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Historical Water Quality Trends in Georgian Bay Embayments

A Paleolimnological Study

Prepared for: Georgian Bay Forever
Job #: J120024

August, 2013

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August, 2013 HESL Job #: J120024

David Sweetnam
Georgian Bay Forever
Caledon, ON L7E 5T2

Dear Mr. Sweetnam:

Re: Historical Water Quality Trends in Georgian Bay Embayments – A Paleolimnological Study

We are pleased to submit this final report on historical water quality trends in Georgian Bay Embayments. The report includes the methods used for collecting and analyzing the sediments and presents the results and interpretations for the various analyzed indicators.

The main findings of our study are:

- Before European settlement, North Bay (TP 13 ug/L) and South Bay (TP 11 ug/L), were mesotrophic, based on fossil diatom algae analysis, while South Bay had naturally more anoxia than North Bay;
- With the onset of watershed deforestation in the 19th century, minor shifts in algae and midge larvae communities were observed;
- A moderate, more consistent change across sediment indicators, suggesting slight nutrient enrichment, was observed in the 1950s/1960s and is likely related to development in the watershed and the shoreline, with a stronger effect seen in South Bay than in North Bay;
- Significant shifts in algae and midge larvae assemblages to more littoral communities in the late 1960s and again after 1980 indicate increased availability of shallow water habitat, likely due to reduced water levels and increased water clarity;
- Overall, water quality in North and South Bays appears to be influenced by upstream influences (i.e., the Severn River for South Bay) and exchange with Georgian Bay (North Bay) as well as by local shoreline disturbance.
- The aquatic biota have responded as strongly to changes in habitat in the past ca. 30 years as to any water quality changes since pre-settlement times.

In closing, we thank you for the opportunity to assist Georgian Bay Forever with this interesting project.

Sincerely,
Hutchinson Environmental Sciences Ltd.

Dörte Köster

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Signatures

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Executive Summary

The Honey Harbour area of Georgian Bay is heavily used by cottagers and boaters and consequently there have been concerns raised about the impact of development and recreational use on water quality. For the last ca. 30 years, monitoring efforts have provided much insight into the current status and functioning of the Georgian Bay embayments. These data, however, were collected well after the development of shorelines with cottages and resorts and therefore it is currently unknown to what extent land use had affected water quality before monitoring started and what the relative importance of land use in any recent ecosystem changes may be. Recognizing the influence of multiple stressors on the aquatic ecosystem, management and stewardship by concerned stakeholders in Georgian Bay requires information on what aspects of change may be manageable locally (e.g., land use and stewardship) and what aspects are beyond immediate local control (e.g., climate change, water level changes and invading species).

Georgian Bay Forever has recognized that the lack of background data from the time period before European settlement and shoreline development represents a critical knowledge gap for evaluating current conditions and the recent observations in the inner bays of Georgian Bay. Hutchinson Environmental Sciences was retained to design and complete a study on historical nutrient status, deep-water oxygen conditions, aquatic plant abundance and algae community composition from pre-settlement until current times by the means of paleolimnological techniques, i.e., the analysis of bottom sediments.

The sites selected for this study were North Bay and South Bay, two embayments north-east of the community of Honey Harbour, in Georgian Bay Township, District of Muskoka. These bays have limited water exchange with the open waters of Georgian Bay, as they are protected by numerous islands that make up the eastern Georgian Bay coastline. North Bay is the deeper bay of the two, with a small Canadian Shield watershed and occasional mixing with the Georgian Bay open waters. South Bay receives water from a tributary, a branch of the Severn River, draining in part off-shield land of southern Ontario. This bay has no detectable exchange with the open Georgian Bay waters, due to the predominating water influx from the tributary.

Sediment cores were collected at deep locations in North and South Bay to represent open water conditions and in a shallow, sheltered bay of North Bay to represent near-shore conditions. Sediment ages were determined by lead-210 radioisotope analysis. Fossil midge (chironomid) larvae, diatom algae, algal pigments and organic matter content were analyzed in the deep water cores and plant macrofossils in the near-shore core. Animal and plant community composition was interpreted in terms of habitat and nutrient preferences. Pigment concentrations and organic matter content were used to evaluate past primary productivity and pigment composition to describe algal assemblages. Deep-water oxygen conditions were reconstructed using a chironomid inference model and surface water total phosphorus concentrations were reconstructed using a diatom inference model. The patterns in sediment indictors were compared to known historical patterns of land use as well as climate and water level data from the area.

The main conclusions of this study were as follows:

- Before European settlement, North Bay (TP 13 ug/L) and South Bay (TP 11 ug/L) were mesotrophic, while South Bay had naturally more anoxia than North Bay;
- With the onset of watershed deforestation in the 19th century, minor shifts in algae and midge larvae communities were observed in both bays, consistent with slight nutrient enrichment from increased overland runoff;
- The largest changes in diatom algae and midge larvae communities as well as overall algae production were observed in the 1950s/1960s and were indicative of additional but slight nutrient enrichment. These were likely related to cottage development and watershed alterations, with a stronger effect seen in South Bay than in North Bay;
- Significant shifts in algae and midge larvae assemblages to more littoral communities in the late 1960s and again after 1980 indicate increased availability of shallow water habitat, likely due to reduced water levels, increased water clarity and increased aquatic macrophyte abundance;
- A minor, but consistent diatom algae change after 1980 indicated increased water column stability, possibly related to climate warming, and coincided with the increased abundance of chrysophyte algae, a regionally reported phenomenon.
- The more pronounced nutrient enrichment of South Bay is likely due to the influence of the Severn River watershed and the more limited water exchange with the Georgian Bay open waters compared to North Bay in addition to shoreline development.
- Overall, water quality in North and South Bays appears to be influenced by upstream influences (i.e., the Severn River for South Bay) and exchange with Georgian Bay (North Bay) as well as by local shoreline disturbance.
- The aquatic biota have responded as strongly to changes in habitat in the past ca. 30 years as to any water quality changes since pre-settlement times.

The Georgian Bay embayment sediment study filled an important data gap by describing conditions predating the water quality monitoring programs that started in 1980. This places existing water quality measurements into context with the natural background conditions and historic changes. By matching observed patterns in the sediment cores with known historical land use activities, and by comparing the records of the two hydrologically different bays, we gained insight into the timing and causes of water quality changes. We also identified differing sensitivity to nutrient enrichment between the bays. These pieces of information put the currently collected monitoring data into a long-term perspective and help direct future monitoring and stewardship efforts.

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1. Introduction

The Honey Harbour area of Georgian Bay is made up of many small embayments that have variable morphometry and limited water exchange with the open waters of Georgian Bay. This area is heavily used by cottagers and boaters and consequently there have been concerns raised about the impact of recreational use on water quality (Georgian Bay Forever 2013). Recent water quality studies conducted by the Severn Sound Environmental Association and by Georgian Bay Forever did not indicate substantial changes in water quality or trophic status indicators in the inner bays of Georgian Bay in the last circa 30 years (Hutchinson Environmental Sciences 2011). Other observations, such as small recent changes in Secchi depth and chlorophyll *a,* as well as the increase in chrysophyte algae and rooted aquatic plants were observed but may be regional phenomena, as similar observations have been made across many Ontario lakes. All these data were collected well after the development of shorelines with cottages and resorts and therefore it is currently unknown to what extent land use had affected water quality before monitoring started and what the role of land use in any recent ecosystem changes may be.

Some of the observed changes in water quality may be a response to regional processes or an external set of multiple stressors such as climate change, changing water levels and invading species, but localized changes such as nutrient enrichment or sedimentation cannot be ruled out with existing information. Management and stewardship of environmental changes by concerned stakeholders in Georgian Bay requires information on what aspects of change may be manageable locally (e.g., land use and stewardship) and what aspects are beyond immediate local control (e.g., climate change, water level changes and invading species).

Georgian Bay Forever has recognized that the lack of background data from the time period before European settlement and shoreline development represents a critical knowledge gap for evaluating current conditions and the recent observations in the inner bays of Georgian Bay. This report describes a study designed to obtain information on nutrient status, deep-water oxygen conditions, aquatic plant abundance and algae community composition from pre-settlement until current times by the means of paleolimnological techniques, i.e., the analysis of bottom sediments. This information will supplement that obtained by conventional monitoring over the past 20 years to describe a more complete history of water quality. Cross-referencing the timing and nature of changes inferred from the paleo record against known changes in land use, water level, climate and other potential causation factors will help to determine the most likely cause or causes of the observed changes.

