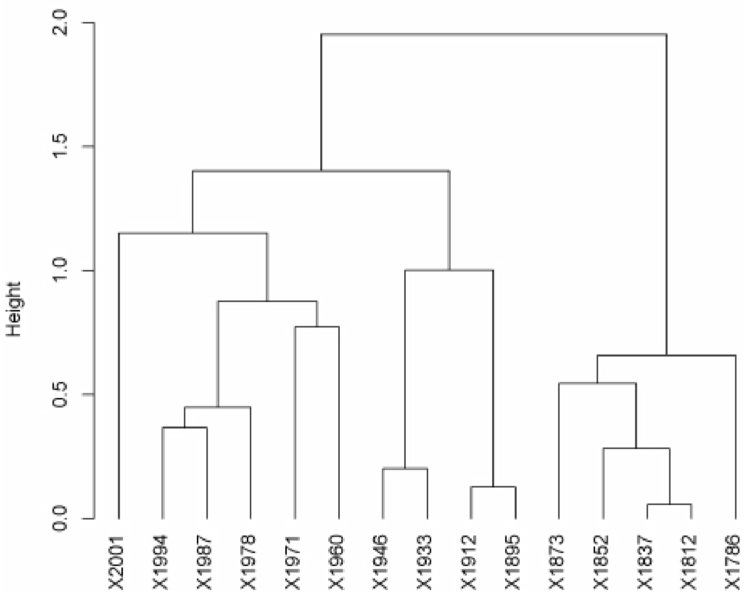


Figure 148. Constrained cluster analysis of downcore diatom assemblages from Peary Lake core (VOYA, 1786-2001).

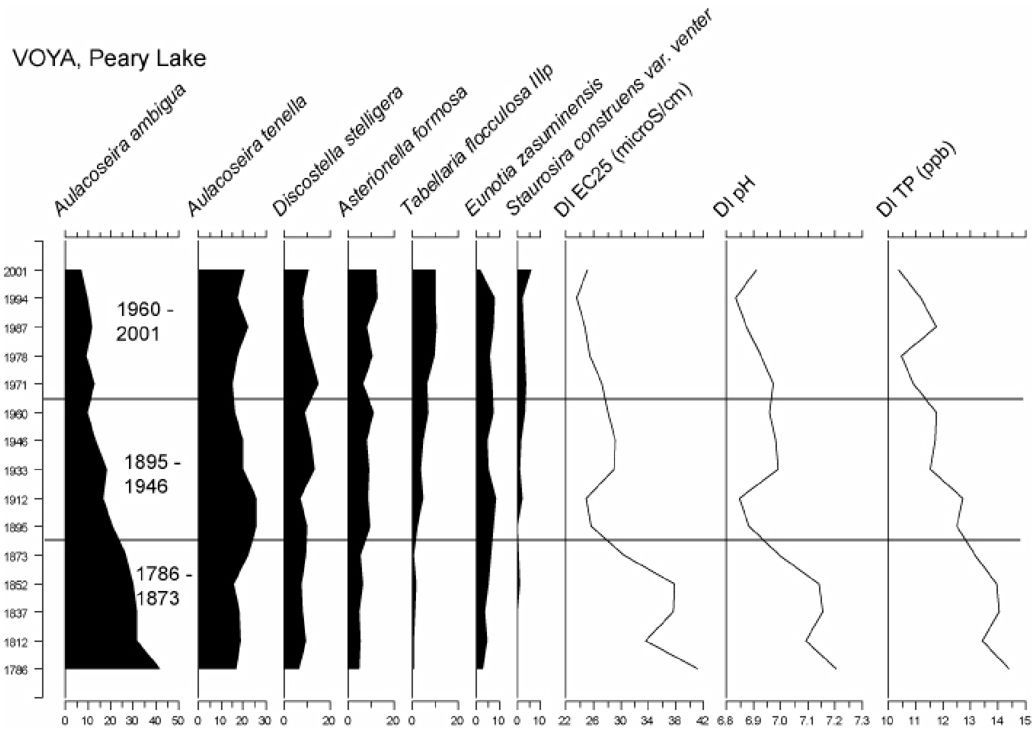


Figure 149. Stratigraphic diagram of relative abundance of dominant diatoms in Peary Lake core (VOYA, 1786-2001) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Cruiser Lake: Fifteen samples were analyzed for subfossil diatom communities from Cruiser Lake covering a period from 1783 to 2004 AD. A detrended correspondence analysis and constrained cluster analysis of the diatom assemblages recognized three major stratigraphic zones: Zone 1 (1783-1872), Zone 2 (1897-1984), and Zone 3 (1990-2004) (Figures 150, 151). A total of 297 diatom taxa was encountered in the core. Throughout this period the diatom community in Cruiser Lake was dominated by a few planktonic diatom species (Figure 152). *Discostella stelligera* remained at almost 40% of the assemblage throughout the core. A morphological variant of *Cyclotella ocellata* (*C. ocellata* Type-1) was a subdominant before Euro-American settlement and was then supplanted by *Asterionella formosa*. The three most recent samples in the core contained *Cyclotella ocellata* of the type.

Zone 1 was characterized by high abundance of *Discostella stelligera* and *Cyclotella ocellata* Type-1. The planktonic species *Asterionella formosa* and *Synedra tenera* subdominated. Zone 1 represented pre-Euro-American settlement (Figure 152). Zone 2 was characterized by continued dominance by *Discostella stelligera*, decreased abundance of *Cyclotella ocellata* Type-1 and *Synedra tenera*, and increased abundance of *Asterionella formosa*. The core top Zone 3 samples (1990-2004), show increased abundance of *Cyclotella ocellata* and *Asterionella formosa* and loss of *Synedra tenera*, which sets them slightly apart from the other Zone 2 samples. The sample dated 1990 has an odd abundance of the attached species *Encyonema minutum*.

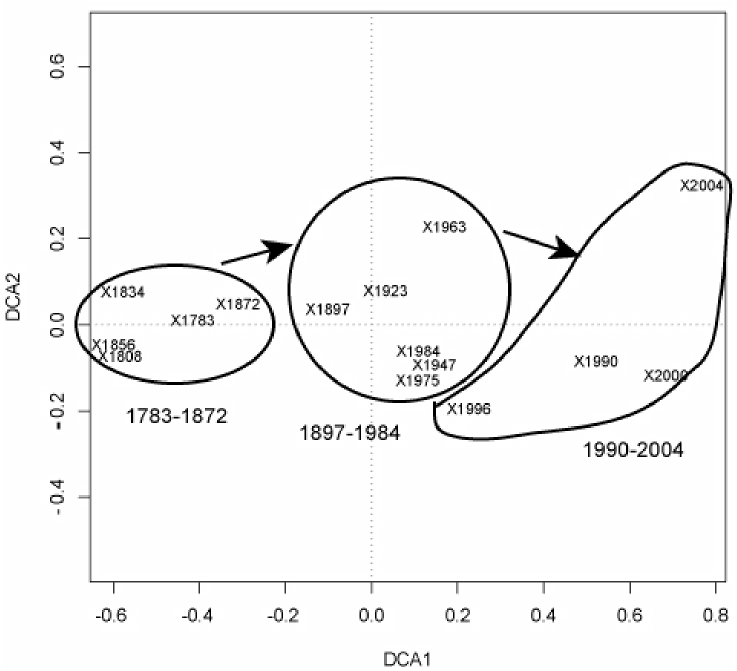


Figure 150. DCA of downcore diatom assemblages from Cruiser Lake core (VOYA, 1783-2004); axes 1 and 2 loadings plotted for core depths-dates.

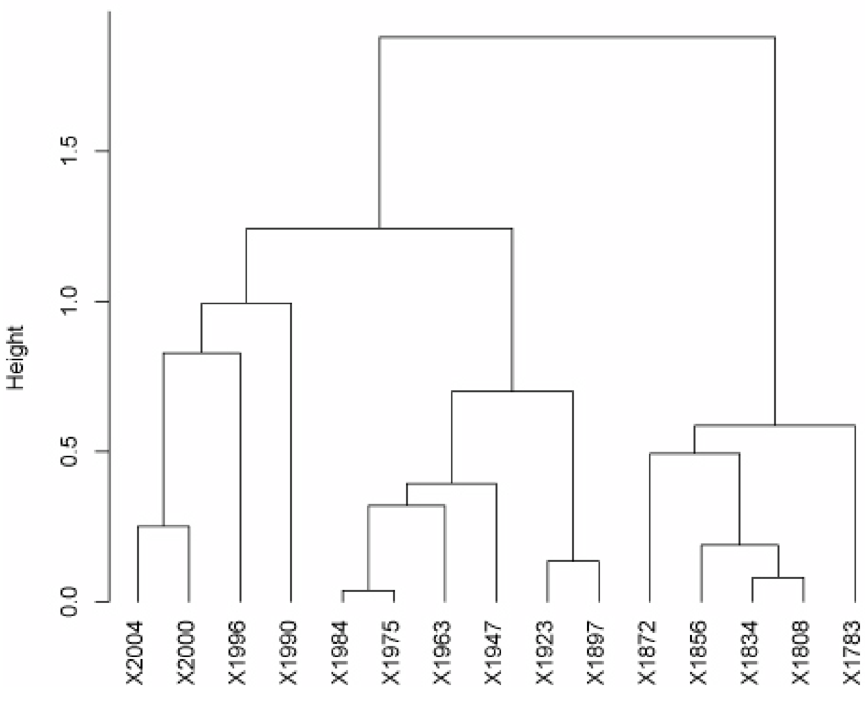


Figure 151. Constrained cluster analysis of downcore diatom assemblages from Cruiser Lake core (VOYA, 1783-2004).

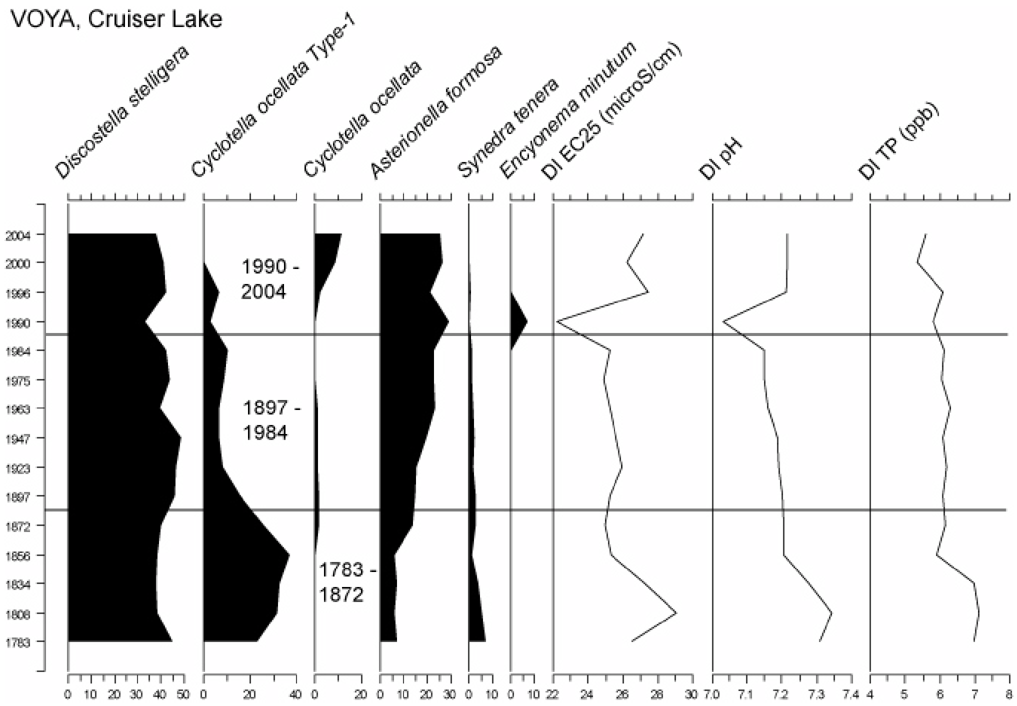


Figure 152. Stratigraphic diagram of relative abundance of dominant diatoms in Cruiser Lake core (VOYA, 1783-2004) against core date (Year A.D.). Three diatom-inferred environmental reconstructions are shown: EC25 (µS/cm), pH, and TP (ppb).

Environmental Reconstructions

Ek Lake: Diatom-inferred reconstructions of water quality of the three inland lakes at VOYA showed little change in historical levels of conductivity, pH, and total phosphorus. Throughout the last 200 years, diatom-inferred TP in Ek Lake ranged only from 9 to 13 ppb, conductivity from 28 to 48 µS/cm, and pH between 6.9 and 7.3. None of the variability in these parameters represented a significant change based on model error estimates (Figure 146).

Peary Lake: Although upcore trends toward decreased conductivity, pH, and TP were reconstructed in the Peary Lake core between 1786 and 2001, the changes were not significant (Figure 149). Diatom inferred TP varied from 14 ppb at the core base to 10.5 ppb at the core top. Reconstructed pH ranged from 7.2 to 6.8 between the core base and upcore levels. Conductivity had a similar trend as pH, with a decrease from 42 mS/cm in sediments around 1786 to 24 µS/cm at the core top.

Cruiser Lake: Historical patterns of water quality inferred from subfossil diatom communities exhibited no significant changes between 1783 and 2004 in Cruiser Lake (Figure 152). Conductivity varied between 22 and 29 µS/cm, inferred pH ranged from 7.05 to 7.35, and TP in this oligotrophic lake reconstructed between 5.5 and 7 ppb.

Relation to Land Use/History

A record of major land-use changes from VOYA was assembled by Larry Kallemeyn and coauthors as part of a separate project (Edlund et al. 2010). Land-use histories can be compared with trophic reconstructions and diatom stratigraphic zones from the sediment cores to determine whether major changes in ecological conditions are temporally correlated with specific disturbances in the watershed.

Park Summary

The analysis of three sediment cores from VOYA lakes provided a first opportunity to study ecological and biogeochemical changes that occurred during the last 200 years in some of VOYA's smaller lake systems. A companion study on the environmental history of VOYA's large lakes (Rainy, Namakan, Kabetogama), and an upgradient and undammed lake (Lac La Croix), reported that diatom communities in all the large lakes were initially impacted by first-cut logging and Euro-American settlement (Serieyssol et al. 2009, Edlund et al. 2010). Damming occurred nearly simultaneously with large scale logging in Voyageurs, and in the Namakan-Kabetogama Reservoir, the cores further recorded increases in sedimentation rates following damming. More interesting in the large lake cores were diatom community shifts after the 1970s. While these may be the result of climate change, other factors including land use (e.g., continued pulpwood cutting in the watershed, increases in beaver numbers) and hydromanagement also explained significant portions of the variance in the diatom communities (Serieyssol et al. 2009, Edlund et al. 2010).

Similar to the large lakes, Voyageurs' inland lakes showed changes in their diatom communities and biogeochemistry in the last 200 years. However, in contrast to other GLKN lakes we investigated (e.g., Manitou Lake, SLBE), diatom communities and geochemical records in VOYA did not indicate dramatic changes. Three types of responses are common among the three lakes. First, sedimentation rates increased in all three lakes. In Ek Lake the increase began early, around 1900, whereas in Peary and Cruiser Lakes, sedimentation rates increased after the 1920s. Logging records from the Voyageurs region (Edlund et al. 2010) generally peaked in the early 20th century and it is conceivable that the increased sedimentation rates resulted from logging. Second, all three lakes indicated the greatest shifts in diatom communities during the late 1800s, ranging from a shift in Ek Lake between 1844 and 1868, in Peary Lake between 1873 and 1895, and in Cruiser Lake between 1872 and 1897. For northern Minnesota, this time frame closely corresponded to initial Euro-American interests and settlement in the region (Edlund et al. 2010). The response of the diatom community may have been a harbinger of bigger changes brought on by larger-scale logging. Historical records indicated that initial cutting in the region in the 1800s took place adjacent to lakes (Serieyssol et al. 2009), which could have provided the trigger for slightly earlier changes in the diatom communities in comparison to the sedimentation rates.