2. History of the Study Area

Evidence of Aboriginal inhabitants of the area was found from as early as 7,000 years ago (EDA Collaborative Inc. and Planning Solutions 2011). The predominant traditional aboriginal land uses in this area were hunting and gathering, which would not have had any impact on water quality. In the early 18th century, the Ojibwa from the Great Lakes arrived in the area and in 1812 a reserve was established for them on Beausoleil Island, outside of the North and South Bay watersheds, where they practiced agriculture. Aboriginal agricultural use of the North and South Bay watersheds is unlikely due to the unfavourable soil conditions.

Europeans traveled the Georgian Bay coast first in the 1600s and 1700s for fur trading. By the 1800s, small villages had sprouted around the many fur trade posts. As the fur trade declined subsequently, settlers turned to the huge natural resources around them for trade instead. They branched out into fishing and lumber operations, spurring the need for railroads and shipyards to transport goods. Primitive lumber camps were established along most of the Bays' river corridors (Ketcheson, undated).

Beginning in the late 1840s the Ontario government gradually implemented a policy of northern expansion in Canada West. As part of this policy Muskoka was surveyed and made accessible during the next two decades (Muskoka, Parry Sound Genealogy Group 2013). In 1850 a treaty was signed between the Honorable B. Robinson and 36 chiefs of the Ojibway Nation ceding to the government the parcel of land northwest of Penetanguishene to Sault Saint Marie and eastward to the Ottawa River. Lumbermen and companies from Simcoe and York Counties moved into the area, especially after 1855 when the railroad was completed to Collingwood. Settlement was slow until the passing of the Free Grant and *Homestead Act* of 1868, which offered free land against the obligation to “clear and have under cultivation at least 15 acres” and several other requirements. Some of the lumbermen and transient sailors became farmers when free land was given in 1868 (Muskoka, Parry Sound Genealogy Group 2013). By 1881, the entire population of Muskoka had increased to 13,000. Between 1900 and 1910 the pines that were valued for shipbuilding, were depleted and the number of farmers decreased by 50% due to the poor land (Muskoka, Parry Sound Genealogy Group 2013). The population history of the immediate Honey Harbor area was not directly inferable from that source.

The first large influx of visitors to the area occurred at the start of the 20th century, when the Victoria House-Cottage Hotel was built on the Delawana Inn site and the Royal Muskoka Hotel was opened on Royal Island (EDA Collaborative Inc. and Planning Solutions 2011). In 1922, the Trent Severn Waterway was completed, which had been under construction for a number of years. To ensure the water depth required for ship travel along the route, numerous dams were erected, one of them on Baxter Lake, which is located upstream of South Bay.

Extensive cottage development on the shorelines of eastern Georgian Bay and in other Muskoka areas did not occur until the economy flourished again after the two world wars, around 1950.

3. Site Description

The sites selected for this study were North Bay and South Bay (Figure 1), two embayments north-east of the community of Honey Harbour, in Georgian Bay Township, District of Muskoka. These bays have limited water exchange with the open waters of Georgian Bay, as they are protected by numerous islands that make up the eastern Georgian Bay coastline. The shorelines of both bays are densely developed with cottages and multi-season residences, thanks to a well developed road network. Honey Harbour is the only Georgian Bay community that is not fully serviced by municipal sewers (EDA Collaborative Inc. and Planning Solutions 2011); therefore all residences are equipped with septic systems.

The main differences between North Bay and South Bay are their depth, the size and nature of their watersheds and the resulting flushing rates and exchange with the Georgian Bay open waters. North Bay is the deeper bay of the two, with a maximum depth of 22 m in the inner bay and of 20 m in the outer bay. The watershed has a size of approximately 9 km^2 and includes the typical surrounding forested Canadian

Shield. It has usually limited mixing with Georgian Bay open waters, but in very windy years, such as 2006, water mixing with the lower-nutrient and higher-conductivity Georgian Bay waters does occur and can result in large inter-annual differences in phosphorus concentrations in this bay (Schiefer et al. 2006).

South Bay receives water from a major tributary at its northeastern end. This tributary is a branch of the Severn River that flows through Gloucester Pool and Baxter Lake and then into South Bay (Schiefer et al. 2006), draining a local watershed area of 113 km^2. This tributary causes a naturally higher flushing rate of South Bay compared to North Bay[1] and introduces higher conductivity (harder) Severn River water. It also represents a barrier against exchange with the open waters of Georgian Bay and therefore is less susceptible to wind-driven mixing events, resulting in a more stable water quality in South Bay.

In North Bay, one sediment core was collected at an open, deep-water location of the outer bay at 15 m depth and one sediment core was collected in a small, sheltered, shallow bay (approx. 3 m depth) at the eastern end of the bay. In South Bay, one core was collected from a deep-water site, at 11 m depth.

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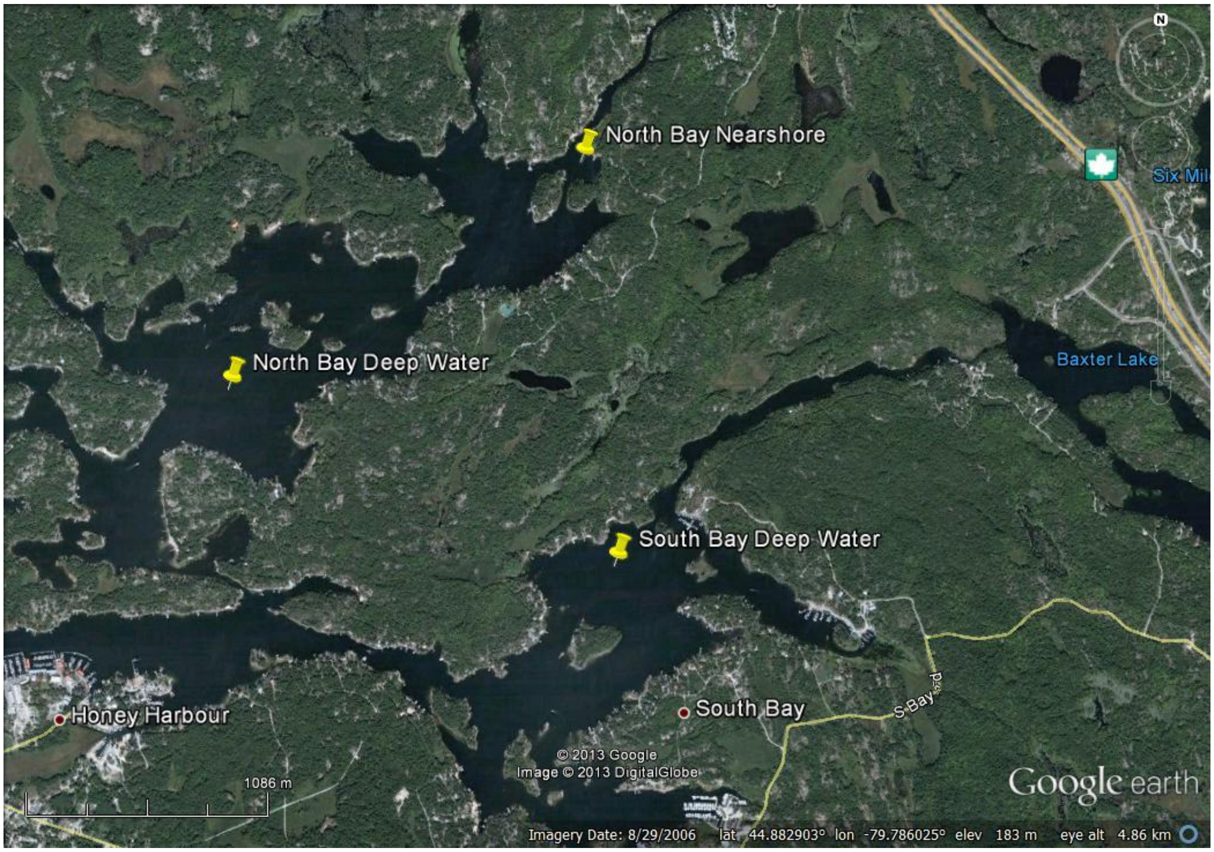
[1] *Flushing rate can be described by the "areal water loading rate", or* q_s, *the total annual flow through a water body divided by its surface area. The value is 2.2m for North Bay and 11.1m for South Bay, such that the flushing rate of South Bay is 5X that of North Bay.*

Figure 1. Map of Sites and Coring Locations



4. Methods

4.1 Field Procedures

Sediment cores were collected on July 12, 2012, using a gravity corer fitted with a 6.5-cm diameter plastic tube. Cores were covered with black bags to limit light exposure that degrades pigments and transported on ice and upright to the sub-sampling location. The sediment cores were sectioned on the same day into 0.5 or 1 cm-thick slices, which were immediately stored in the dark, at 4°C.