Ek Lake had two main biostratigraphic zones in post-Euro-American sediments with a community shift identified between the 1960 and 1972 samples and separation of pre-1844 samples. The zone from 1972 to 2000 was characterized by increased abundance of *Asterionella formosa* and decreased abundance of *Eunotia zasuminensis*. Very little is known of the ecology of *Eunotia zasuminensis* apart from its planktonic autecology (most *Eunotia* are attached species) and its distribution in softwater and slightly acidic lakes. *Asterionella formosa*, on the other hand, commonly responds to increased nutrient loading and in some lake systems is an indicator of eutrophication. We would not suggest that Ek Lake is a eutrophic system, but nutrient dynamics may have changed in the course of its history. Based on modern water quality measurements, Ek Lake would be considered mesotrophic (TSI; Elias and VanderMeulen 2008). As for the timing of these changes in VOYA, the 1960s represented a period of rapid increase in beaver populations on the peninsula which may have driven hydrological changes in Ek Lake. Alternatively, a shift in planktonic species from *Aulacoseira* to cyclotelloid (e.g. *Discostella*) taxa is a common pattern among boreal lakes in the northern hemisphere in response to a warming climate (Rühland et al. 2008).

After Euro-American settlement, Peary Lake's diatom communities went through a brief transitional period that corresponded to the peak of logging in the region (samples dated post-1895). Similar to Cruiser and Ek Lakes, *Asterionella formosa* increased in abundance following Euro-American settlement, and similar to Ek Lake, *Tabellaria flocculosa* IIIp increased in abundance in Peary Lake. Sedimentation rates also increased in Peary Lake after first cut logging from 1920 to 1970, before decreasing up core. The most recent biostratigraphic zone (1960-2001) in Peary Lake showed higher variability in the diatom communities and decreased abundance of *Aulacoseira* concomitant with increased abundance of cyclotelloid species similar to the Ek Lake response and potentially related to climate drivers (Rühland et al. 2008).

After Euro-American settlement and first cut logging in VOYA, the lakes had varying environmental histories. Cruiser Lake had weak biostratigraphic zonation after Euro-American settlement; the top four samples were slightly separated from the previous decades. Although there are no substantial changes in weight percent organics, inorganics, or carbonates, BSi content decreased and flux of all geochemical components increased upcore, suggesting some subtle ecological changes occurred in the 20th century. The greater abundance of *Asterionella formosa* in post-Euro-American core levels might suggest potential minor increases in nutrient loading and the upcore increases in *Cyclotella ocellata* were consistent with hypotheses forwarded by Rühland et al. (2008) on biological response to earlier summer stratification.

In comparison to the larger VOYA lakes and some of the more easterly GLKN lakes, a signal of ecological change is not as clear in the inland VOYA lakes that might be associated with recent climate change. In the large VOYA lakes and in nearby Lac La Croix, shifts in diatom communities occurred in the late 1970s or early 1980s in a time frame strongly correlated to recent warming trends (Serieyssol et al. 2009, Edlund et al. 2010). Similar shifts in diatom communities occurred in a large number of arctic, boreal and sub boreal lakes (Smol et al. 2005, Rühland et al. 2008). The ecological changes in the large VOYA lakes were also correlated to land use trends in the region, especially continued pulpwood cutting and beaver numbers. We anticipated that the smaller lakes might have stronger responses to climate drivers, but it is clear that the most significant changes in diatom communities occurred during the late 19th-early 20th century. Changes that might be indicative of climate drivers are much less temporally constrained in the smaller lakes with community shifts that ranged between the 1950s (Peary) and the 1980s (Cruiser). Apparent climate-driven shifts in arctic to boreal lakes ranged across a time span from the 19th century to the late 20th century with earlier changes in arctic lakes and later changes in boreal lakes (Rühland et al. 2008). Also of importance is that the inland lakes on the Kabetogama peninsula were not expected to be responding to some of the broader land use drivers of change that are occurring in the watersheds of the larger VOYA lakes (e.g., pulpwood logging outside of VOYA boundaries but within the watershed; Edlund et al. 2010).

Repeat Samples (SLBE, PIRO)

To determine the amount of biological change in the GLKN park lakes and potential drivers of change, surface sediments are being collected every three to five years and assessed for changes in the diatom communities in the context of historical change as measured in long sediment cores. In 2008, repeat surface samples were collected at PIRO and in 2009, from SLBE. Floristic change was assessed using the squared chord distance (Simpson et al. 2005) between consecutive surface sediment samples and compared to two markers or periods of biological change in each lake: pre-Euro-American settlement to modern (i.e. top sample in long core) and park formation to modern.

The squared chord distance was plotted for each lake from which a long sediment core was analyzed and for each lake whose surface sediments were repeatedly sampled (Figure 153). In these analyses we defined a squared chord distance of 0.39 as the measure of low floristic change (Bennion et al. 2004, Simpson et al. 2005). Based on the long sediment core analysis, the greatest amount of floristic change in diatom assemblages was not surprisingly found between the pre-Euro-American settlement samples and the most modern core sample. In seven of the thirteen cored GLKN lakes, the squared chord measure indicated large floristic changes between pre-Euro-American settlement and modern lake condition. The SLBE lakes (except Florence), PIRO's Beaver Lake, ISRO's Richie Lake, VOYA's Cruiser Lake, and APIS's Outer Lagoon all show significant floristic change. In addition to SLBE's Florence Lake, PIRO's Grand Sable, ISRO's Ahmik and Harvey Lakes, and VOYA's Ek and Perry Lakes did not indicate large floristic changes between their pre-Euro-American and modern floras (Figure 153).

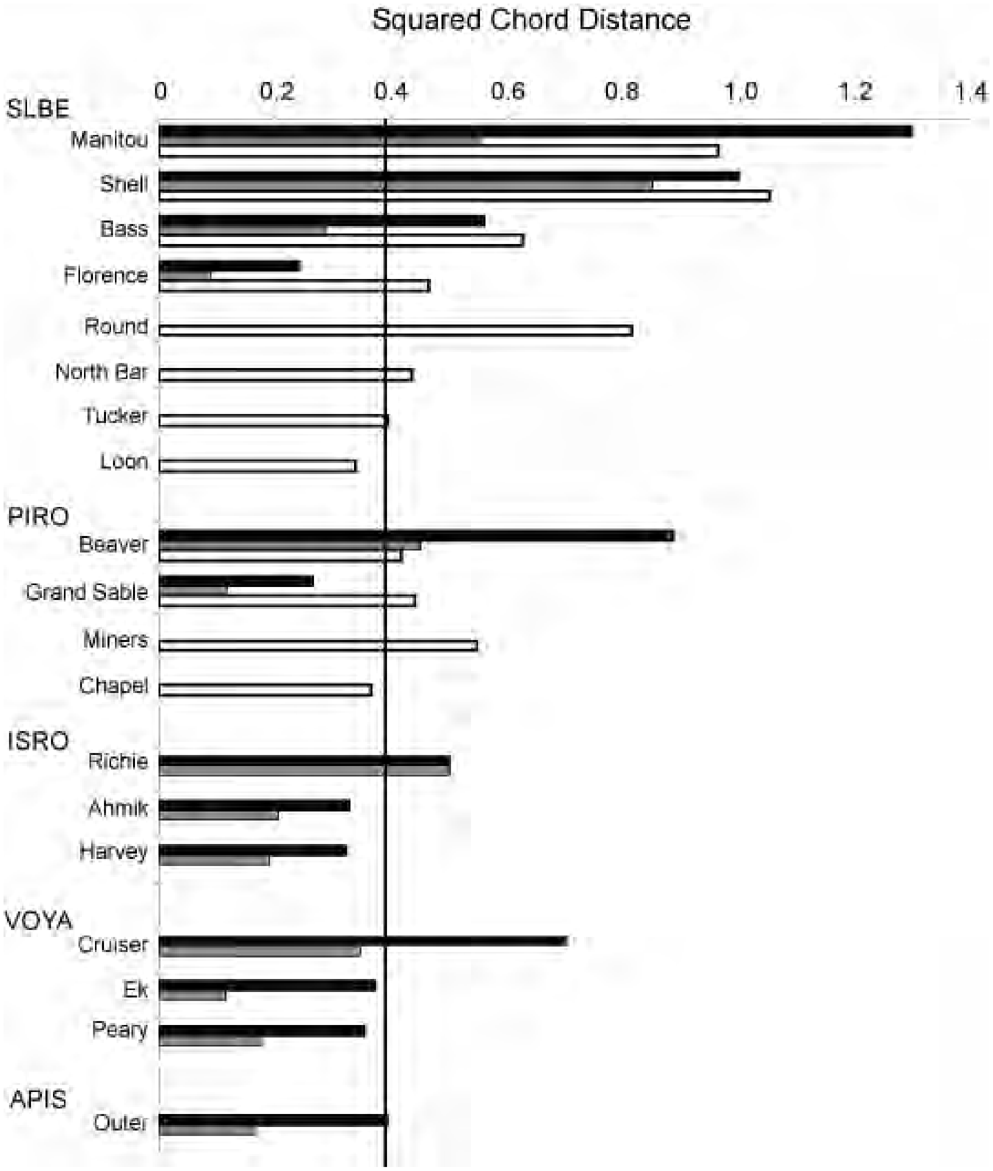


Figure 153. Plot of squared chord distances for long sediment cores and surface repeat samples from GLKN park lakes. Black filled bars represent squared chord distance between presettlement samples and top of core samples, gray filled bars represent squared chord distance between samples deposited at park formation and top of core samples, white bars represent distance between calibration set samples collected in 2005 from SLBE and PIRO lakes compared to surface sediment samples collected in 2008 (PIRO) or 2009 (SLBE). The line at 0.39 represents the cutoff for low level floristic change (see text and Simpson et al. 2005).

The second measure of floristic change was calculated for the time period between park formation and the most modern sample analyzed in the long sediment cores. Again some lakes from SLBE (Manitou, Shell), PIRO's Beaver, and ISRO's Richie showed relatively large floristic changes during the period of NPS management (Figure 153). However, the other nine lakes, including all the VOYA lakes and APIS's Outer Lagoon had low floristic change during the time of NPS management (Figure 153).

Finally, for eight SLBE lakes and four PIRO lakes, repeat samples taken in 2008 or 2009 were compared to surface sediment diatom samples collected in 2005. PIRO's Chapel Lake and SLBE's Loon and Tucker Lakes do not show large floristic changes, but surprisingly, the majority of the repeat samples show significant floristic change (Figure 153). In particular, the SLBE lakes (Manitou, Shell, Round, and Bass) show especially large floristic changes between 2005 and 2009. Florence Lake, which showed little change between pre-Euro-American and modern, and even smaller change between park formation and modern in the long sediment core, showed much larger changes between 2005 and 2009. At PIRO, floristic changes in Beaver, Grand Sable, and Miners Lakes were slightly greater than our squared chord distance cutoff of 0.39 (Figure 153).

We examined the species-level changes in many of the lakes to determine what taxa drove the larger floristic changes between the 2005 and 2008/2009 repeat samples. At Miners Lake (PIRO) *Staurosirella pinnata* increased from 1.5% in 2005 to more than 13% in 2008 and *Pseudostaurosira brevistriata* dropped in abundance from 4.3 % in 2005 to 1.3% in 2008. Surface sediments from Grand Sable Lake (PIRO) showed that *Fragilaria crotonensis* increased from 9.1% abundance in 2005 to 18.9% in 2008, *Staurosira construens* v. *venter* increased from 2.3% to 5.7% during the same time frame, and *Aulacoseira ambigua* dropped from 13.5% to 10.4% between 2005 and 2008. At SLBE, Manitou Lake *Aulacoseira ambigua* increased in abundance from 0.9% to 20.7% and *Fragilaria crotonensis* increased from 0.9% to 16.0% between 2005 and 2009. Bass Lake (SLBE) lost *Cyclotella sp. mich-like* (21% to 0.45% abundance) and *Asterionella formosa* (2.2% to 0% abundance) between 2005 and 2009. *Denticula tenuis* declined from 38.9% to 6.7% abundance between 2005 and 2009 in Shell Lake (SLBE), while *Adlafia bryophila* increased from 0% to 14.9% over the same time period. At Round Lake in SLBE, *Denticula tenuis* (5.1% to 25.3%) and *Cyclotella michiganiana* (1.8% to 8.3%) increased in abundance, whereas *Staurosira construens* (26.1% to 6.1%) and *Pseudostaurosira brevistriata* (13.6% to 3.5%) decreased in abundance in surface sediment samples taken in 2005 and 2009. And in Florence Lake, which showed low floristic change during the last 200 years, samples taken in 2005 and 2009 indicated larger floristic changes driven by increased abundance in *Staurosira construens* v. *venter* from 28.1% in 2005 to 39.6% in 2009 and decreased abundance in *Encyonopsis microcephala* from 7.8% in 2005 to 0.2% in 2009.

To explore potential abiotic drivers of recent change in the GLKN lakes, the original surface sediment sample and its corresponding repeat sample were passively plotted on the CCA ordination (axes 1 and 2) of the GLKN diatom calibration set. At PIRO, movement of the diatom communities between 2005 and 2008 in Beaver, Grand Sable, and Miners Lakes most strongly aligned with the DOC and TP gradients (Figure 154). Chapel Lake (PIRO) trended towards the fourth quadrant, representing a slight negative shift along the N and P nutrient gradients (Figure 154). At SLBE, the repeat samples from Florence, Loon, Bass, and Manitou Lakes had general trend of movement along CCA axis 2 upon that strongly aligned with the nutrient and DOC gradients (Figure 155). In contrast, Round and North Bar Lakes moved negatively along CCA axis 2 (Figure 155).

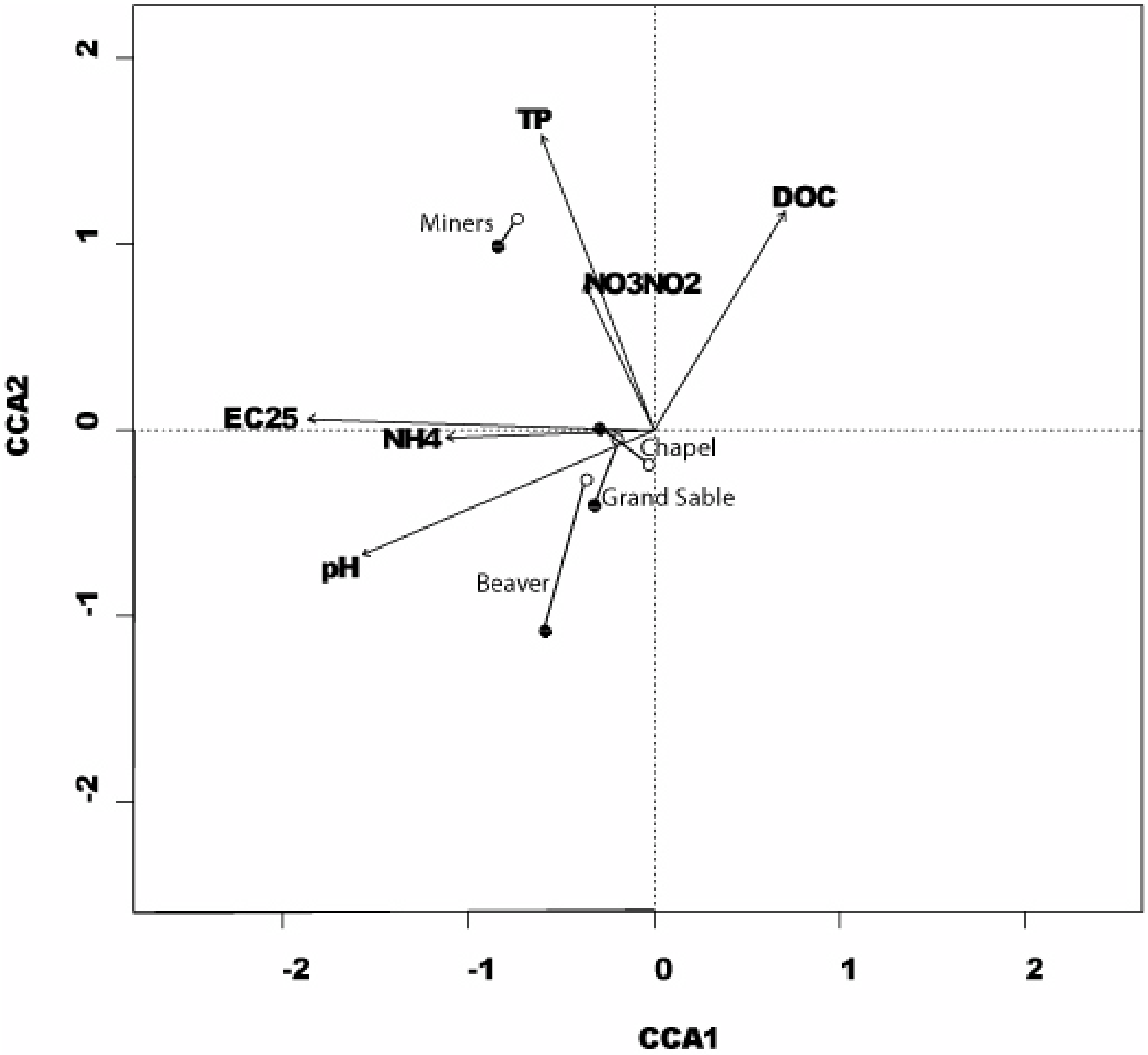


Figure 154. The 2008 repeat surface sediment samples from PIRO passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance. Filled circles represent surface sediment samples taken in 2005, open circles represent repeat surface sediment samples taken in 2008 (PIRO).