The length of the cores measured 27 cm at the North Bay deep-water site, 30 cm at the North Bay near-shore site and 40 cm at the South Bay site.

Photo 1. Core Collection Apparatus with Sediment Core

Note: This picture was taken at another site, but the same piece of equipment was used in North and South Bay.

Table 1. List of Sub-sampled Core Sections

Interval thickness	North Bay Deep-water core (cm from top)	North Bay Near-shore core (cm from top)	South Bay core (cm from top)
0.5 cm	0-10	0–15	-
1 cm	10-30	15-25	0-40

4.2 Sample Analyses

4.2.1 Analysis Strategy

, The analysis strategy was based on pre-established time periods, where known major stressors to water quality were expected, in order to optimize the obtained information within the available resources. In addition, analyses were focused on time periods when observed changes in the aquatic ecosystem were reported, e.g., the recent increase in aquatic plant abundance. The main periods of interest included the following:

1) Pre-settlement period (pre-1800)
2) Logging period (1820-1900)
3) Post-war depression (1920-1940)
4) Cottage Development (1950 to present)
5) Post-zebra mussel invasion (1980 to present)

The advantage of this approach was that a diverse array of analyses was possible on a limited number of samples, providing independent evidence of water quality and aquatic ecosystem change over time, while respecting limited resources. The disadvantage of this approach was that any unexpected changes between these main time periods may have been missed. Complete high-resolution analyses of thinner sediment core sections representing shorter and more time intervals from the study sites would be required to assure that all historical trends in water quality have been identified, which was outside the scope of this study.

4.2.2 Lead-210 Analysis

The lead-210 dating analyses were completed first, in order to provide chronologies for the cores. At least two sub-samples representing the main periods of interest were then selected for the analysis of sediment indicators, with higher numbers of samples for recent times to allow for correlation with climate and water level records. Subsamples of ca. 5 to 10 g wet weight were submitted to a laboratory specialized in sediment chronologies, MyCore Scientific Inc. Sediments were analyzed using alpha-spectrometry of ^{210}Po (polonium-210), which is part of the decay series of ^{210}Pb (commonly referred to as lead-210). In short, each radioactive decay of ^{210}Po emits an alpha particle that is counted by the spectrometer. The counts per unit time and mass unit of sediment represent the ^{210}Po activity. Assuming isotopic equilibrium, the ^{210}Pb activity is equal to the ^{210}Po activity. Using the known half-life of these isotopes, the activity data were then used in the calculation of sediment ages (see section 4.3.1).

4.2.3 Algal Pigments

For algal pigment analysis, a known pre-weighed amount of 0.74 g (± 0.24 g) and 0.91 g (± 0.04 g) of freeze-dried sediment per subsample was treated from the North Bay and South Bay cores, respectively. Pigments were extracted into 5 ml (final volume) of 100% acetone, and pre-processed by sonication in an ice bath for heat dissipation. Sample vials were purged of oxygen/air and placed in an atmosphere of argon.

The extraction was allowed to continue for 24 h at -20 °C. Sediments were separated from the supernatant by centrifugation in a refrigerated unit and filtration through 2 µm PTFE filters. Aliquots were analyzed using high performance liquid chromatography (Waters HPLC, model no 600/626 with a Waters Photodiode Array 2996, a Waters 2475 Multi λ Fluorescence detector and a refrigerated waters autosampler 717, (Zapata et al. 2000)). Individual pigments were identified and quantified using external standards purchased from DHI (Denmark). Sedimentary pigment concentrations were expressed relative to organic matter content, in order to control for the potential confounding effect of variable inorganic sediment deposition. Organic matter and carbonate content were measured by loss on ignition (Heiri et al. 2001) and pigment concentrations were expressed relative to the organic content as ng pigment/mg organic matter. Pigments are susceptible to degradation when oxygen, light and temperatures are elevated. Phaeophytin *a* (Ph *a*) is a specific breakdown product of chlorophyll *a* (Chl *a*) and so the ratio of Chl *a* : Ph *a* was calculated as an indicator of pigment degradation (Leavitt and Hodgson, 2001).

4.2.4 Chironomids

The fossil remains of midge (chironomid) larvae that are preserved in the sediments are their head capsules, which are composed of chitin. Subsamples for chironomid analyses were soaked in KOH 10% overnight. The samples were filtered into a 100 µm-mesh. The remnant was poured into a Bogorov tray and observed under a stereomicroscope at 10x magnification. Each head capsule found was mounted individually into a drop of Hydromatrix on a microscope slide. The head capsules were identified under a Motic microscope at 40-100x magnification. The identification followed Larocque and Rolland (2006). The head capsules were counted and reported as percentages.

4.2.5 Diatoms

In order to extract the siliceous cell walls of diatoms that are used for microscopic identification, subsamples for diatoms were treated with a 10% hydrochloric acid mixture to eliminate calcium carbonate from the sediment. This was followed by treating the sediment with a 1:1 mixture of strong sulfuric and nitric acids which were then heated for several hours to digest organic remains. Once digestion was complete, the samples were repeatedly rinsed with deionized water in order to neutralize the pH. The concentrated slurry was then diluted to obtain optimal counting concentrations and small volumes of sample were dried on glass microscope cover slips. The dried cover slips were mounted on microscope slides using Zrax medium, which has a high refractive index (>1.7), allowing observations under high magnification. Diatoms were identified and counted at 1250x magnification using a Nikon microscope equipped with differential interference contrast optics and using immersion oil. Photographs of the most common species were taken using a microscope camera.

4.2.6 Plant Macrofossils

Macrofossil samples were prepared by washing wet sediment samples through a 125-µm mesh screen with lukewarm tap water. Material retained on the sieve was sorted in water using a binocular dissecting microscope at 8-40x magnification. All identifiable macrofossils were enumerated. When multiple types of remains were present from single taxa, the most abundant type was used in numerical analyses. Data were presented as influx of macrofossils per surface area and year, in order to correct for increased sediment density with depth and changes in sedimentation rates. Analyses focused on the identification and enumeration of plant macrofossils; however animal macrofossils present in the samples were also counted. All identifications were made to the finest taxonomic resolution possible, with the aid of the modern reference samples (Courtesy of Lakehead University, Department of Anthropology) as well as with the use of keys by Martin and Barkley (2000), Berggren (1969), Montgomery (1977), Schoch et al. (1988) and Artjuschenko (1990).

4.2.7 Climate and Water Level Records

Mean annual temperature and total annual precipitation records were obtained from Environment Canada's National Climate Data and Information Archive for eight stations located within 25 km of Honey Harbour (http://www.climate.weatheroffice.gc.ca/climateData/canada_e.html) (Table 2). We used multiple stations because they covered different time periods at differing levels of seasonal detail. The records were combined by calculating mean values for each year where multiple station data existed. Only station years with at least 11 months of data were included in the calculations. The combined record extends from 1884 to 2012 and includes 106 years of temperature data and 110 years of precipitation data. Annual water level records for Lake Huron dating back to 1918 were obtained from the website of the Canadian Hydrometric Service (Department of Fisheries and Oceans 2013).

The water level and climate data were averaged over the time period represented by each sediment interval from the South Bay and North Bay cores for comparison with the paleolimnological records,.

Table 2. Environment Canada Climate Station Information

Station Name	Latitude (°N)	Longitude (°W)	Elevation (m a.s.l.)	Climate ID	First Year of Record	Last Year of Record	Years with Precipitation Data	Years with Temperature Data
Beausoleil	44.85	-79.87	183	6110617	2004	2006	3	3
Big Chute	44.88	79.67	190.5	6110731	1913	1972	13	13
Coldwater	44.7	79.67	182.9	6111766	1883	1954	44	49
Coldwater Warminster	44.63	79.54	285	6111769	1971	2012	38	37
Honey Hbr Beausoleil	44.85	79.87	182.9	6113490	1974	2003	23	24
Midland Huronia A	44.68	79.93	234.7	6115130	1987	2002	14	14
Midland Water Pollution Control Plant	44.76	79.88	180	6115127	1889	2012	63	31
Waubaushene	44.77	-79.7	181.4	6119399	1936	1956	15	14

4.3 Data Analysis

4.3.1 Chronology

The constant-rate-of-supply (CRS) model was used to estimate sediment ages from lead-210 activity data (Appleby and Oldfield, 1978). This is the most commonly used model for establishing sediment ages for lakes with regular sedimentation patterns. It assumes that the supply of lead from the watershed and the atmosphere occurred at the same rate over the time that the sediment was formed, which is a reasonable assumption for our study sites. ^{210}Pb concentrations are therefore assumed to change in the cores due to radioactive decay (aging) and changes in sediment accumulation rate.

The sediment layers beneath the lowest dated depth were estimated using a linear extrapolation of the lowest five dated samples and their cumulative dry mass. While a linear fit is not the appropriate model for long sediment chronologies due to the compaction of sediments, it is the simplest available approximation for a short section of sediment, for which compaction would not change significantly. In addition, any other model would require assumptions that we cannot verify. Also, the purpose of the radioisotopic analysis was mainly to determine the specific sediment dates for known post-settlement activities and assure that the oldest analyzed sediments represent pre-settlement times, which is still fulfilled with this approach.

4.3.2 Diatom-based TP Reconstruction

We applied a diatom-based phosphorus model to the fossil diatom data in order to reconstruct historical total phosphorus (TP) concentrations. For the model used in our study, the data from three previously published diatom-based TP inference models in Ontario (Hall and Smol 1996; Reavie and Smol 2001; Werner and Smol 2005) and one unpublished dataset from the Oak Ridges Moraine (Prévost, personal communication) were compiled into one large set of Ontario lakes (n = 210). This procedure has the advantage that information on species ecology regarding nutrient concentrations contained in all of these datasets is combined into one model, increasing the chance of finding all fossil species encountered in a sediment core in the model. We used the method of weighted averaging with inverse deshrinking and tolerance down-weighting, as this method resulted in the best model performance, as indicated by the correlation between measured and modeled TP values (jackknifed coefficient of determination: $r^2_{jack} = 0.40$) and the error (RMSEP = 0.20). The model had a similar statistical performance as previously published models (compared to Hall and Smol: 0.41, Reavie and Smol: 0.47, Werner and Smol: 0.44).

In order to assess the applicability of the model, we assessed how well the fossil diatom communities found in the collected cores were represented in the model. We documented the percentage of individuals in the fossil samples that were accounted for in the model and also estimated modern analogues. This technique determines the differences between fossil and model assemblages by the way of a multivariate distance method (chord distance), which allows assessing if these differences lie within an acceptable level of statistical variance of the model assemblages.

4.3.3 Chironomid-based Oxygen Reconstruction

A chironomid-based inference model developed by Quinlan and Smol (2010) was applied to the chironomid fossil assemblages in the North and South Bay cores to reconstruct oxygen concentrations as Volume-Weighted Hypolimnetic Oxygen (VWHO). The model was constructed from fossil chironomid assemblages and oxygen data from 80 lakes on the Precambrian Shield in south central Ontario (Quinlan and Smol, 2001). This weighted-averaging model with inverse deshrinking and tolerance down-weighting provides good estimates of VWHO (root mean squared error of prediction, RMSEP = 2.06 mg O_2/L) with a strong relationship between measured and modeled values (jackknifed coefficient of determination, $r^2_{jack} = 0.57$). Reconstructions were performed using the computer program C2, version 1.5 (Juggins, 2007).