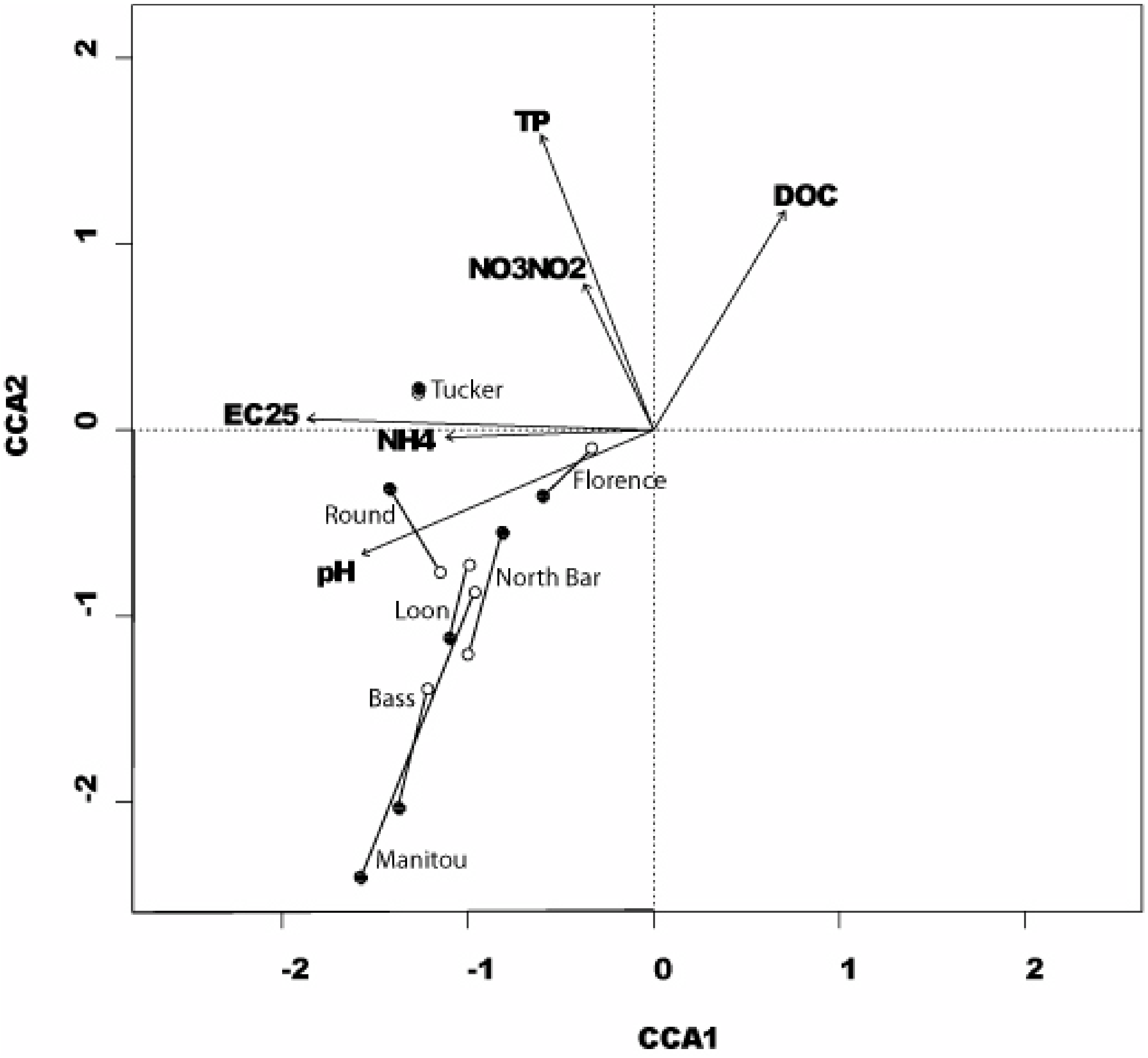


Figure 155. The 2009 repeat surface sediment samples from SLBE passively plotted on the CCA of GLKN diatom calibration set. Vectors show environmental variables that explain significant independent variation in diatom abundance. Filled circles represent surface sediment samples taken in 2005, open circles represent repeat surface sediment samples taken in 2009 (SLBE).

Discussion

Sediment records preserved in lakes have become increasingly important for determining reference lake conditions, understanding historical ecological change, and documenting the impact of environmental drivers on aquatic resources. Although many geochemical and biological proxies are preserved in lake sediments, diatoms are one of the most important and widely used proxies for environmental reconstruction because they are readily preserved, can be identified to the species level, and respond rapidly to environmental change. Additionally, statistical methods have been developed to use diatoms to quantitatively reconstruct water quality parameters such as pH or total phosphorus (Fritz et al. 1999). For example, the state of Minnesota used the analysis of diatoms in sediment cores to determine the reference nutrient condition of lakes and further used this information to establish nutrient criteria for different lake types at the ecoregional level (Ramstack et al. 2003, Heiskary and Wilson 2008). The relevance of combining historical information in the sediment record with modern lake sampling has also expanded research applications. In the St. Croix National Scenic Riverway, a combination of diatom-based TP reconstructions from sediment cores, whole basin sediment phosphorus inventories, and modern assessment of sources of phosphorus was used to develop nutrient reduction strategies for the Riverway (Edlund et al. 2009a, b, Triplett et al. 2009).

The use of diatoms as a monitoring tool has been more focused on river and stream assessment for biotic integrity and ecosystem health (Hunsaker and Carpenter 1990, Kentucky Department of Environmental Protection 2002). However, their use as biomonitors in lakes has been increasing, especially when the historical sediment record can be utilized as a tool for interpreting modern change (Charles et al. 1994). For example, top-bottom core analysis is part of the National Lakes Assessment; a two time period approach allows recent lake trajectories to be determined over large geographic scales (U.S. Environmental Protection Agency 2009). Other straightforward applications have involved repeat sediment coring to overcome the vagaries of open-water biological monitoring. Stoermer et al. (1996) recored a site in Lake Erie in the 1990s and compared it to a core taken in the 1980s to determine the biological impacts of zebra mussel introduction and nutrient reductions; at the time, monitoring of Lake Erie was limited and the sediments provided an integrated sample of biological change.

In the current study, we further built on these approaches by combining analysis of sediment cores in the GLKN park lakes with repeated sampling of modern sedimented diatom communities to determine historical biological change, modern biological change, and the potential drivers of change. Thirteen sediment cores were analyzed for changes in geochemistry and diatom communities from ca. 1800 AD through the 2000s AD. Surface sediments were collected from more than 60 lakes in the GLKN parks in conjunction with water quality monitoring to document the modern diatom assemblages and determine the abiotic gradients that control diatom abundance and distribution in the GLKN parks. Weighted averaging models were developed to use sediment diatom assemblages to quantitatively estimate pH, total phosphorus, and conductivity. Models were applied to sediment cores to determine the background or reference condition of lakes and assess the extent and timing of change in each lake. Biological change was estimated over two time periods using the squared chord distance between pre-Euro-American settlement and modern diatom communities and between diatom communities deposited at the time of each park's formation and modern diatom communities. Lastly, surface sediment diatom communities in two parks were resampled in 2008 and 2009 to determine the amount of diatom community change since 2005.

The nine GLKN parks span large ecoregional, latitudinal, and longitudinal gradients ranging from boreal islands (ISRO) in the middle of Lake Superior to riverways passing through large metropolitan areas (MISS). Their latitude ranges from INDU's 41°N to VOYA's 48°N and longitude from SLBE's 84°W to VOYA's 93°W. As a result, samples from their lakes had very high diversity of diatoms with over 1,900 taxa encountered in the surface sediment samples alone. Accounting for outlier sites the primary environmental gradients controlling distribution and abundance of diatoms and thus available for developing quantitative reconstruction models were pH, conductivity, and total phosphorus. These were among the gradients that are typically identified as independently controlling diatom abundance in temperate regions (e.g., Ramstack et al. 2003, Shinneman et al. 2009) and we developed weighted averaging models for each parameter. Concerns have been voiced on the development of multiple quantitative models from a single calibration dataset, particularly on the independence of the species-environment relationship and species response to gradients (resource vs. tolerance-based responses; Anderson 2000, Shinneman et al. 2009). In the case of the GLKN parks, we chose to develop multiple quantitative models, recognizing that independent mechanisms can affect lake nutrients, pH, and conductivity. We also recognized the limitations of multiple models, noting that in some of the environmental reconstructions on GLKN cores, patterns of change were identical between reconstructed parameters. We coupled these techniques with passive plotting methods to identify or corroborate drivers of ecological change.

For each sediment core that was analyzed, we applied weighted averaging reconstruction models to explore historical changes in lake water pH, conductivity, and total phosphorus. Although all lakes showed some biological change during the last 200 years, most of the GLKN lakes did not indicate significant changes in their pH, conductivity, or TP levels throughout the last 200 years suggesting that from a water quality standpoint, most lakes were not significantly impacted from their reference or pre-Euro-American settlement conditions. Lakes that showed significant changes were primarily located in SLBE and included changes in conductivity (Manitou, Florence, Shell, Bass), and pH (Manitou, Bass). The timing of the water quality shifts at SLBE was consistent with the development of farming in the region and may be related to hydrological changes associated with land clearance.

Similar approaches on other lakes in GLKN parks also identified varying levels of diatom-inferred water quality changes. At SACN, two cores recovered from Lake St. Croix showed significant increases in diatom-inferred total phosphorus especially after World War II. Timing of changes at SACN was strongly correlated to significant land use modifications including the shift to mechanized farming, introduction of supplemental chemical fertilizers, suburban expansion, and development of centralized wastewater treatment (Edlund et al. 2009a, b). In the VOYA large lakes (Namakan, Kabetogama, Rainy), small but significant increases in total phosphorus concentrations were only identified in Namakan Lake in response to damming and hydromanagement (Serieyssol et al. 2009). The other large lakes showed minimal changes in water quality although all lakes show biological changes, including evidence for increased incidence of cyanobacterial blooms (Kling 2005, Edlund et al. 2010).

In contrast to minimal inferred water quality changes in the GLKN park lakes, the biological communities in the cored lakes all showed some degree of biostratigraphic change during the last 200 years as resolved with ordination or clustering methods. Analysis of squared chord distance among diatom communities throughout time intervals as broad as pre-Euro-American settlement vs. modern or park formation vs. modern, showed that only in select parks and lakes these floristic changes were considered relatively large (Bennion et al. 2004, Simpson et al. 2005). The SLBE lakes (Manitou, Bass, Shell) indicated relatively large floristic changes between Euro-American settlement and modern samples and select lakes in VOYA (Cruiser), ISRO (Richie), and PIRO (Beaver) similarly showed larger floristic changes. Floristic changes since park inception were smaller in all lakes; however, in several of the SLBE (Manitou, Shell), PIRO (Beaver), and ISRO (Richie) lakes, diatom community changes since park formation were relatively large.

Ordination and clustering algorithms are commonly used to identify biostratigraphic zones in sediment cores; we used both techniques to highlight periods of rapid biological change. In the GLKN lakes analyzed for this study, two periods of biological change were regularly identified (Figure 156). Lakes showing two periods of biological change were not limited to the GLKN lakes used in this study (Figure 156). An additional six lakes were similarly cored and analyzed from at or near GLKN parks including Swamp and Speckled Trout Lakes near Grand Portage National Monument (GRPO) (Christensen et al. in press) and Rainy, Namakan, Kabetogama, Lac La Croix Lakes from VOYA (Serieyssol et al. 2009, Edlund et al. 2010).

The first period of biological change corresponded closely with Euro-American settlement in the region and associated land use alterations such as logging, land clearance, and dam construction. The first biological shifts took place from the 1870s through the 1940s (Figure 156) and in most lakes represented the largest diatom community change in the last 200 years, an observation based on first order clustering and shifts primarily along the first DCA ordination axis. Concomitant with biological shifts in the GLKN lakes were geochemical shifts, notably increases in sedimentation rates and inorganic content and flux in many cores. These changes were likely a result of enhanced erosion due to land clearance, changes in runoff, and potentially changes in lake levels.

In most lakes we also resolved a secondary biological shift in the sediment cores that took place as early as the 1950s and as late at the 2000s, with many lakes showing change in the 1970s to 1980s (Figure 156). For many of the parks this came as a surprise – one might expect that under NPS management and protection that lakes would show very little shift. The biological changes cannot be easily ascribed to known land use changes, although some lakes exhibit their secondary shifts concurrent with park formation (e.g., Grand Sable Lake at PIRO). Regardless, in no case did the GLKN lakes return to a reference (pre-Euro-American) biological community while under NPS management and protection.

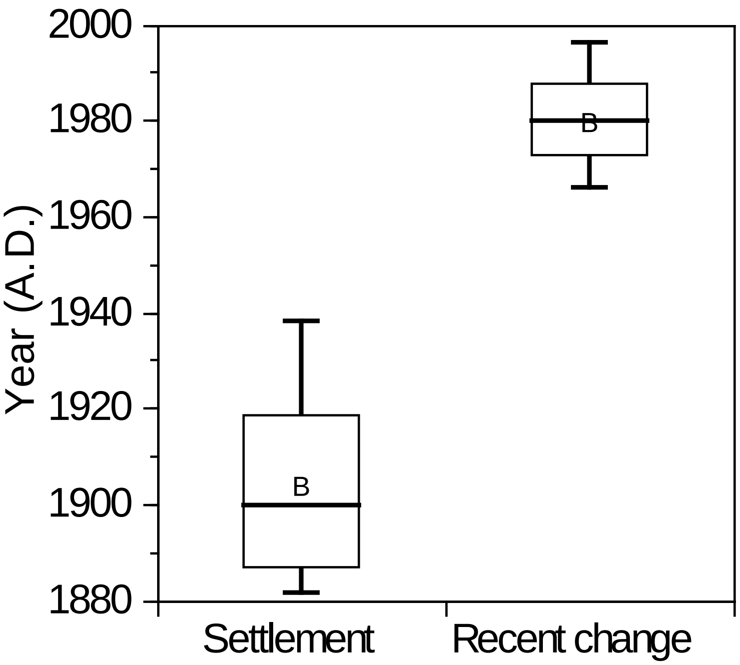


Figure 156. Timeline of primary (Euro-American settlement) and recent secondary biological changes in GLKN lakes. These data also include Speckled Trout and Swamp lakes from Grand Portage Indian Reservation (near GRPO), and Namakan, Kabetogama, Rainy, and Lac La Croix lakes that were analyzed under separate projects (Christensen et al., in press; Serieyssol et al. 2009; Edlund et al. 2010). The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median) respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). The small black box corresponds to the mean (n=19) of the data. Early or primary biological changes occurred from 1870s to 1940s and were associated with Euro-American settlement in the region and associated land use changes (logging, land clearance, damming, settlement). Secondary biological changes occurred from the 1960s to 2000s and are not easily attributed to land use changes; secondary changes may be associated with other drivers including climate warming.