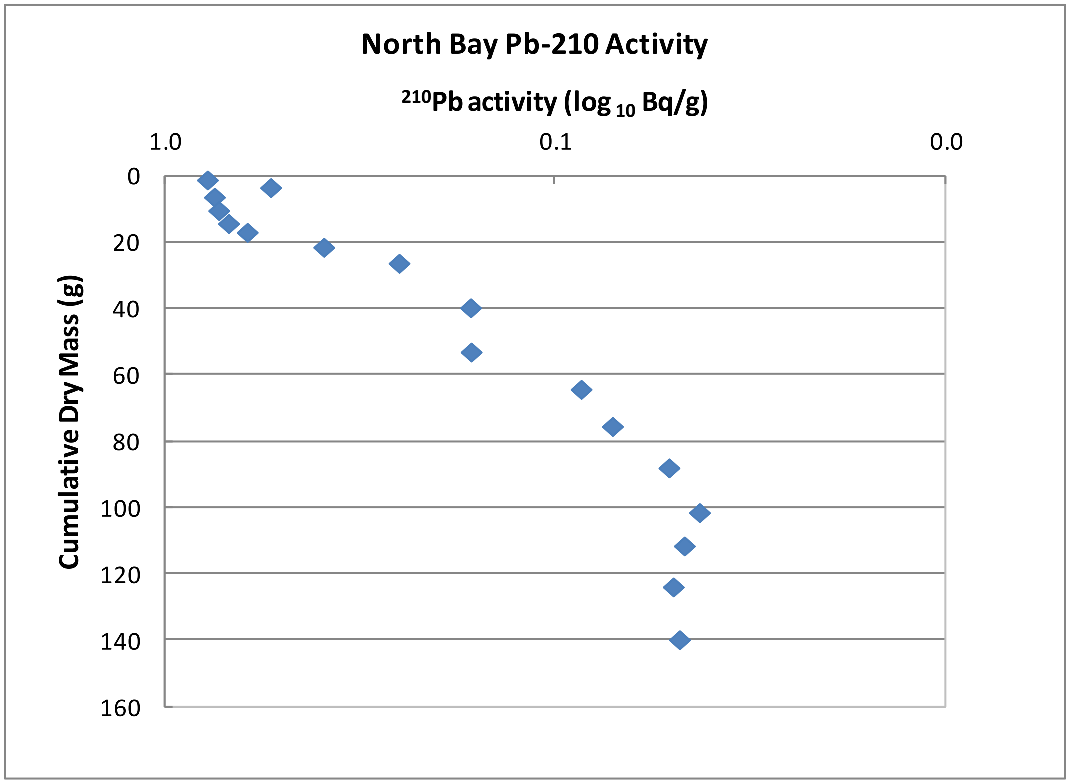
5. Results

5.1 Chronology

5.1.1 North Bay Deep Water

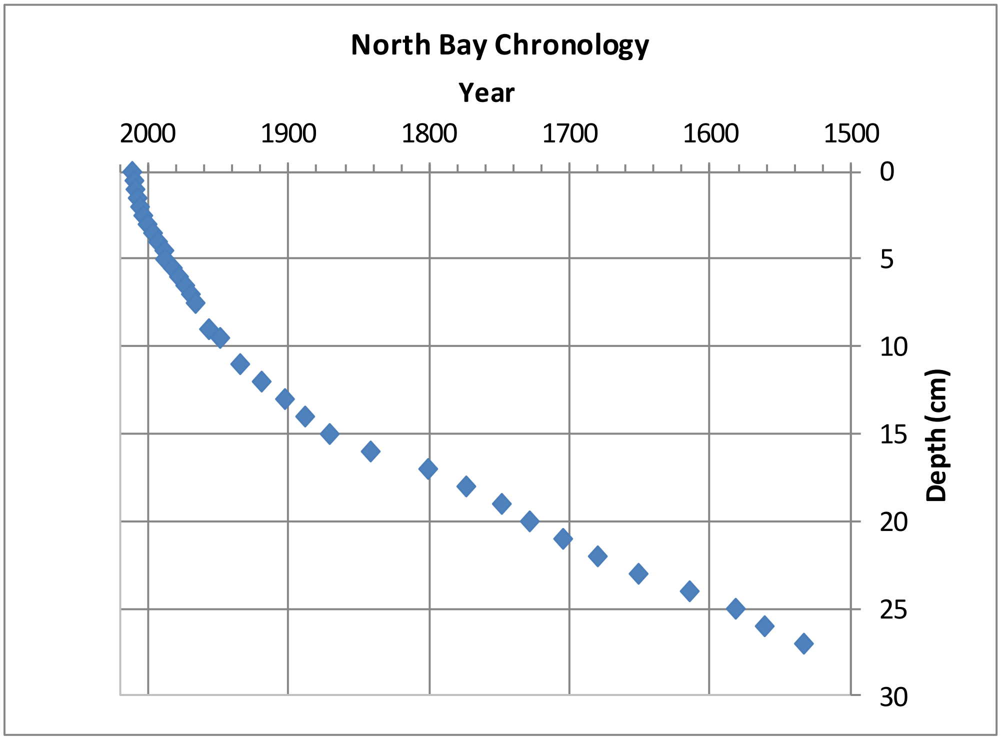
The North Bay deep-water core profile of lead-210 showed the typical exponential decline of radioisotope activity with accumulated sediment mass. When plotting the activity on a logarithmic scale, such a pattern is shown as a linear decline until background levels are reached (Figure 2).

Figure 2. Lead-210 Activity Profile for North Bay Deep-Water Sediment Core



The sediment chronology was established using the measured activity levels and the CRS model (Figure 3). The oldest dated sediment layer was at 15 cm depth, which represented approximately the year 1872. The extrapolation of sediment ages beyond the dated levels resulted in an estimated date of 1530 for the bottom-most sample (27 cm) of the core.

Figure 3. Chronology for the North Bay Deep-Water Core



Note: This chronology is based on Lead-210 dating of the intervals displayed in Figure 2. Linear interpolation was used for samples between dated levels and dates for older samples were extrapolated (see methods for details).

5.1.2 North Bay Nearshore

The near-shore core collected in North Bay showed a similar pattern to the deep-water core from the same bay, with a near-linear decline in log lead-210 activity with accumulated sediment mass. Background values were reached at a lesser depth (11 cm), indicating a lower sedimentation rate at this location. Given the small surface area of this sheltered bay compared to the larger open area where the deep-water core was taken (Figure 1), a lower sedimentation rate was expected.

Figure 4. Lead-210 Activity Profile for North Bay Near-Shore Sediment Core

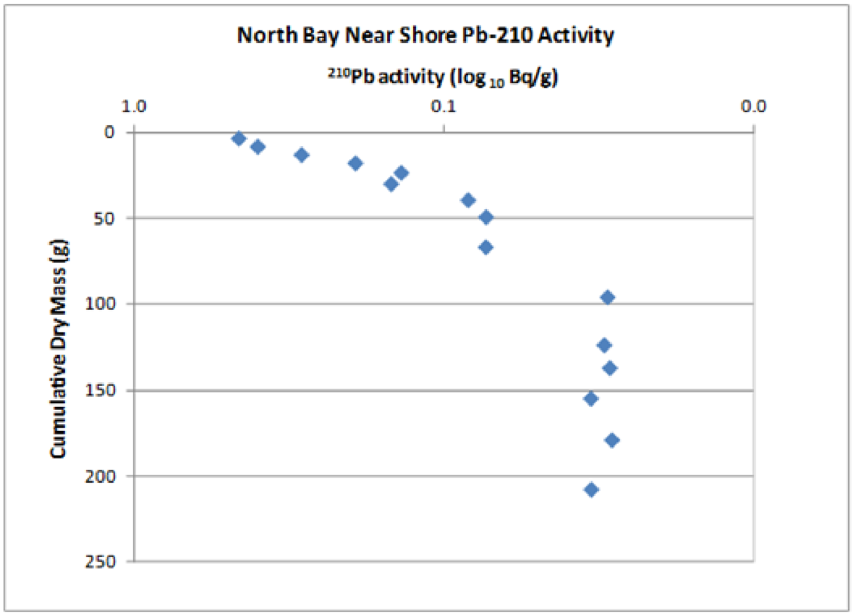
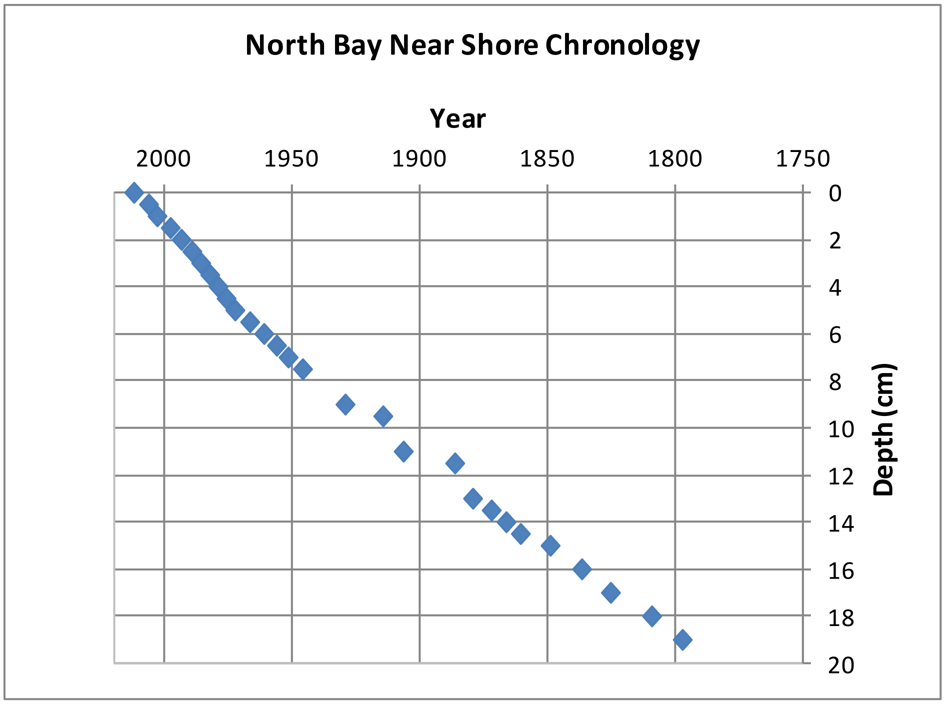


Figure 5. Chronology for the North Bay Near-Shore Core



5.1.3 South Bay

The South Bay core showed a near-linear decline in log lead-210 activity with depth in two phases, above and below ca. 15 cm depth, where activities varied and the slope of the activity decline changed. Sedimentation rates declined above 15 cm (ca. 1955), and returned to higher values above 10 cm (ca. 1980). The lowest lead-210 dated level was 34 cm with a date of 1848. The oldest core sample of 39-40 cm in the South Bay core was estimated to represent 1760, based on extrapolation of lead-210 dates.

Compared to North Bay, the South Bay sediments have accumulated at a higher rate. This result was expected due to the comparatively larger watershed, which includes the upstream Baxter Lake and part of the Severn River.

Figure 6. Lead-210 Activity Profile for South Bay Sediment Core

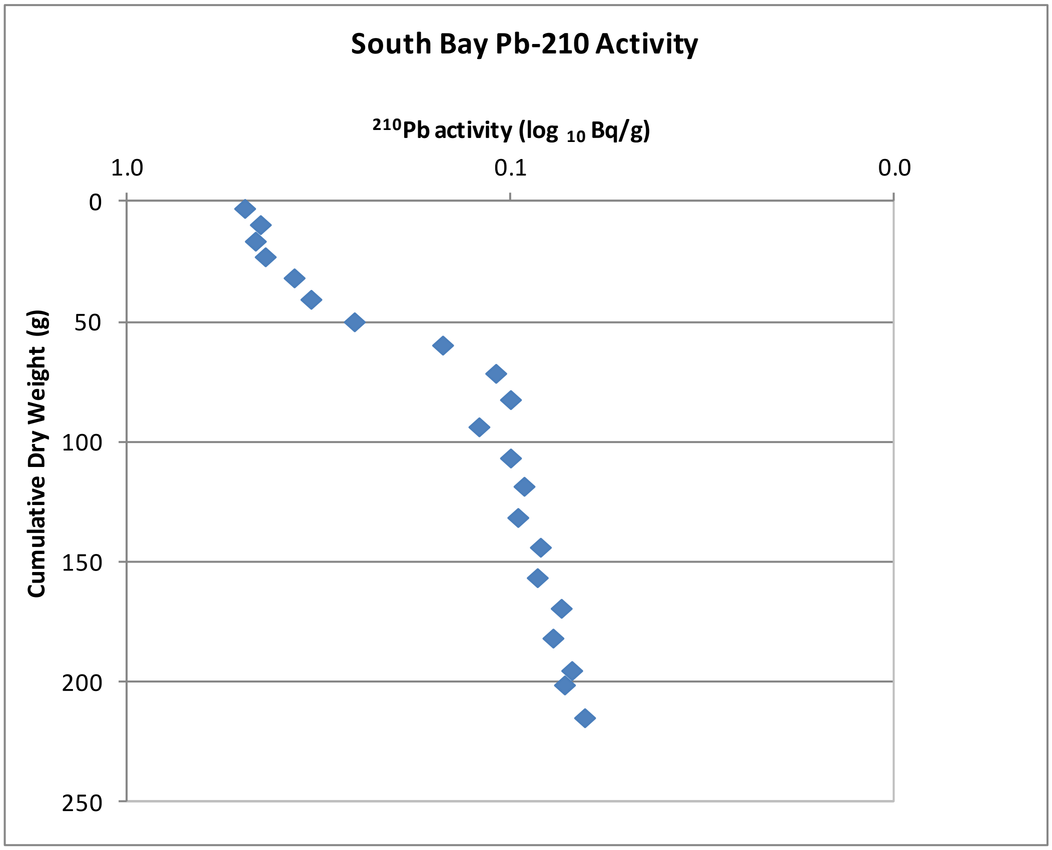
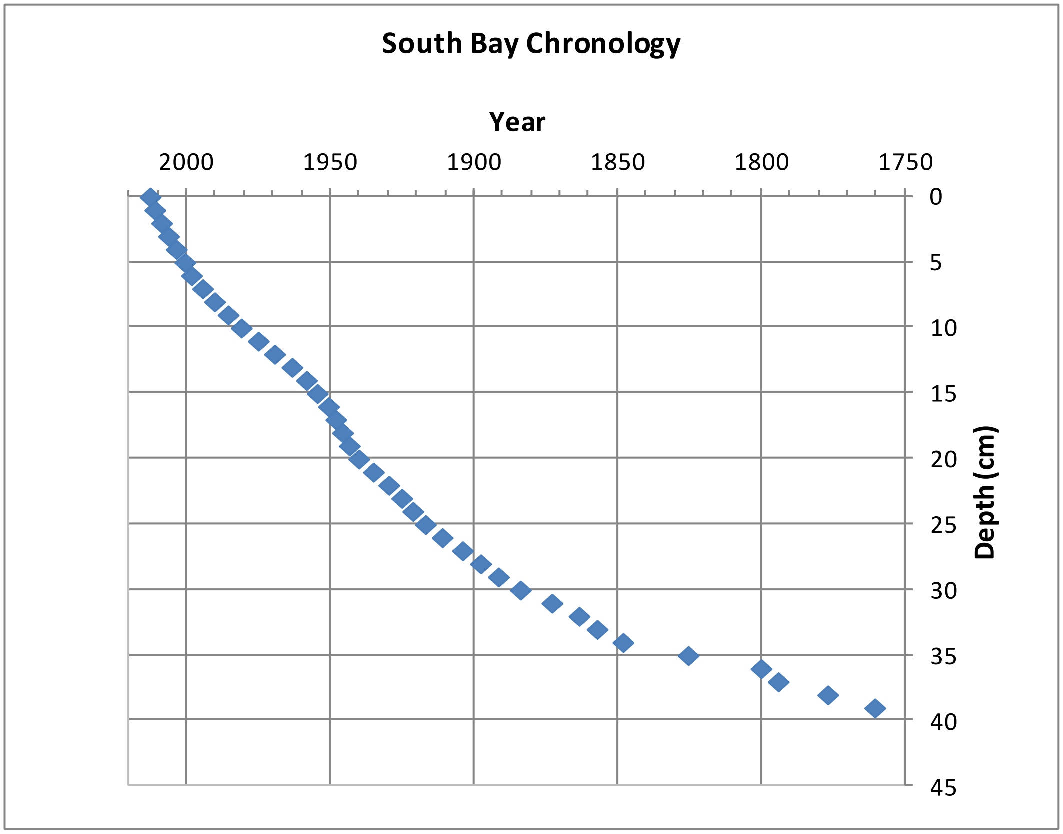


Figure 7. Chronology for South Bay Deep-Water Core



The instrumental records from climate stations near Honey Harbour provide a nearly continuous record of mean annual temperature (Figure 8) and precipitation (Figure 9) that extends back to the late 1800s. There are gaps in earliest part of the record to ~1940 and measurement frequency (i.e., the number of data points per year) varied between years and stations, however, the data provide sufficient resolution to identify major patterns in temperature and precipitation over the time intervals represented by the sedimentary record for comparison with the paleolimnological records. The record of measured water levels is shorter and begins in 1918 (Figure 10).

Mean annual temperatures displayed an overall pattern of warming over the period of record consistent with global warming trends. In the earliest part of the record from 1886 to 1917, mean annual temperature was 5.2°C. There is a gap in the record from 1918 to 1930, after which time temperatures increased until ~1960 with a mean temperature of 5.7°C over that time period. From 1960 to 2000, mean temperature increased over the previous 30-year period to 6.5°C. Temperatures fluctuated with cooler temperatures in the 1960s to the early 1980s, warmer temperatures in the late 1980s and a return to cooler temperatures in the early 1990s. From the late 1990s to 2012, temperatures increased again with a mean of 7.7°C and included the three hottest years of the record (1998, 2010, 2012).

Mean annual precipitation over the period of record was 927 mm. Precipitation declined in the earliest part of the record from 1884 to the early 1920s reaching the lowest recorded value of 518 mm in 1917. There are several missing years of data in the record from 1917 to 1940, but this period includes the so-called "dirty thirties" when drought conditions persisted in xxx and were likely in the study area. From the 1940s to present, there have been large fluctuations in precipitation, but this period is characterized by generally higher precipitation (mean precipitation = 981 mm) than in the preceding ~60 years (mean precipitation = 827 mm). Key patterns in precipitation in the late 20th Century include a peak in 1951, lows in the early 1960s reaching the lowest precipitation observed in the last 70 years of 692 mm in 1964, and a period of relatively stable precipitation from the mid 1960s to 2000 but with a large peak in 1985 to 1429 mm which is the highest recorded precipitation in the record. In the 21st Century, average annual precipitation was lower than in the late 20th Century at 971 mm, with lower than average precipitation occurring in 2002, 2005-2007 and in 2010. High precipitation occurred in the last year of record in 2011, which was the third highest precipitation recorded since 1884.

Water levels have varied widely since 1918, but overall patterns are generally consistent with the precipitation record. From 1918 to 1930, mean water level was 176.4 masl. From 1931 to 1937, water levels were consistently low with a mean of 175.9 masl., coincident with drought conditions that occurred at that time. Water levels recovered over the next fifteen years and reached a peak in 1952, after extreme precipitation in 1951. Water levels then declined in over the next decade to the lowest recorded level of 175.7 m a.s.l. in 1964, in the same year of record low precipitation. Water levels increased from 1964 to a maximum in 1973, then peaked again in 1986, the latter peak occurring the year following record high precipitation of 1985. Water levels then declined to levels in the 1990s that were lower than in the previous two decades. Water levels continued to decline and since 1999, have been consistently low with a mean of 176 masl., but still higher than the extreme low water levels that occurred in the 1930s and early 1960s. The high precipitation that occurred in 2011 was not reflected in a change in the water level in 2011 or 2012. This illustrates the complex nature of water levels in Georgian Bay that are controlled by factors other than precipitation.