Alternatively, the secondary shifts in diatom communities may be related to climate change. Rühland et al. (2008) synthesized more than 200 lake sediment records from arctic, subarctic, alpine, and boreal regions and noted that lakes showed diatom community shifts that might be linked to climate change. The arctic lakes showed changes as early as the mid- to late-1800s, alpine lakes in the 1920s and temperate boreal lakes in the 1970s. Although not formally tested, the climate response mechanism considered most likely to be driving biological changes was related to longer ice-free periods, longer growth periods, and earlier and longer periods of stratification. Abrupt or threshold diatom community shifts in lakes were characterized by loss of *Aulacoseira* species, which thrive in well-mixed conditions, loss of benthic fragilarioid species that are considered more competitive in colder and ice-covered conditions, and increased numbers of small cyclotelloid diatoms that prefer more stable stratified lake conditions (Rühland et al. 2008). Other potential non-land use drivers of change including increased nitrogen deposition (tested at Lake of the Woods, Ontario) were not well correlated with biological changes (Rühland et al. 2008).

In many of the GLKN lakes we saw similar biological shifts as proposed in the climate response model of Rühland et al. (2008). For example, increases in *Cyclotella comensis* and *Cyclotella mich-like* begin in Lake Manitou (SLBE) between the 1972 and 1982 samples concomitant with a decrease in *Aulacoseira ambigua* (Figure 54). At PIRO's Beaver Lake, increased abundance of *Cyclotella comensis* and *Cyclotella sp. mich-like* is similarly coupled with decreased abundance of *Aulacoseira ambigua* after 1986 (Figure 81). However, the changes in the GLKN lakes did not always follow this model. In PIRO's Grand Sable Lake, decreased abundance of *Aulacoseira ambigua* and *A. subarctica* after 1973 was coupled with increased abundance of *Asterionella formosa* and *Fragilaria crotonensis* (Figure 78). *Fragilaria crotonensis* has not been identified as a major player in response to climate warming; however, it is known to have a rather high temperature optimum (14-16°C; Stoermer and Ladewski 1976) and metalimnetic abundance peaks (Bradbury 1988). Other lakes with secondary shifts in abundance of *Fragilaria crotonensis* included Richie Lake (ISRO), Ahmik (ISRO), Manitou (SLBE), and Bass (SLBE). This secondary biological response was more difficult to explain in the shallow lakes that do not have well developed planktonic diatom communities (such as Shell [SLBE], Harvey [ISRO], and Outer Lagoon [APIS]), but we note that biological shifts still occurred in these lakes within the time frame of the 1970s-1990s.

A similar timing of biological shifts was noted in cores from VOYA's large lakes (Namakan, Rainy, Kabetogama) and the upstream Lac La Croix (under wilderness protection) in the late 1970s to early 1980s (Serieyssol et al. 2009, Edlund et al. 2010). Efforts were made to attribute this change to known climate, land use, and hydromanagement drivers. For most lakes, the changes in diatom communities could be uniquely explained first by landscape drivers including pulpwood cutting and beaver populations and secondly by climate drivers. Hydromanagement usually explained the smallest unique variation in the diatom data; the interaction of landscape, climate, and hydromanagement was also a significant explanatory factor (Edlund et al. 2010).

Perhaps the most surprising result of this study came during the analysis of floristic change between repeat surface samples from PIRO (collected 2008) and SLBE (collected in 2009) lakes compared to surface samples collected in 2005 from the same lakes. Results showed that only three of the 12 lakes showed low levels of floristic change (Figure 153). The other nine lakes showed higher levels of floristic change for some lakes was even greater than the amount of change calculated between pre-Euro-American settlement and modern samples (Figure 153). Three things must be considered in the explanation of these results: taxonomic consistency, unequal time intervals integrated within sediment samples, and the possibility that GLKN lakes are undergoing a period of unprecedented biological change. First, significant efforts were made to ensure taxonomic consistency in all counts by collecting images of all but minor taxa in surface sediments and core samples. Second, there is a general pattern in lake sediment cores that sections at the top of the core incorporate far fewer years of sedimentation than the bottom levels of a core where sediment compaction may lead to a 1-cm core section representing 10 to 20 years of sedimentation. For example, in Manitou Lake (SLBE) the 0 to 2 cm section of the core represented one year of sediment accumulation, whereas in Cruiser Lake (VOYA) the 0-1 cm section represented nearly three years of sediment accumulation. In contrast, the 67 to 69 cm level in the Manitou Lake (SLBE) core represented 6 to 7 years of sedimentation, whereas the 12 to 13 cm level in the Cruiser Lake (VOYA) core represented more than 20 years of sediment accumulation. Where this might lead to inflated measures of floristic change is when a 0 to 1 cm section is analyzed from a lake with high sedimentation rates and the sample represents only a subannual (season) period of sedimentation. This should be considered as future sampling and repeat sampling proceeds in the GLKN lakes; consideration may need to be given to sampling the 0 to 2 or even 0 to 3 cm section of surface sediments to effectively sample several years of sedimentation.

Lastly, the large floristic changes recorded in the PIRO and SLBE lakes between 2005 and 2008/2009 may truly represent recent unprecedented biological shifts in the GLKN lakes. The lakes that showed large floristic changes clearly had significant shifts in species composition between the original (2005) and repeat samples taken in 2008 and 2009 (see Results). Some of the shifts appeared to be following patterns that began several decades ago and may be climate-driven (e.g., the continued loss of *Aulacoseira ambigua*, but gain of *Fragilaria crotonensis* in Grand Sable Lake (PIRO)). At PIRO, top-down impacts following introduction of the invasive predatory zooplankter *Bythotrephes* in Beaver Lake in 1997 and in Grand Sable Lake in a 2003 may be driving changes in the primary producer communities (L. Loope, PIRO Aquatic Biologist, pers. comm.). Other records were less clear such as the drivers behind changes in abundance of *Denticula tenuis* in SLBE's Round and Shell Lakes.

The recent change in GLKN lakes were not limited to just diatom assemblages. In ISRO's Richie Lake, an extensive cyanobacterial bloom occurred in August 2007, a phenomenon that was hitherto unknown in that system. Cyanobacterial blooms are predicted to increase in frequency and are increasingly being reported from "pristine" lakes (Wagner and Adrian 2009). It seems that a recurring result of research on the environmental history of GLKN lakes was that many lakes showed biological and geochemical changes in sediments deposited after the 1970s to 1980s. Because these lakes are spread across a wide geographic region, and are in relatively pristine and protected areas, it is unlikely that land use was driving recent changes but rather climate had driven observed ecological changes in the lakes. Climate-linked mechanisms of recent ecological change may include 1) shorter duration of ice cover that leads to earlier warming of surface water, earlier and longer stratification, and longer growing seasons, and 2) increased frequency or intensity of summer storms that may lead to increased availability of nutrients when lake waters mix more frequently. This large potential for further environmental change within the protected borders of the national parks warrants that water quality and biological monitoring programs are an essential part of park resource management.

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Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes.

Appendix 1 presents a list of diatom species found in sixty surface sediment samples at percent abundances of >1% in two or more samples or >5% in one sample. The diatoms are listed using their currently accepted names and genus-level assignments. The nature of diatom analysis and a paucity of floristic and survey work on GLKN diatoms makes certain identification of each specimen difficult. As such, some species are assigned provisional names or identifiers that are specific to this project or have been used in other diatom analysis projects. Many of these provisionally identified diatoms likely represent undescribed or new species. All provisional names are identified with a "(prov. ID)" designation.

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample.

APLSND – ISFLDT

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***APLSND***	***APMICH***	***APOUTR***	***APSTCK***	***INLONG***	***ISAHMK***	***ISBEAV***	***ISDESR***	***ISFLDT***
Asterionella formosa	ASTFORMO	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.035	0.000
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000
Staurosira construens	SRACONST	0.000	0.000	0.000	0.000	0.226	0.054	0.002	0.022	0.000
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.009	0.000	0.002	0.004	0.000	0.000	0.000	0.000	0.000
Denticula tenuis var. crassula	DENTENCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella comensis	CYCCOMEN	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.260	0.000
Cyclotella ocellata	CYCOCELL	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Discostella stelligera	CYCSTELL	0.000	0.000	0.000	0.008	0.000	0.000	0.074	0.004	0.002
Navicula cryptotenella	NAVCRYPT	0.000	0.173	0.039	0.013	0.002	0.019	0.027	0.000	0.009
Aulacoseira subarctica	AULSUBAR	0.000	0.000	0.000	0.000	0.000	0.011	0.015	0.007	0.000
Staurosira construens var. venter	SRACONVE	0.305	0.004	0.000	0.010	0.070	0.230	0.021	0.033	0.143
Aulacoseira ambigua	AULAMBIG	0.000	0.000	0.000	0.000	0.056	0.024	0.027	0.267	0.000
Staurosirella pinnata	SLLPINNA	0.064	0.000	0.000	0.000	0.151	0.271	0.124	0.011	0.090
Aulacoseira granulata	AULGRANU	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000
Aulacoseira tenella	AULTENEL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana	CYCMENEG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudostaurosira microstriata	PRAMICRO	0.000	0.000	0.231	0.096	0.000	0.000	0.000	0.000	0.017
Synedra tenera	FRATENER	0.000	0.006	0.010	0.002	0.000	0.000	0.000	0.000	0.000
Aulacoseira italica	AULITALI	0.000	0.000	0.000	0.000	0.020	0.000	0.017	0.000	0.000
Eunotia zazuminensis	EUNZASUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis	FRACROTO	0.000	0.000	0.000	0.000	0.000	0.017	0.004	0.046	0.000
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.000	0.006	0.000	0.002	0.002	0.000	0.000	0.000	0.000
Pseudostaurosira brevistriata	PRABREVI	0.000	0.000	0.000	0.006	0.095	0.009	0.017	0.004	0.051
Puncticulata bodanica	CYCBODAN	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.004	0.000
Achnanthidium minutissimum	ACHMINUT	0.105	0.069	0.000	0.138	0.014	0.002	0.011	0.004	0.075
Cocconeis placentula var. lineata	COCPLALI	0.000	0.000	0.000	0.000	0.011	0.002	0.000	0.000	0.015
Tabellaria flocculosa	TABFLOCC	0.022	0.002	0.018	0.000	0.000	0.000	0.000	0.002	0.004

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

APLSND – ISFLDT

(See Table 1 for six character lake codes.)

Taxon	Taxon Code	Lake Code								
		APLSND	***APMICH***	***APOUTR***	***APSTCK***	***INLONG***	***ISAHMK***	***ISBEAV***	***ISDESR***	***ISFLDT***
Cyclotella michiganiana	CYCMICHI	0.000	0.000	0.000	0.004	0.000	0.000	0.025	0.042	0.006
Brachysira neoexilis	BRANEOEX	0.024	0.054	0.043	0.103	0.000	0.000	0.002	0.000	0.004
Encyonopsis cesatii	ENPCESAT	0.000	0.093	0.002	0.008	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira elliptica GLEI (prov. ID)	SRAELLIP	0.000	0.000	0.000	0.002	0.090	0.019	0.000	0.000	0.002
Synedra delicatissima	SYNDELIC	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.024	0.000
Stephanodiscus minutulus	SUSMINUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000
Denticula kuetzingii	DENKEUTZ	0.000	0.082	0.000	0.000	0.000	0.000	0.006	0.000	0.004
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.000	0.000	0.000	0.002	0.000	0.004	0.004	0.000	0.002
Encyonopsis microcephala	ENPMICRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Rossithidium linearis	ROSLINEA	0.011	0.006	0.000	0.027	0.000	0.013	0.000	0.000	0.036
Staurosirella pinnata var. intercedens	SLLPININ	0.000	0.000	0.000	0.000	0.000	0.019	0.069	0.000	0.000
Eunotia faba	EUNFABA	0.000	0.000	0.067	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus parvus	SUSPARVU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora cf. blackfordensis (prov. ID)	SELBLCKF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.004	0.015
Nitzschia perminuta	NITPERMI	0.007	0.006	0.059	0.019	0.000	0.000	0.000	0.000	0.011
Pinnularia interrupta	PININTEP	0.002	0.009	0.006	0.002	0.000	0.002	0.017	0.000	0.011
Cyclostephanos invisitatus	CSPINVIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

APLSND – ISFLDT

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***APLSND***	***APMICH***	***APOUTR***	***APSTCK***	***INLONG***	***ISAHMK***	***ISBEAV***	***ISDESR***	***ISFLDT***
Navicula minima	NAVMINIM	0.000	0.000	0.000	0.002	0.014	0.015	0.006	0.000	0.026
Nupela cf schoemaniana	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.053	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina var. mesolepta	FRACAPME	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diploneis modica	DIPMODCA	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula cryptocephala	NAVCRYCP	0.000	0.052	0.000	0.000	0.002	0.004	0.000	0.002	0.000
Stauroforma exiguiformis	STFEXIGF	0.002	0.000	0.027	0.050	0.000	0.000	0.000	0.000	0.000
Nitzschia gracilis	NITGRACI	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.002	0.000
Navicula radiosa	NAVRADIO	0.000	0.050	0.002	0.000	0.005	0.002	0.000	0.002	0.000
Encyonopsis subminuta	ENPSUBMI	0.029	0.048	0.000	0.019	0.000	0.002	0.002	0.000	0.004
Amphora perpusilla	AMPPERPU	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Frustulia rhomboides	FRURHOMB	0.002	0.000	0.045	0.040	0.000	0.000	0.000	0.000	0.000
Puncticulata lemanica	CYCBODLE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Navicula globosa	NAVGLOBO	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
Karayevia clevei	KARCLEVE	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.004
Fragilaria crotonensis var. oregona	FRACROOR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus niagarae	SUSNIAGA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula submuralis	NAVSUBMU	0.002	0.000	0.000	0.002	0.000	0.015	0.021	0.007	0.036
Aulacoseira perglabra	AULPERGL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora laevissima	SELLAEVI	0.000	0.035	0.000	0.002	0.000	0.000	0.000	0.002	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

APLSND – ISFLDT

See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***APLSND***	***APMICH***	***APOUTR***	***APSTCK***	***INLONG***	***ISAHMK***	***ISBEAV***	***ISDESR***	***ISFLDT***
Fragilaria nanana	FRANANAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora subcostulata	AMPSUBCO	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Aulacoseira laevissima	AULLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella pseudostelligera	CYCPSEUD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000
Brachysira vitrea	BRAVITRE	0.002	0.000	0.000	0.021	0.000	0.000	0.000	0.000	0.002
Nitzschia amphibia	NITAMPHI	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.006
Fragilaria capucina	FRACAPUC	0.024	0.000	0.000	0.000	0.023	0.004	0.000	0.004	0.000
Amphora pediculus	AMPPEDIC	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.000
Achnanthes conspicua	ACECONSP	0.004	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.000
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium pusillum	ROSPUSIL	0.009	0.000	0.000	0.002	0.000	0.002	0.000	0.000	0.017
Eunotia pectinalis	EUNPECTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula mediocris	NAVMEDCR	0.000	0.000	0.022	0.027	0.000	0.000	0.000	0.000	0.004
Psammothidium marginulatum	PSAMARGI	0.002	0.000	0.004	0.027	0.000	0.000	0.000	0.000	0.009
Synedra filiformis	SYNFILIF	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthidium exiguum	ACHEXIGU	0.000	0.000	0.000	0.000	0.002	0.026	0.011	0.000	0.013
Navicula rhynchocephala	NAVRHYNC	0.009	0.006	0.000	0.000	0.000	0.000	0.002	0.000	0.011
Sellaphora disjuncta	SELDISJU	0.002	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.004
Amphora libyca	AMPLIBYC	0.007	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Navicula verecunda	NAVVEREC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.000	0.000	0.000	0.000	0.000	0.024	0.002	0.000	0.000
Sellaphora vitabunda	SELVITAB	0.000	0.000	0.000	0.002	0.000	0.017	0.000	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

APLSND – ISFLDT

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***APLSND***	***APMICH***	***APOUTR***	***APSTCK***	***INLONG***	***ISAHMK***	***ISBEAV***	***ISDESR***	***ISFLDT***
Nitzschia sublinearis	NITSUBLI	0.011	0.015	0.004	0.023	0.000	0.000	0.002	0.002	0.000
Nitzschia palea	NITPALEA	0.022	0.000	0.000	0.000	0.002	0.000	0.008	0.000	0.009
Fragilaria vaucheriae	FRAVAUCH	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.000	0.011
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.004
Navicula leptostriata	NAVLEPTO	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. subsalina	SRACONSU	0.013	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.006
Tabellaria flocculosa Strain III (prov. ID)	TABFLOC3	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000
Achnanthes saccula	PSASACCU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000
Geissleria decussis	GEIDECUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Sellaphora seminulum	SELSEMIN	0.009	0.000	0.000	0.000	0.000	0.009	0.006	0.000	0.019
Planothidium lanceolatum	PLALANCE	0.002	0.000	0.000	0.000	0.018	0.002	0.000	0.000	0.000
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora pupula	SELPUPUL	0.000	0.000	0.000	0.000	0.000	0.006	0.019	0.000	0.009
Cyclotella seratula	CYCSERAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra filiformis var. exilis	SYNFILEX	0.007	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000
Synedra radians	SYNRADIA	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Tabellaria fenestrata	TABFENES	0.009	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000
Encyonema neogracile	ENCNEOG	0.000	0.013	0.016	0.008	0.000	0.000	0.000	0.000	0.000
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia fonticola	NITFONTI	0.015	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.006
Psammothidium abundans var. rosenstockii	PSAABURO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Eucocconeis flexella	EUCFLEXE	0.000	0.015	0.000	0.015	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

APLSND – ISFLDT

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***APLSND***	***APMICH***	***APOUTR***	***APSTCK***	***INLONG***	***ISAHMK***	***ISBEAV***	***ISDESR***	***ISFLDT***
Reimeria sinuata	REISINUA	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011
Gomphonema angustatum	GOMANGUS	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula utermoehlii	CAVUTERM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia incisa	EUNINCIS	0.011	0.004	0.002	0.002	0.000	0.000	0.004	0.000	0.011
Amphora ovalis	AMPOVALI	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.002
Martyana martyi	MARMARTY	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Eunotia arcus	EUNARCUS	0.000	0.004	0.012	0.000	0.000	0.000	0.000	0.000	0.002
Nitzschia bacillum	NITBACIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Sellaphora capitata	SELPUPCA	0.007	0.011	0.000	0.002	0.000	0.006	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

ISGORG-PIBEAV

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***ISGORG***	***ISHARV***	***ISRICH***	***ISSARG***	***ISSISK***	***MS852***	***MSCNRP***	***MSSPLK***	***PIBEAV***
Asterionella formosa	ASTFORMO	0.000	0.000	0.043	0.053	0.028	0.000	0.000	0.002	0.126
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.000	0.000	0.000	0.126	0.000	0.000	0.000	0.245
Staurosira construens	SRACONST	0.000	0.494	0.000	0.026	0.000	0.006	0.005	0.000	0.002
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.000	0.000	0.000	0.020	0.032	0.000	0.000	0.000	0.000
Denticula tenuis var. crassula	DENTENCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Cyclotella comensis	CYCCOMEN	0.000	0.000	0.000	0.000	0.258	0.000	0.000	0.000	0.052
Cyclotella ocellata	CYCOCELL	0.000	0.000	0.000	0.000	0.008	0.000	0.002	0.000	0.000
Discostella stelligera	CYCSTELL	0.024	0.000	0.040	0.071	0.142	0.013	0.005	0.012	0.009
Navicula cryptotenella	NAVCRYPT	0.015	0.000	0.010	0.004	0.000	0.004	0.000	0.000	0.002
Aulacoseira subarctica	AULSUBAR	0.000	0.000	0.043	0.318	0.006	0.013	0.000	0.008	0.000
Staurosira construens var. venter	SRACONVE	0.129	0.124	0.014	0.012	0.000	0.009	0.021	0.004	0.026
Aulacoseira ambigua	AULAMBIG	0.000	0.000	0.097	0.093	0.002	0.000	0.014	0.027	0.119
Staurosirella pinnata	SLLPINNA	0.050	0.145	0.020	0.030	0.008	0.024	0.000	0.000	0.011
Aulacoseira granulata	AULGRANU	0.000	0.000	0.028	0.004	0.000	0.009	0.031	0.037	0.000
Aulacoseira tenella	AULTENEL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana	CYCMENEG	0.000	0.000	0.000	0.000	0.000	0.245	0.252	0.219	0.000
Pseudostaurosira microstriata	PRAMICRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra tenera	FRATENER	0.004	0.000	0.221	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira italica	AULITALI	0.000	0.000	0.065	0.000	0.000	0.000	0.000	0.004	0.007
Eunotia zazuminensis	EUNZASUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis	FRACROTO	0.000	0.000	0.022	0.020	0.011	0.002	0.000	0.000	0.020
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudostaurosira brevistriata	PRABREVI	0.022	0.000	0.000	0.018	0.000	0.090	0.010	0.006	0.002
Puncticulata bodanica	CYCBODAN	0.000	0.000	0.010	0.020	0.006	0.000	0.000	0.000	0.004
Achnanthidium minutissimum	ACHMINUT	0.151	0.009	0.030	0.018	0.013	0.000	0.005	0.000	0.037

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

ISGORG-PIBEAV

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***ISGORG***	***ISHARV***	***ISRICH***	***ISSARG***	***ISSISK***	***MS852***	***MSCNRP***	***MSSPLK***	***PIBEAV***
Cocconeis placentula var. lineata	COCPLALI	0.000	0.000	0.000	0.000	0.000	0.024	0.136	0.004	0.000
Tabellaria flocculosa	TABFLOCC	0.004	0.000	0.128	0.004	0.002	0.000	0.000	0.000	0.000
Cyclotella michiganiana	CYCMICHI	0.004	0.000	0.049	0.053	0.055	0.000	0.000	0.000	0.017
Brachysira neoexilis	BRANEOEX	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonopsis cesatii	ENPCESAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.092	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.090	0.021	0.029	0.000
Staurosira elliptica GLEI	SRAELLIP	0.002	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra delicatissima	SYNDELIC	0.000	0.000	0.006	0.010	0.000	0.000	0.007	0.014	0.002
Stephanodiscus minutulus	SUSMINUS	0.000	0.000	0.000	0.008	0.000	0.028	0.017	0.058	0.002
Denticula kuetzingii	DENKEUTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.081	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.000	0.000	0.000	0.004	0.000	0.004	0.019	0.000	0.002
Encyonopsis microcephala	ENPMICRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.000	0.071	0.004	0.000
Rossithidium linearis	ROSLINEA	0.050	0.000	0.000	0.000	0.002	0.002	0.000	0.000	0.000
Staurosirella pinnata var. intercedens	SLLPININ	0.022	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000
Eunotia faba	EUNFABA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus parvus	SUSPARVU	0.000	0.000	0.000	0.004	0.000	0.011	0.005	0.056	0.000
Sellaphora cf. blackfordensis (prov. ID)	SELBLCKF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.000	0.000	0.004	0.000	0.002	0.000	0.000	0.000	0.002
Nitzschia perminuta	NITPERMI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pinnularia interrupta	PININTEP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

ISGORG-PIBEAV

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***ISGORG***	***ISHARV***	***ISRICH***	***ISSARG***	***ISSISK***	***MS852***	***MSCNRP***	***MSSPLK***	***PIBEAV***
Cyclostephanos invisitatus	CSPINVIS	0.000	0.000	0.000	0.000	0.000	0.023	0.029	0.054	0.000
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.006	0.005	0.056	0.000
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Navicula minima	NAVMINIM	0.054	0.009	0.004	0.002	0.000	0.000	0.000	0.000	0.000
Nupela cf schoemaniana	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.000	0.000	0.000	0.000	0.000	0.028	0.002	0.000	0.009
Fragilaria capucina var. mesolepta	FRACAPME	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.008	0.000
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.053	0.000	0.000	0.000	0.000
Diploneis modica	DIPMODCA	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.023	0.000
Navicula cryptocephala	NAVCRYCP	0.009	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Stauroforma exiguiformis	STFEXIGF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia gracilis	NITGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Navicula radiosa	NAVRADIO	0.004	0.000	0.002	0.006	0.002	0.000	0.000	0.000	0.000
Encyonopsis subminuta	ENPSUBMI	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora perpusilla	AMPPERPU	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.002	0.017
Frustulia rhomboides	FRURHOMB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puncticulata lemanica	CYCBODLE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula globosa	NAVGLOBO	0.009	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karayevia clevei	KARCLEVE	0.011	0.000	0.000	0.006	0.000	0.022	0.005	0.002	0.009
Fragilaria crotonensis var. oregona	FRACROOR	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Stephanodiscus niagarae	SUSNIAGA	0.000	0.000	0.000	0.002	0.000	0.000	0.002	0.006	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000
Navicula submuralis	NAVSUBMU	0.009	0.019	0.010	0.006	0.002	0.000	0.000	0.000	0.000
Aulacoseira perglabra?	AULPERGL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

ISGORG-PIBEAV

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***ISGORG***	***ISHARV***	***ISRICH***	***ISSARG***	***ISSISK***	***MS852***	***MSCNRP***	***MSSPLK***	***PIBEAV***
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035
Sellaphora laevissima	SELLAEVI	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria nanana	FRANANAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
Amphora subcostulata	AMPSUBCO	0.004	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.009
Aulacoseira laevissima	AULLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella pseudostelligera	CYCPSEUD	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000
Brachysira vitrea	BRAVITRE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Nitzschia amphibia	NITAMPHI	0.009	0.000	0.000	0.000	0.000	0.006	0.033	0.002	0.000
Fragilaria capucina	FRACAPUC	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.004	0.000
Amphora pediculus	AMPPEDIC	0.009	0.000	0.000	0.002	0.000	0.006	0.000	0.000	0.000
Achnanthes conspicua	ACECONSP	0.028	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.028	0.007	0.008	0.000
Rossithidium pusillum	ROSPUSIL	0.002	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Eunotia pectinalis	EUNPECTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula mediocris	NAVMEDCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Psammothidium marginulatum	PSAMARGI	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra filiformis	SYNFILIF	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.017
Achnanthidium exiguum	ACHEXIGU	0.015	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Navicula rhynchocephala	NAVRHYNC	0.000	0.000	0.000	0.000	0.000	0.022	0.002	0.000	0.000
Sellaphora disjuncta	SELDISJU	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Amphora libyca	AMPLIBYC	0.000	0.000	0.000	0.000	0.000	0.004	0.007	0.002	0.007
Navicula verecunda	NAVVEREC	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

ISGORG-PIBEAV

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***ISGORG***	***ISHARV***	***ISRICH***	***ISSARG***	***ISSISK***	***MS852***	***MSCNRP***	***MSSPLK***	***PIBEAV***
Sellaphora vitabunda	SELVITAB	0.013	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia sublinearis	NITSUBLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
Nitzschia palea	NITPALEA	0.004	0.000	0.000	0.004	0.000	0.006	0.010	0.023	0.004
Fragilaria vaucheriae	FRAVAUCH	0.002	0.000	0.000	0.000	0.004	0.004	0.000	0.000	0.002
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.021	0.000	0.000	0.000	0.004	0.000	0.000	0.000
Navicula leptostriata	NAVLEPTO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. subsalina	SRACONSU	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain III (prov. ID)	TABFLOC3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthes saccula	PSASACCU	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Geissleria decussis	GEIDECUS	0.000	0.000	0.000	0.000	0.000	0.004	0.017	0.000	0.000
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.004
Sellaphora seminulum	SELSEMIN	0.002	0.002	0.000	0.000	0.000	0.000	0.007	0.000	0.000
Planothidium lanceolatum	PLALANCE	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.000
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora pupula	SELPUPUL	0.011	0.000	0.000	0.000	0.000	0.002	0.005	0.004	0.000
Cyclotella seratula	CYCSERAT	0.000	0.000	0.000	0.000	0.002	0.000	0.007	0.012	0.000
Synedra filiformis var. exilis	SYNFILEX	0.000	0.000	0.018	0.016	0.000	0.000	0.000	0.000	0.000
Synedra radians	SYNRADIA	0.000	0.000	0.002	0.006	0.000	0.000	0.000	0.000	0.007
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria fenestrata	TABFENES	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema neogracile	ENCNEOG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia fonticola	NITFONTI	0.002	0.000	0.000	0.000	0.000	0.002	0.000	0.004	0.000
Psammothidium abundans v. rosenstockii	PSAABURO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