Figure 8. Instrumental temperature record from climate stations near Honey Harbour showing the annual mean, and the mean temperatures over the time period represented by each sediment interval in the North Bay (NB) and South Bay (SB) cores.

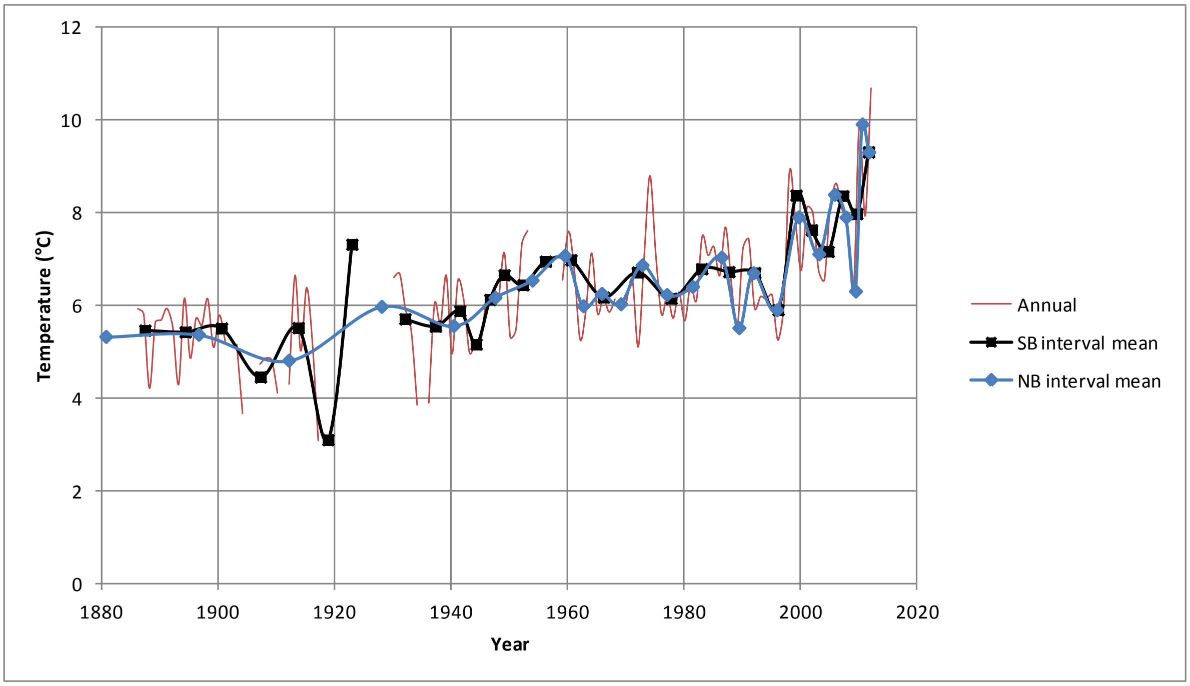


Figure 9. Instrumental precipitation record from climate stations near Honey Harbour showing the annual mean, and the mean precipitation for the time period represented by each sediment interval in the North Bay (NB) and South Bay (SB) cores.

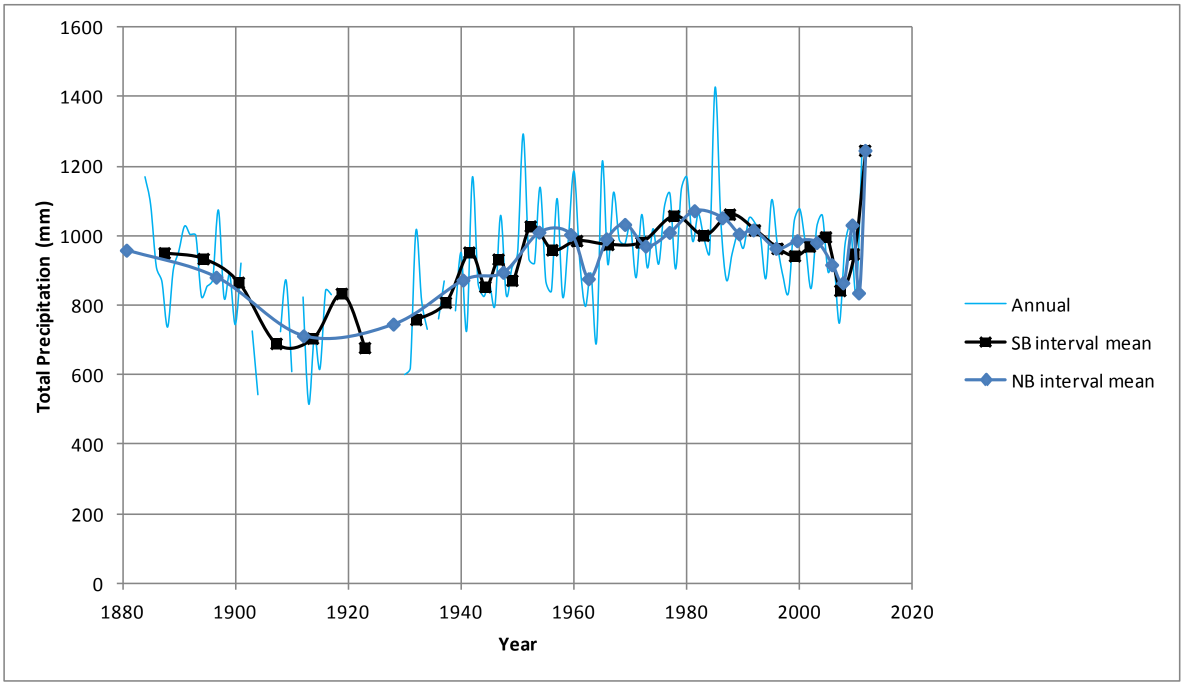
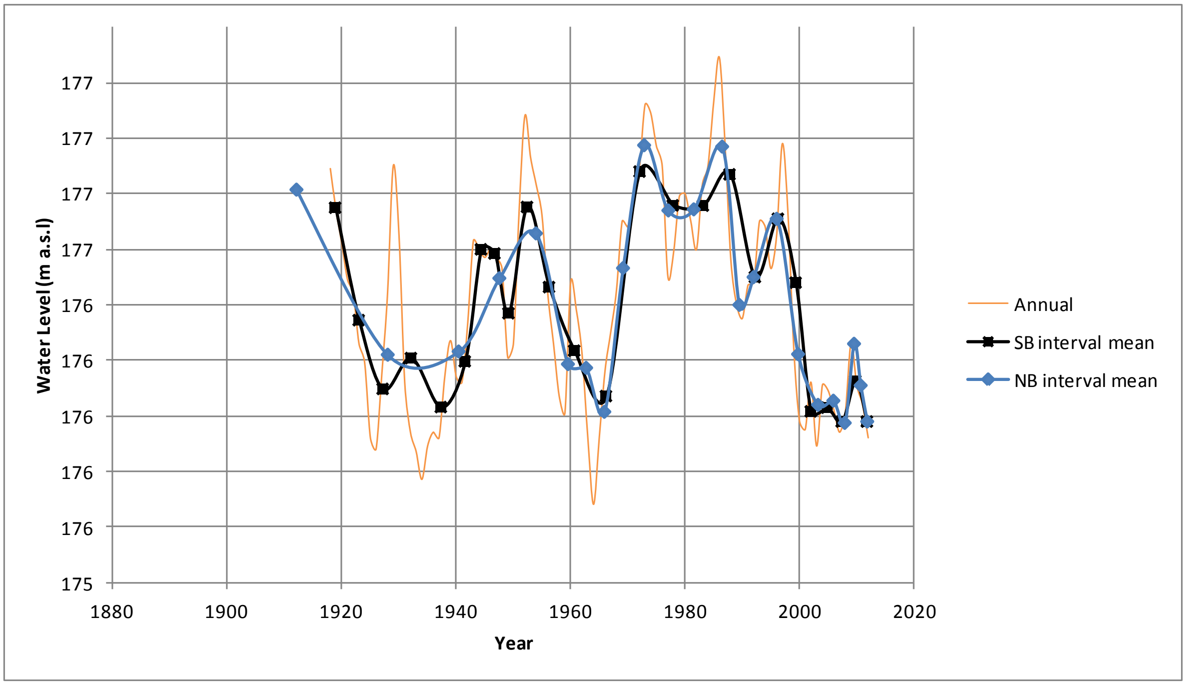


Figure 10. Annual water levels and mean water levels for the time period represented by each sediment interval in the North Bay (NB) and South Bay (SB) cores.