ISGORG-PIBEAV

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***ISGORG***	***ISHARV***	***ISRICH***	***ISSARG***	***ISSISK***	***MS852***	***MSCNRP***	***MSSPLK***	***PIBEAV***
Eucocconeis flexella	EUCFLEXE	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.004
Reimeria sinuata	REISINUA	0.000	0.000	0.000	0.002	0.000	0.002	0.014	0.004	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.004	0.005	0.000	0.000
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema angustatum	GOMANGUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Navicula utermoehlii	CAVUTERM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia incisa	EUNINCIS	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Amphora ovalis	AMPOVALI	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana martyi	MARMARTY	0.009	0.000	0.004	0.002	0.000	0.000	0.000	0.000	0.007
Eunotia arcus	EUNARCUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia bacillum	NITBACIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora capitata	SELPUPCA	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Asterionella formosa	ASTFORMO	0.043	0.081	0.042	0.000	0.000	0.000	0.006	0.000	0.002
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.004	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Staurosira construens	SRACONST	0.019	0.012	0.033	0.021	0.000	0.017	0.034	0.004	0.015
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Denticula tenuis var. crassula	DENTENCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella comensis	CYCCOMEN	0.004	0.067	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Cyclotella ocellata	CYCOCELL	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella stelligera	CYCSTELL	0.114	0.042	0.007	0.000	0.000	0.000	0.011	0.002	0.071
Navicula cryptotenella	NAVCRYPT	0.000	0.002	0.007	0.009	0.004	0.001	0.000	0.011	0.000
Aulacoseira subarctica	AULSUBAR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. venter	SRACONVE	0.047	0.023	0.031	0.126	0.000	0.077	0.051	0.092	0.065
Aulacoseira ambigua	AULAMBIG	0.000	0.135	0.106	0.000	0.000	0.000	0.002	0.002	0.056
Staurosirella pinnata	SLLPINNA	0.024	0.013	0.009	0.015	0.000	0.139	0.068	0.019	0.024
Aulacoseira granulata	AULGRANU	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.013	0.266
Aulacoseira tenella	AULTENEL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana	CYCMENEG	0.002	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.009
Pseudostaurosira microstriata	PRAMICRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra tenera	FRATENER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira italica	AULITALI	0.000	0.073	0.216	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia zazuminensis	EUNZASUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis	FRACROTO	0.073	0.091	0.049	0.000	0.000	0.000	0.064	0.002	0.039
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.000	0.000	0.000	0.000	0.173	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Pseudostaurosira brevistriata	PRABREVI	0.045	0.000	0.038	0.043	0.046	0.014	0.053	0.088	0.011
Puncticulata bodanica	CYCBODAN	0.011	0.006	0.002	0.000	0.169	0.000	0.000	0.000	0.000
Achnanthidium minutissimum	ACHMINUT	0.077	0.064	0.020	0.073	0.023	0.027	0.055	0.043	0.009
Cocconeis placentula var. lineata	COCPLALI	0.017	0.000	0.007	0.068	0.000	0.055	0.047	0.077	0.002
Tabellaria flocculosa	TABFLOCC	0.067	0.027	0.026	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella michiganiana	CYCMICHI	0.058	0.002	0.000	0.000	0.004	0.000	0.000	0.000	0.000
Brachysira neoexilis	BRANEOEX	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonopsis cesatii	ENPCESAT	0.000	0.000	0.000	0.000	0.073	0.000	0.000	0.000	0.000
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira elliptica GLEI (prov. ID)	SRAELLIP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra delicatissima	SYNDELIC	0.004	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.006
Stephanodiscus minutulus	SUSMINUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013
Denticula kuetzingii	DENKEUTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.002	0.002	0.000	0.021	0.000	0.057	0.053	0.080	0.004
Encyonopsis microcephala	ENPMICRO	0.002	0.004	0.000	0.000	0.008	0.000	0.000	0.000	0.002
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.073	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Rossithidium linearis	ROSLINEA	0.019	0.008	0.004	0.071	0.000	0.011	0.000	0.002	0.000
Staurosirella pinnata var. intercedens	SLLPININ	0.006	0.000	0.002	0.011	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Eunotia faba	EUNFABA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus parvus	SUSPARVU	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.022
Sellaphora cf. blackfordensis (prov. ID)	SELBLCKF	0.000	0.000	0.000	0.000	0.063	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.000	0.002	0.000	0.000	0.000	0.004	0.000	0.000	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.006	0.000	0.000	0.026	0.000	0.062	0.004	0.000	0.030
Nitzschia perminuta	NITPERMI	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pinnularia interrupta	PININTEP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos invisitatus	CSPINVIS	0.000	0.000	0.000	0.000	0.000	0.002	0.008	0.000	0.056
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula minima	NAVMINIM	0.000	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nupela cf schoemaniana	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.017	0.004	0.013	0.049	0.000	0.050	0.053	0.030	0.011
Fragilaria capucina var. mesolepta	FRACAPME	0.000	0.000	0.002	0.002	0.000	0.049	0.053	0.004	0.037
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diploneis modica	DIPMODCA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.000	0.022
Navicula cryptocephala	NAVCRYCP	0.000	0.002	0.002	0.002	0.002	0.000	0.000	0.002	0.000
Stauroforma exiguiformis	STFEXIGF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia gracilis	NITGRACI	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000
Navicula radiosa	NAVRADIO	0.004	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000
Encyonopsis subminuta	ENPSUBMI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Amphora perpusilla	AMPPERPU	0.000	0.021	0.000	0.024	0.000	0.000	0.000	0.000	0.000
Frustulia rhomboides	FRURHOMB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puncticulata lemanica	CYCBODLE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula globosa	NAVGLOBO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karayevia clevei	KARCLEVE	0.006	0.000	0.011	0.019	0.000	0.028	0.017	0.041	0.019
Fragilaria crotonensis var. oregona	FRACROOR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.032
Stephanodiscus niagarae	SUSNIAGA	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037
Navicula submuralis	NAVSUBMU	0.000	0.000	0.026	0.000	0.000	0.006	0.013	0.013	0.002
Aulacoseira perglabra?	AULPERGL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000
Sellaphora laevissima	SELLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria nanana	FRANANAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora subcostulata	AMPSUBCO	0.004	0.004	0.002	0.013	0.000	0.025	0.034	0.032	0.004
Aulacoseira laevissima	AULLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella pseudostelligera	CYCPSEUD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brachysira vitrea	BRAVITRE	0.000	0.002	0.000	0.000	0.006	0.000	0.000	0.000	0.000
Nitzschia amphibia	NITAMPHI	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.006	0.000
Fragilaria capucina	FRACAPUC	0.013	0.002	0.007	0.004	0.000	0.008	0.030	0.002	0.000
Amphora pediculus	AMPPEDIC	0.000	0.000	0.000	0.000	0.000	0.028	0.015	0.024	0.006
Achnanthes conspicua	ACECONSP	0.004	0.002	0.009	0.009	0.000	0.002	0.019	0.013	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.011	0.011	0.000	0.000
Rossithidium pusillum	ROSPUSIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.000
Eunotia pectinalis	EUNPECTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula mediocris	NAVMEDCR	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Psammothidium marginulatum	PSAMARGI	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra filiformis	SYNFILIF	0.013	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthidium exiguum	ACHEXIGU	0.009	0.002	0.007	0.006	0.000	0.004	0.004	0.004	0.000
Navicula rhynchocephala	NAVRHYNC	0.002	0.000	0.002	0.000	0.000	0.007	0.000	0.026	0.000
Sellaphora disjuncta	SELDISJU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora libyca	AMPLIBYC	0.000	0.004	0.002	0.011	0.000	0.000	0.000	0.000	0.000
Navicula verecunda	NAVVEREC	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.000	0.000	0.000	0.000	0.000	0.013	0.002	0.022	0.000
Sellaphora vitabunda	SELVITAB	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.000	0.000	0.015	0.023	0.006	0.002
Nitzschia sublinearis	NITSUBLI	0.011	0.004	0.000	0.011	0.017	0.000	0.000	0.004	0.006
Nitzschia palea	NITPALEA	0.006	0.000	0.002	0.004	0.000	0.000	0.000	0.006	0.004
Fragilaria vaucheriae	FRAVAUCH	0.002	0.000	0.000	0.002	0.000	0.006	0.006	0.002	0.009
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula leptostriata	NAVLEPTO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. subsalina	SRACONSU	0.004	0.000	0.000	0.002	0.000	0.002	0.002	0.009	0.000
Tabellaria flocculosa Strain III	TABFLOC3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Achnanthes saccula	PSASACCU	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Geissleria decussis	GEIDECUS	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.019	0.006
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.006	0.019	0.011	0.019	0.000	0.000	0.008	0.002	0.000
Sellaphora seminulum	SELSEMIN	0.004	0.004	0.002	0.004	0.000	0.002	0.000	0.002	0.000
Planothidium lanceolatum	PLALANCE	0.004	0.002	0.009	0.011	0.000	0.002	0.019	0.015	0.002
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.019	0.015	0.000	0.000
Sellaphora pupula	SELPUPUL	0.002	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella seratula	CYCSERAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra filiformis var. exilis	SYNFILEX	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra radians	SYNRADIA	0.006	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria fenestrata	TABFENES	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema neogracile	ENCNEOG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia fonticola	NITFONTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Psammothidium abundans v. rosenstockii	PSAABURO	0.000	0.006	0.000	0.000	0.010	0.000	0.000	0.000	0.000
Eucocconeis flexella	EUCFLEXE	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000
Reimeria sinuata	REISINUA	0.011	0.000	0.002	0.002	0.000	0.015	0.004	0.006	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.015	0.013	0.000	0.000
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

PICHAP-SC09

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***PICHAP***	***PIGRSA***	***PILTBV***	***PIMINE***	***PITRAP***	***SC01a***	***SC01b***	***SC05***	***SC09***
Gomphonema angustatum	GOMANGUS	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Navicula utermoehlii	CAVUTERM	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Eunotia incisa	EUNINCIS	0.002	0.002	0.004	0.002	0.000	0.001	0.000	0.000	0.000
Amphora ovalis	AMPOVALI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana martyi	MARMARTY	0.006	0.000	0.011	0.011	0.000	0.013	0.000	0.000	0.004
Eunotia arcus	EUNARCUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia bacillum	NITBACIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011
Sellaphora capitata	SELPUPCA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Asterionella formosa	ASTFORMO	0.004	0.022	0.000	0.019	0.009	0.002	0.000	0.000	0.000
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.213	0.000	0.075	0.564	0.034	0.029	0.030	0.002
Staurosira construens	SRACONST	0.008	0.009	0.000	0.006	0.028	0.024	0.075	0.261	0.002
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Denticula tenuis var. crassula	DENTENCR	0.000	0.007	0.000	0.004	0.000	0.009	0.000	0.051	0.389
Cyclotella comensis	CYCCOMEN	0.000	0.385	0.022	0.295	0.213	0.192	0.055	0.132	0.000
Cyclotella ocellata	CYCOCELL	0.000	0.000	0.000	0.066	0.000	0.000	0.022	0.000	0.000
Discostella stelligera	CYCSTELL	0.020	0.000	0.013	0.000	0.000	0.000	0.002	0.004	0.000
Navicula cryptotenella	NAVCRYPT	0.000	0.015	0.065	0.002	0.000	0.006	0.016	0.018	0.318
Aulacoseira subarctica	AULSUBAR	0.008	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000
Staurosira construens var. venter	SRACONVE	0.020	0.018	0.281	0.025	0.002	0.024	0.129	0.073	0.000
Aulacoseira ambigua	AULAMBIG	0.116	0.002	0.000	0.052	0.009	0.291	0.000	0.002	0.000
Staurosirella pinnata	SLLPINNA	0.028	0.009	0.000	0.012	0.020	0.004	0.018	0.028	0.002
Aulacoseira granulata	AULGRANU	0.188	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira tenella	AULTENEL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana	CYCMENEG	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudostaurosira microstriata	PRAMICRO	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Synedra tenera	FRATENER	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000
Aulacoseira italica	AULITALI	0.000	0.000	0.000	0.000	0.011	0.037	0.000	0.000	0.000
Eunotia zazuminensis	EUNZASUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis	FRACROTO	0.200	0.007	0.000	0.060	0.009	0.047	0.000	0.010	0.004
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.006

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Pseudostaurosira brevistriata	PRABREVI	0.000	0.000	0.000	0.066	0.011	0.075	0.106	0.136	0.000
Puncticulata bodanica	CYCBODAN	0.000	0.015	0.016	0.000	0.000	0.000	0.002	0.004	0.006
Achnanthidium minutissimum	ACHMINUT	0.006	0.011	0.067	0.044	0.007	0.011	0.002	0.010	0.004
Cocconeis placentula var. lineata	COCPLALI	0.002	0.000	0.000	0.008	0.000	0.000	0.000	0.004	0.000
Tabellaria flocculosa	TABFLOCC	0.000	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella michiganiana	CYCMICHI	0.000	0.051	0.109	0.008	0.020	0.011	0.011	0.018	0.013
Brachysira neoexilis	BRANEOEX	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Encyonopsis cesatii	ENPCESAT	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.004	0.011
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira elliptica GLEI (prov. ID)	SRAELLIP	0.000	0.000	0.047	0.000	0.000	0.000	0.000	0.006	0.000
Synedra delicatissima	SYNDELIC	0.004	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Stephanodiscus minutulus	SUSMINUS	0.014	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Denticula kuetzingii	DENKEUTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.000	0.000
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonopsis microcephala	ENPMICRO	0.000	0.026	0.078	0.004	0.005	0.000	0.000	0.006	0.015
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium linearis	ROSLINEA	0.002	0.015	0.025	0.012	0.000	0.004	0.000	0.004	0.004
Staurosirella pinnata var. intercedens	SLLPININ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia faba	EUNFABA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Stephanodiscus parvus	SUSPARVU	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora cf. blackfordensis (prov. ID)	SELBLCKF	0.000	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.006	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia perminuta	NITPERMI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pinnularia interrupta	PININTEP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos invisitatus	CSPINVIS	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.002	0.000	0.015	0.027	0.055	0.000
Navicula minima	NAVMINIM	0.000	0.002	0.013	0.000	0.000	0.000	0.051	0.012	0.000
Nupela cf schoemaniana (prov. ID)	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.006	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina var. mesolepta	FRACAPME	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
Diploneis modica	DIPMODCA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula cryptocephala	NAVCRYCP	0.000	0.000	0.000	0.002	0.000	0.002	0.000	0.000	0.000
Stauroforma exiguiformis	STFEXIGF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia gracilis	NITGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Navicula radiosa	NAVRADIO	0.000	0.002	0.004	0.004	0.000	0.000	0.000	0.002	0.002
Encyonopsis subminuta	ENPSUBMI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Amphora perpusilla	AMPPERPU	0.000	0.000	0.000	0.046	0.000	0.000	0.000	0.000	0.000
Frustulia rhomboides	FRURHOMB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puncticulata lemanica	CYCBODLE	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Navicula globosa	NAVGLOBO	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.004	0.000
Karayevia clevei	KARCLEVE	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis var. oregona	FRACROOR	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus niagarae	SUSNIAGA	0.016	0.000	0.000	0.000	0.039	0.000	0.000	0.000	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula submuralis	NAVSUBMU	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira perglabra?	AULPERGL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora laevissima	SELLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
Fragilaria nanana	FRANANAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora subcostulata	AMPSUBCO	0.012	0.000	0.000	0.012	0.000	0.017	0.018	0.008	0.000
Aulacoseira laevissima	AULLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella pseudostelligera	CYCPSEUD	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brachysira vitrea	BRAVITRE	0.000	0.009	0.033	0.000	0.000	0.002	0.000	0.012	0.021
Nitzschia amphibia	NITAMPHI	0.000	0.000	0.009	0.000	0.000	0.000	0.011	0.000	0.000
Fragilaria capucina	FRACAPUC	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Amphora pediculus	AMPPEDIC	0.010	0.000	0.000	0.000	0.000	0.002	0.024	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Achnanthes conspicua	ACECONSP	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.002	0.000
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.000	0.000	0.028	0.011	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium pusillum	ROSPUSIL	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia pectinalis	EUNPECTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula mediocris	NAVMEDCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Psammothidium marginulatum	PSAMARGI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra filiformis	SYNFILIF	0.004	0.011	0.027	0.004	0.000	0.000	0.000	0.000	0.000
Achnanthidium exiguum	ACHEXIGU	0.000	0.004	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Navicula rhynchocephala	NAVRHYNC	0.000	0.000	0.000	0.000	0.000	0.002	0.016	0.000	0.000
Sellaphora disjuncta	SELDISJU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora libyca	AMPLIBYC	0.000	0.000	0.000	0.002	0.000	0.009	0.024	0.000	0.002
Navicula verecunda	NAVVEREC	0.000	0.020	0.000	0.002	0.000	0.000	0.000	0.024	0.000
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora vitabunda	SELVITAB	0.000	0.004	0.000	0.000	0.004	0.002	0.000	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia sublinearis	NITSUBLI	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.008
Nitzschia palea	NITPALEA	0.002	0.002	0.016	0.000	0.002	0.004	0.002	0.000	0.000
Fragilaria vaucheriae	FRAVAUCH	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.004
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula leptostriata	NAVLEPTO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. subsalina	SRACONSU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Tabellaria flocculosa Strain III (prov. ID)	TABFLOC3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthes saccula	PSASACCU	0.000	0.000	0.020	0.004	0.000	0.000	0.000	0.000	0.000
Geissleria decussis	GEIDECUS	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.000
Sellaphora seminulum	SELSEMIN	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.004	0.000
Planothidium lanceolatum	PLALANCE	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora pupula	SELPUPUL	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.008
Cyclotella seratula	CYCSERAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra filiformis var. exilis	SYNFILEX	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Synedra radians	SYNRADIA	0.000	0.018	0.011	0.004	0.002	0.000	0.000	0.004	0.000
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria fenestrata	TABFENES	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema neogracile	ENCNEOG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia fonticola	NITFONTI	0.014	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Psammothidium abundans v. rosenstockii	PSAABURO	0.000	0.007	0.000	0.015	0.002	0.009	0.011	0.002	0.006
Eucocconeis flexella	EUCFLEXE	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.006
Reimeria sinuata	REISINUA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SC11-SLSHLL
(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SC11***	***SLBASS***	***SLFLOR***	***SLLOON***	***SLMANT***	***SLNBAR***	***SLOTTR***	***SLROND***	***SLSHLL***
Gomphonema angustatum	GOMANGUS	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.013
Navicula utermoehlii	CAVUTERM	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.010	0.000
Eunotia incisa	EUNINCIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora ovalis	AMPOVALI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana martyi	MARMARTY	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Eunotia arcus	EUNARCUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia bacillum	NITBACIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora capitata	SELPUPCA	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Asterionella formosa	ASTFORMO	0.000	0.277	0.660	0.093	0.272	0.178	0.013	0.106	0.097
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens	SRACONST	0.186	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.000	0.026	0.000	0.027	0.024	0.000	0.000	0.000	0.418
Denticula tenuis var. crassula	DENTENCR	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella comensis	CYCCOMEN	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Cyclotella ocellata	CYCOCELL	0.017	0.000	0.000	0.000	0.128	0.000	0.000	0.000	0.000
Discostella stelligera	CYCSTELL	0.002	0.000	0.004	0.169	0.327	0.086	0.196	0.030	0.157
Navicula cryptotenella	NAVCRYPT	0.025	0.000	0.004	0.000	0.002	0.002	0.000	0.000	0.000
Aulacoseira subarctica	AULSUBAR	0.000	0.031	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. venter	SRACONVE	0.046	0.037	0.013	0.065	0.008	0.123	0.196	0.074	0.002
Aulacoseira ambigua	AULAMBIG	0.000	0.033	0.025	0.181	0.000	0.056	0.000	0.064	0.000
Staurosirella pinnata	SLLPINNA	0.073	0.009	0.000	0.004	0.002	0.016	0.000	0.047	0.000
Aulacoseira granulata	AULGRANU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira tenella	AULTENEL	0.000	0.094	0.000	0.156	0.000	0.000	0.000	0.055	0.116
Cyclotella meneghiniana	CYCMENEG	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Pseudostaurosira microstriata	PRAMICRO	0.000	0.000	0.013	0.000	0.000	0.000	0.013	0.076	0.000
Synedra tenera	FRATENER	0.000	0.000	0.018	0.000	0.000	0.000	0.013	0.000	0.000
Aulacoseira italica	AULITALI	0.000	0.000	0.000	0.000	0.012	0.021	0.000	0.000	0.000
Eunotia zazuminensis	EUNZASUM	0.000	0.216	0.000	0.008	0.000	0.000	0.000	0.000	0.021
Fragilaria crotonensis	FRACROTO	0.008	0.000	0.000	0.002	0.006	0.007	0.000	0.000	0.000
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.002	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.002

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Pseudostaurosira brevistriata	PRABREVI	0.173	0.009	0.000	0.008	0.000	0.035	0.000	0.023	0.000
Puncticulata bodanica	CYCBODAN	0.000	0.000	0.007	0.000	0.004	0.000	0.004	0.000	0.000
Achnanthidium minutissimum	ACHMINUT	0.015	0.013	0.051	0.025	0.008	0.021	0.053	0.019	0.012
Cocconeis placentula var. lineata	COCPLALI	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa	TABFLOCC	0.000	0.000	0.002	0.000	0.000	0.109	0.011	0.047	0.000
Cyclotella michiganiana	CYCMICHI	0.019	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000
Brachysira neoexilis	BRANEOEX	0.000	0.000	0.004	0.002	0.000	0.002	0.019	0.000	0.000
Encyonopsis cesatii	ENPCESAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira elliptica GLEI (prov. ID)	SRAELLIP	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.000	0.000
Synedra delicatissima	SYNDELIC	0.000	0.004	0.000	0.000	0.002	0.000	0.000	0.000	0.002
Stephanodiscus minutulus	SUSMINUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Denticula kuetzingii	DENKEUTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonopsis microcephala	ENPMICRO	0.000	0.000	0.000	0.004	0.000	0.005	0.000	0.000	0.004
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium linearis	ROSLINEA	0.050	0.002	0.009	0.000	0.012	0.000	0.017	0.008	0.004
Staurosirella pinnata var. intercedens	SLLPININ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia faba	EUNFABA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Stephanodiscus parvus	SUSPARVU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora cf. blackfordensis	SELBLCKF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000
Nitzschia perminuta	NITPERMI	0.000	0.000	0.011	0.000	0.000	0.000	0.017	0.013	0.000
Pinnularia interrupta	PININTEP	0.000	0.002	0.000	0.000	0.000	0.000	0.059	0.028	0.000
Cyclostephanos invisitatus	CSPINVIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula minima	NAVMINIM	0.031	0.000	0.000	0.000	0.000	0.005	0.008	0.000	0.000
Nupela cf schoemaniana (prov. ID)	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina var. mesolepta	FRACAPME	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diploneis modica	DIPMODCA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula cryptocephala	NAVCRYCP	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stauroforma exiguiformis	STFEXIGF	0.000	0.002	0.000	0.002	0.000	0.000	0.002	0.002	0.000
Nitzschia gracilis	NITGRACI	0.000	0.000	0.016	0.000	0.000	0.009	0.013	0.004	0.000
Navicula radiosa	NAVRADIO	0.006	0.000	0.000	0.013	0.006	0.005	0.000	0.000	0.004
Encyonopsis subminuta	ENPSUBMI	0.000	0.000	0.007	0.000	0.000	0.000	0.004	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Amphora perpusilla	AMPPERPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Frustulia rhomboides	FRURHOMB	0.000	0.002	0.000	0.004	0.002	0.000	0.000	0.000	0.002
Puncticulata lemanica	CYCBODLE	0.000	0.000	0.027	0.027	0.008	0.035	0.002	0.032	0.037
Navicula globosa	NAVGLOBO	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karayevia clevei	KARCLEVE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis var. oregona	FRACROOR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus niagarae	SUSNIAGA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula submuralis	NAVSUBMU	0.000	0.000	0.000	0.002	0.000	0.002	0.023	0.002	0.000
Aulacoseira perglabra? (prov. ID)	AULPERGL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora laevissima	SELLAEVI	0.000	0.000	0.000	0.000	0.000	0.002	0.013	0.000	0.000
Fragilaria nanana	FRANANAN	0.000	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000
Amphora subcostulata	AMPSUBCO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira laevissima	AULLAEVI	0.000	0.004	0.000	0.000	0.000	0.000	0.002	0.034	0.000
Discostella pseudostelligera	CYCPSEUD	0.000	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.000	0.009	0.000	0.002	0.000	0.000	0.000	0.000	0.025
Brachysira vitrea	BRAVITRE	0.002	0.000	0.000	0.004	0.004	0.007	0.000	0.000	0.004
Nitzschia amphibia	NITAMPHI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina	FRACAPUC	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Amphora pediculus	AMPPEDIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthes conspicua	ACECONSP	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Rossithidium pusillum	ROSPUSIL	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.002	0.000
Eunotia pectinalis	EUNPECTI	0.000	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula mediocris	NAVMEDCR	0.000	0.000	0.000	0.000	0.000	0.005	0.004	0.002	0.000
Psammothidium marginulatum	PSAMARGI	0.000	0.000	0.000	0.000	0.002	0.012	0.000	0.000	0.000
Synedra filiformis	SYNFILIF	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Achnanthidium exiguum	ACHEXIGU	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula rhynchocephala	NAVRHYNC	0.004	0.000	0.000	0.002	0.000	0.007	0.000	0.004	0.000
Sellaphora disjuncta	SELDISJU	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.025	0.000
Amphora libyca	AMPLIBYC	0.006	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Navicula verecunda	NAVVEREC	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000
Sellaphora vitabunda	SELVITAB	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia sublinearis	NITSUBLI	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Nitzschia palea	NITPALEA	0.004	0.002	0.000	0.002	0.008	0.005	0.000	0.004	0.004
Fragilaria vaucheriae	FRAVAUCH	0.002	0.000	0.000	0.000	0.000	0.016	0.000	0.002	0.000
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula leptostriata	NAVLEPTO	0.000	0.000	0.011	0.002	0.000	0.000	0.011	0.006	0.000
Staurosira construens var. subsalina	SRACONSU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain III (prov. ID)	TABFLOC3	0.000	0.004	0.000	0.002	0.000	0.000	0.000	0.000	0.002

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Achnanthes saccula	PSASACCU	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Geissleria decussis	GEIDECUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.006	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora seminulum	SELSEMIN	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.011	0.000
Planothidium lanceolatum	PLALANCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora pupula	SELPUPUL	0.008	0.002	0.000	0.006	0.000	0.002	0.000	0.002	0.000
Cyclotella seratula	CYCSERAT	0.000	0.006	0.000	0.000	0.002	0.009	0.000	0.013	0.000
Synedra filiformis var. exilis	SYNFILEX	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Synedra radians	SYNRADIA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.004
Tabellaria fenestrata	TABFENES	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema neogracile	ENCNEOG	0.000	0.000	0.002	0.002	0.000	0.000	0.008	0.002	0.002
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.002	0.000
Nitzschia fonticola	NITFONTI	0.000	0.000	0.000	0.000	0.000	0.005	0.002	0.000	0.000
Psammothidium abundans v. rosenstockii	PSAABURO	0.008	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Eucocconeis flexella	EUCFLEXE	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Reimeria sinuata	REISINUA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema angustatum	GOMANGUS	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

SLTUCK-VOLOCA

(See Table 1 for six character lake codes.)

		Lake Code								
Taxon	**Taxon Code**	***SLTUCK***	***VOAGNS***	***VOBEAS***	***VOBRWN***	***VOCRUS***	***VOEK***	***VOFSHM***	***VOJORG***	***VOLOCA***
Navicula utermoehlii	CAVUTERM	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia incisa	EUNINCIS	0.000	0.000	0.007	0.002	0.000	0.002	0.000	0.000	0.000
Amphora ovalis	AMPOVALI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana martyi	MARMARTY	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia arcus	EUNARCUS	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Nitzschia bacillum	NITBACIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora capitata	SELPUPCA	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Asterionella formosa	ASTFORMO	0.438	0.126	0.039	0.088	0.176	0.088	0.444	0.209
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens	SRACONST	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.092	0.002	0.108	0.020	0.055	0.086	0.025	0.081
Denticula tenuis var. crassula	DENTENCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella comensis	CYCCOMEN	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Cyclotella ocellata	CYCOCELL	0.000	0.069	0.000	0.356	0.013	0.000	0.000	0.000
Discostella stelligera	CYCSTELL	0.080	0.154	0.148	0.275	0.082	0.086	0.014	0.107
Navicula cryptotenella	NAVCRYPT	0.000	0.019	0.000	0.000	0.006	0.002	0.000	0.000
Aulacoseira subarctica	AULSUBAR	0.002	0.000	0.004	0.031	0.000	0.021	0.036	0.017
Staurosira construens var. venter	SRACONVE	0.000	0.015	0.080	0.002	0.008	0.036	0.005	0.021
Aulacoseira ambigua	AULAMBIG	0.000	0.000	0.132	0.000	0.000	0.113	0.062	0.025
Staurosirella pinnata	SLLPINNA	0.000	0.004	0.000	0.002	0.019	0.006	0.016	0.000
Aulacoseira granulata	AULGRANU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira tenella	AULTENEL	0.005	0.000	0.087	0.000	0.000	0.231	0.000	0.180
Cyclotella meneghiniana	CYCMENEG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudostaurosira microstriata	PRAMICRO	0.025	0.006	0.000	0.000	0.000	0.008	0.000	0.008
Synedra tenera	FRATENER	0.007	0.000	0.000	0.000	0.002	0.002	0.005	0.002
Aulacoseira italica	AULITALI	0.000	0.039	0.000	0.000	0.105	0.000	0.000	0.000
Eunotia zazuminensis	EUNZASUM	0.000	0.000	0.165	0.000	0.000	0.075	0.000	0.124
Fragilaria crotonensis	FRACROTO	0.000	0.000	0.000	0.000	0.038	0.021	0.103	0.000
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Pseudostaurosira brevistriata	PRABREVI	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000
Puncticulata bodanica	CYCBODAN	0.000	0.000	0.013	0.029	0.011	0.002	0.000	0.000
Achnanthidium minutissimum	ACHMINUT	0.073	0.041	0.037	0.029	0.017	0.017	0.018	0.045
Cocconeis placentula var. lineata	COCPLALI	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Tabellaria flocculosa	TABFLOCC	0.032	0.039	0.000	0.000	0.000	0.002	0.009	0.004
Cyclotella michiganiana	CYCMICHI	0.000	0.048	0.000	0.035	0.025	0.000	0.007	0.000
Brachysira neoexilis	BRANEOEX	0.021	0.004	0.004	0.000	0.006	0.002	0.005	0.002
Encyonopsis cesatii	ENPCESAT	0.000	0.004	0.000	0.002	0.000	0.000	0.000	0.000
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira elliptica GLEI (prov. ID)	SRAELLIP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra delicatissima	SYNDELIC	0.000	0.089	0.000	0.011	0.004	0.000	0.000	0.000
Stephanodiscus minutulus	SUSMINUS	0.000	0.000	0.000	0.004	0.084	0.000	0.027	0.000
Denticula kuetzingii	DENKEUTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonopsis microcephala	ENPMICRO	0.000	0.000	0.002	0.007	0.000	0.000	0.000	0.000
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium linearis	ROSLINEA	0.000	0.019	0.004	0.007	0.000	0.000	0.005	0.023
Staurosirella pinnata var. intercedens	SLLPININ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia faba	EUNFABA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Stephanodiscus parvus	SUSPARVU	0.000	0.000	0.000	0.000	0.067	0.000	0.016	0.000
Sellaphora cf. blackfordensis (prov. ID)	SELBLCKF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia perminuta	NITPERMI	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pinnularia interrupta	PININTEP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Cyclostephanos invisitatus	CSPINVIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula minima	NAVMINIM	0.000	0.002	0.000	0.000	0.008	0.000	0.002	0.008
Nupela cf schoemaniana	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina var. mesolepta	FRACAPME	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diploneis modica	DIPMODCA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.000	0.000	0.000	0.000	0.015	0.000	0.034	0.000
Navicula cryptocephala	NAVCRYCP	0.000	0.004	0.000	0.002	0.000	0.000	0.002	0.000
Stauroforma exiguiformis	STFEXIGF	0.002	0.000	0.030	0.000	0.000	0.002	0.000	0.000
Nitzschia gracilis	NITGRACI	0.009	0.000	0.002	0.000	0.000	0.002	0.005	0.000
Navicula radiosa	NAVRADIO	0.000	0.002	0.000	0.004	0.011	0.000	0.005	0.002
Encyonopsis subminuta	ENPSUBMI	0.005	0.019	0.000	0.000	0.000	0.000	0.002	0.002

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Amphora perpusilla	AMPPERPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Frustulia rhomboides	FRURHOMB	0.002	0.000	0.004	0.002	0.000	0.000	0.000	0.004
Puncticulata lemanica	CYCBODLE	0.044	0.000	0.000	0.000	0.017	0.010	0.018	0.012
Navicula globosa	NAVGLOBO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karayevia clevei	KARCLEVE	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000
Fragilaria crotonensis var. oregona	FRACROOR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus niagarae	SUSNIAGA	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula submuralis	NAVSUBMU	0.000	0.002	0.000	0.000	0.013	0.004	0.002	0.000
Aulacoseira perglabra?	AULPERGL	0.002	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora laevissima	SELLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Fragilaria nanana	FRANANAN	0.000	0.000	0.004	0.024	0.002	0.000	0.000	0.000
Amphora subcostulata	AMPSUBCO	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira laevissima	AULLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella pseudostelligera	CYCPSEUD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.018	0.000	0.002	0.000	0.034	0.004	0.005	0.000
Brachysira vitrea	BRAVITRE	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Nitzschia amphibia	NITAMPHI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina	FRACAPUC	0.000	0.000	0.000	0.000	0.008	0.000	0.002	0.000
Amphora pediculus	AMPPEDIC	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Achnanthes conspicua	ACECONSP	0.000	0.000	0.000	0.004	0.006	0.000	0.000	0.000
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Rossithidium pusillum	ROSPUSIL	0.009	0.013	0.000	0.000	0.000	0.004	0.009	0.012
Eunotia pectinalis	EUNPECTI	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000
Navicula mediocris	NAVMEDCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Psammothidium marginulatum	PSAMARGI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
Synedra filiformis	SYNFILIF	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthidium exiguum	ACHEXIGU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula rhynchocephala	NAVRHYNC	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Sellaphora disjuncta	SELDISJU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora libyca	AMPLIBYC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula verecunda	NAVVEREC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Sellaphora vitabunda	SELVITAB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia sublinearis	NITSUBLI	0.000	0.011	0.000	0.004	0.006	0.000	0.000	0.000
Nitzschia palea	NITPALEA	0.000	0.015	0.002	0.004	0.004	0.004	0.002	0.000
Fragilaria vaucheriae	FRAVAUCH	0.000	0.000	0.000	0.000	0.000	0.008	0.002	0.000
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula leptostriata	NAVLEPTO	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Staurosira construens var. subsalina	SRACONSU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthes saccula	PSASACCU	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004
Geissleria decussis	GEIDECUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Sellaphora seminulum	SELSEMIN	0.000	0.004	0.007	0.000	0.000	0.004	0.000	0.000
Planothidium lanceolatum	PLALANCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora pupula	SELPUPUL	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Cyclotella seratula	CYCSERAT	0.002	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Synedra filiformis var. exilis	SYNFILEX	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra radians	SYNRADIA	0.000	0.004	0.000	0.004	0.002	0.000	0.000	0.000
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria fenestrata	TABFENES	0.002	0.002	0.000	0.000	0.000	0.017	0.000	0.000
Encyonema neogracile	ENCNEOG	0.009	0.002	0.000	0.002	0.000	0.002	0.000	0.008
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.000	0.000	0.019	0.002	0.000	0.000
Nitzschia fonticola	NITFONTI	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Psammothidium abundans v. rosenstockii	PSAABURO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eucocconeis flexella	EUCFLEXE	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Reimeria sinuata	REISINUA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOLOIT-VOOSLO

(See Table 1 for six character lake codes.)

		Lake Code							
Taxon	**Taxon Code**	***VOLOIT***	***VOLTR2***	***VOLTSH***	***VOLTTR***	***VOMUKO***	***VONET***	***VOOLRY***	***VOOSLO***
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema angustatum	GOMANGUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula utermoehlii	CAVUTERM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia incisa	EUNINCIS	0.000	0.000	0.002	0.000	0.000	0.004	0.000	0.004
Amphora ovalis	AMPOVALI	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Martyana martyi	MARMARTY	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia arcus	EUNARCUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia bacillum	NITBACIL	0.009	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora capitata	SELPUPCA	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOPEAR-VOWRCL

(See Table 1 for six character lake codes.)

		Lake Code						
Taxon	**Taxon Code**	***VOPEAR***	***VOQUIL***	***VOQURT***	***VORYAN***	***VOSHOE***	***VOTOTH***	***VOWRCL***
Asterionella formosa	ASTFORMO	0.140	0.354	0.114	0.034	0.148	0.263	0.128
Cyclotella sp. mich-like (prov. ID)	CYCSPMCH	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira construens	SRACONST	0.000	0.000	0.004	0.000	0.000	0.000	0.008
Tabellaria flocculosa Strain IIIp (prov. ID)	TABFLO3P	0.099	0.082	0.024	0.007	0.045	0.163	0.202
Denticula tenuis var. crassula	DENTENCR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella comensis	CYCCOMEN	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella ocellata	CYCOCELL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discostella stelligera	CYCSTELL	0.087	0.057	0.000	0.005	0.036	0.163	0.188
Navicula cryptotenella	NAVCRYPT	0.002	0.000	0.000	0.000	0.000	0.002	0.000
Aulacoseira subarctica	AULSUBAR	0.000	0.000	0.006	0.000	0.000	0.000	0.000
Staurosira construens var. venter	SRACONVE	0.016	0.016	0.090	0.121	0.002	0.021	0.000
Aulacoseira ambigua	AULAMBIG	0.097	0.008	0.004	0.062	0.224	0.019	0.028
Staurosirella pinnata	SLLPINNA	0.024	0.004	0.118	0.064	0.000	0.002	0.000
Aulacoseira granulata	AULGRANU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira tenella	AULTENEL	0.103	0.025	0.258	0.039	0.103	0.067	0.119
Cyclotella meneghiniana	CYCMENEG	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudostaurosira microstriata	PRAMICRO	0.000	0.000	0.009	0.000	0.000	0.010	0.016
Synedra tenera	FRATENER	0.014	0.000	0.002	0.000	0.000	0.010	0.004
Aulacoseira italica	AULITALI	0.002	0.004	0.000	0.011	0.056	0.000	0.000
Eunotia zazuminensis	EUNZASUM	0.093	0.000	0.034	0.000	0.177	0.000	0.014
Fragilaria crotonensis	FRACROTO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Neidium ampliatum KLB (prov. ID)	NEIAMPLI	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Pseudostaurosira brevistriata	PRABREVI	0.000	0.000	0.000	0.048	0.013	0.004	0.000
Puncticulata bodanica	CYCBODAN	0.010	0.018	0.000	0.000	0.000	0.000	0.000
Achnanthidium minutissimum	ACHMINUT	0.020	0.055	0.028	0.025	0.009	0.027	0.034
Cocconeis placentula var. lineata	COCPLALI	0.008	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOPEAR-VOWRCL

(See Table 1 for six character lake codes.)

		Lake Code						
Taxon	**Taxon Code**	***VOPEAR***	***VOQUIL***	***VOQURT***	***VORYAN***	***VOSHOE***	***VOTOTH***	***VOWRCL***
Tabellaria flocculosa	TABFLOCC	0.000	0.000	0.002	0.000	0.000	0.006	0.020
Cyclotella michiganiana	CYCMICHI	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brachysira neoexilis	BRANEOEX	0.000	0.021	0.000	0.014	0.000	0.002	0.006
Encyonopsis cesatii	ENPCESAT	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #2 (rough center) (prov. ID)	CYCS2NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella atomus	CYCATOMU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosira elliptica GLEI (prov. ID)	SRAELLIP	0.000	0.000	0.000	0.000	0.000	0.004	0.000
Synedra delicatissima	SYNDELIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus minutulus	SUSMINUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Denticula kuetzingii	DENKEUTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella meneghiniana fo. plana	CYCMENPL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Planothidium lanceolatum var. rostratum	PLAROSTR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Encyonopsis microcephala	ENPMICRO	0.000	0.006	0.000	0.000	0.000	0.000	0.000
Staurosira construens var. pumila	SRACONPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula capitatoradiata	NAVCAPRA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium linearis	ROSLINEA	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Staurosirella pinnata var. intercedens	SLLPININ	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia faba	EUNFABA	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Stephanodiscus parvus	SUSPARVU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora cf. blackfordensis (prov. ID)	SELBLCKF	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella lapponica	SLLLAPPO	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Staurosirella pinnata var. lancettula	SLLPINLA	0.000	0.000	0.052	0.009	0.013	0.000	0.000
Nitzschia perminuta	NITPERMI	0.000	0.000	0.004	0.000	0.000	0.000	0.006
Pinnularia interrupta	PININTEP	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos invisitatus	CSPINVIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclostephanos tholiformis	CSPTHOLI	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOPEAR-VOWRCL

(See Table 1 for six character lake codes.)

		Lake Code						
Taxon	**Taxon Code**	***VOPEAR***	***VOQUIL***	***VOQURT***	***VORYAN***	***VOSHOE***	***VOTOTH***	***VOWRCL***
Cyclotella distinguenda	CYCDISTI	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula minima	NAVMINIM	0.004	0.000	0.004	0.002	0.000	0.000	0.000
Nupela cf schoemaniana	NUPCSCHO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Semiorbis hemicyclus	SEMHEMIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cocconeis neothumensis	COCNEOTH	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina var. mesolepta	FRACAPME	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella sp. #3 (plain center) (prov. ID)	CYCS3NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diploneis modica	DIPMODCA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus hantzschii f. hantzschii	SUSHANTZ	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula cryptocephala	NAVCRYCP	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Stauroforma exiguiformis	STFEXIGF	0.000	0.000	0.015	0.132	0.000	0.000	0.004
Nitzschia gracilis	NITGRACI	0.000	0.000	0.002	0.000	0.000	0.006	0.004
Navicula radiosa	NAVRADIO	0.000	0.000	0.006	0.000	0.000	0.000	0.004
Encyonopsis subminuta	ENPSUBMI	0.000	0.000	0.000	0.000	0.000	0.006	0.006
Amphora perpusilla	AMPPERPU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Frustulia rhomboides	FRURHOMB	0.008	0.006	0.004	0.000	0.011	0.000	0.006
Puncticulata lemanica	CYCBODLE	0.010	0.000	0.000	0.002	0.002	0.044	0.038
Navicula globosa	NAVGLOBO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karayevia clevei	KARCLEVE	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria crotonensis var. oregona	FRACROOR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stephanodiscus niagarae	SUSNIAGA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira granulata var. angustissima	AULGRAAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula submuralis	NAVSUBMU	0.008	0.000	0.006	0.000	0.000	0.002	0.000
Aulacoseira perglabra?	AULPERGL	0.000	0.000	0.000	0.021	0.000	0.000	0.000
Cyclotella sp. coarse striae, plain center (prov. ID)	CYCCPCNA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora laevissima	SELLAEVI	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOPEAR-VOWRCL

(See Table 1 for six character lake codes.)

		Lake Code						
Taxon	**Taxon Code**	***VOPEAR***	***VOQUIL***	***VOQURT***	***VORYAN***	***VOSHOE***	***VOTOTH***	***VOWRCL***
Fragilaria nanana	FRANANAN	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Amphora subcostulata	AMPSUBCO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aulacoseira laevissima	AULLAEVI	0.000	0.000	0.011	0.000	0.000	0.000	0.000
Discostella pseudostelligera	CYCPSEUD	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa var. linearis	TABFLOLI	0.014	0.012	0.000	0.002	0.000	0.006	0.012
Brachysira vitrea	BRAVITRE	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia amphibia	NITAMPHI	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fragilaria capucina	FRACAPUC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphora pediculus	AMPPEDIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthes conspicua	ACECONSP	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclotella delicatula	CYCDELIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema olivaceum	GOMOLIVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rossithidium pusillum	ROSPUSIL	0.000	0.000	0.002	0.000	0.000	0.004	0.004
Eunotia pectinalis	EUNPECTI	0.000	0.021	0.002	0.000	0.004	0.000	0.002
Navicula mediocris	NAVMEDCR	0.000	0.000	0.000	0.000	0.009	0.000	0.000
Psammothidium marginulatum	PSAMARGI	0.000	0.000	0.002	0.000	0.000	0.004	0.006
Synedra filiformis	SYNFILIF	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Achnanthidium exiguum	ACHEXIGU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula rhynchocephala	NAVRHYNC	0.002	0.000	0.000	0.002	0.000	0.000	0.000
Sellaphora disjuncta	SELDISJU	0.002	0.000	0.000	0.000	0.000	0.002	0.000
Amphora libyca	AMPLIBYC	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Navicula verecunda	NAVVEREC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp linear GLEI (prov. ID)	MARSPLNA	0.000	0.000	0.000	0.000	0.002	0.000	0.000
Sellaphora vitabunda	SELVITAB	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Geissleria cummerowi	GEICUMME	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nitzschia sublinearis	NITSUBLI	0.002	0.000	0.000	0.000	0.000	0.002	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOPEAR-VOWRCL

(See Table 1 for six character lake codes.)

		Lake Code						
Taxon	**Taxon Code**	***VOPEAR***	***VOQUIL***	***VOQURT***	***VORYAN***	***VOSHOE***	***VOTOTH***	***VOWRCL***
Nitzschia palea	NITPALEA	0.002	0.002	0.000	0.005	0.002	0.008	0.004
Fragilaria vaucheriae	FRAVAUCH	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula seminulum var. intermedia	NAVSMINT	0.000	0.000	0.004	0.007	0.007	0.000	0.000
Navicula leptostriata	NAVLEPTO	0.002	0.006	0.000	0.021	0.011	0.000	0.002
Staurosira construens var. subsalina	SRACONSU	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain III (prov. ID)	TABFLOC3	0.008	0.002	0.000	0.000	0.020	0.000	0.000
Achnanthes saccula	PSASACCU	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Geissleria decussis	GEIDECUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana sp #1 GLEI (prov. ID)	MARS1GNA	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora seminulum	SELSEMIN	0.002	0.004	0.002	0.002	0.000	0.000	0.000
Planothidium lanceolatum	PLALANCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula sp. cf parsura (prov. ID)	NAVSCPRS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora pupula	SELPUPUL	0.000	0.000	0.000	0.005	0.002	0.002	0.000
Cyclotella seratula	CYCSERAT	0.000	0.000	0.011	0.018	0.000	0.002	0.000
Synedra filiformis var. exilis	SYNFILEX	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Synedra radians	SYNRADIA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tabellaria flocculosa Strain IV (prov. ID)	TABFLOC4	0.012	0.018	0.000	0.000	0.000	0.000	0.000
Tabellaria fenestrata	TABFENES	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Encyonema neogracile	ENCNEOG	0.000	0.004	0.002	0.000	0.002	0.006	0.000
Synedra subrhombica	SYNSUBRH	0.000	0.000	0.000	0.000	0.013	0.004	0.000
Nitzschia fonticola	NITFONTI	0.002	0.002	0.000	0.000	0.000	0.000	0.000
Psammothidium abundans v. rosenstockii	PSAABURO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eucocconeis flexella	EUCFLEXE	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Reimeria sinuata	REISINUA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rhoicosphenia curvata	RHOCURVA	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1. Relative abundance of diatoms in surface sediment samples from 60 GLKN lakes. Data represent diatom taxa found at >1% in 2 or more samples or >5% in one sample (continued).

VOPEAR-VOWRCL

(See Table 1 for six character lake codes.)

		Lake Code						
Taxon	**Taxon Code**	***VOPEAR***	***VOQUIL***	***VOQURT***	***VORYAN***	***VOSHOE***	***VOTOTH***	***VOWRCL***
Encyonema gracile	ENCGRACI	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gomphonema angustatum	GOMANGUS	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navicula utermoehlii	CAVUTERM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia incisa	EUNINCIS	0.004	0.000	0.004	0.000	0.000	0.015	0.002
Amphora ovalis	AMPOVALI	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Martyana martyi	MARMARTY	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eunotia arcus	EUNARCUS	0.000	0.012	0.000	0.000	0.000	0.000	0.000
Nitzschia bacillum	NITBACIL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sellaphora capitata	SELPUPCA	0.000	0.000	0.000	0.007	0.000	0.000	0.000

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