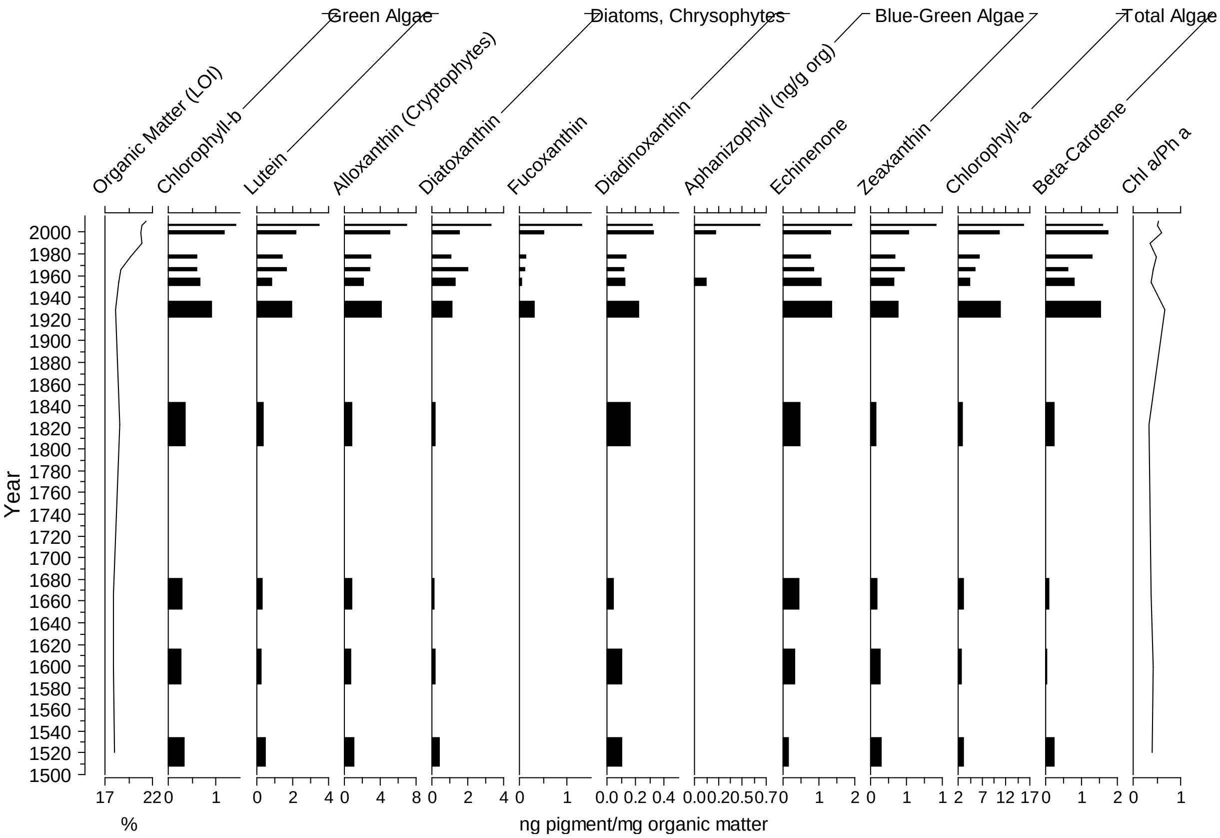
5.2 Algal Production and Community

5.2.1 North Bay

The oldest fossil pigment assemblages extracted from the North Bay core dated back to the late 1600s (Figure 11). The pigment assemblage indicated that green algae (Chlorophyll b, lutein), cryptophytes (alloxanthin), diatoms (diadinoxanthin, diatoxanthin) and blue-green algae (echinenone and zeaxanthin) were all present in the algal community, but relatively low concentrations of pigments indicate that algal biomass was likely low. The pigment assemblage in 1843 was very similar to that in the late 1600s indicating that early settlement did not significantly alter the algal community structure or increase algal productivity.

Sometime between 1843 and 1935, algal productivity increased with higher abundances of all pigments and fucoxanthin (produced by diatoms and chrysophytes) in the record indicating nutrient-enriched conditions and possibly increased occurrence of chrysophytes in the algal community. The timing of this change is coincident with early settlement and may reflect increased nutrient inputs from human activities in the watershed, but the change may also be in response to the period of warmer temperatures, drought and low water levels that occurred in the early 1930s. In the next two samples representing the period of cottage development from 1958 to 1967 , the algal community composition did not change, but pigment concentrations from all groups decreased slightly suggesting that nutrient concentrations may have been lower over that time frame. Beginning in ~1980 and coincident with the zebra-mussel invasion, concentrations of all pigments increased, with a notable increase in aphanizophyll, a pigment that is specific to filamentous blue-green algae, and the chrysophyte pigment, fucoxanthin. These changes suggest an increase in algal production in North Bay with a greater representation of filamentous blue-green algae and chrysophytes. The post-settlement increases in pigment concentrations are not likely due to increased pigment preservation as the ratio of Chlorophyll *a* to phaeophytin *a* is relatively stable throughout the record.

Figure 11. Algal Pigments in North Bay Sediment Core



5.2.2 South Bay

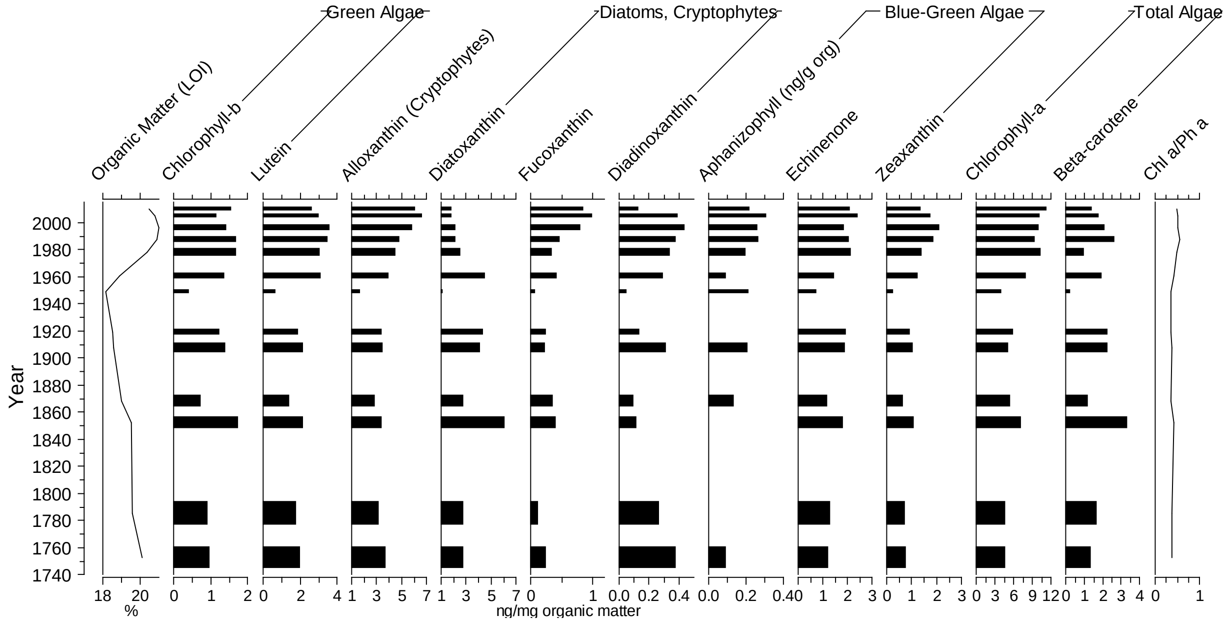
The pre-settlement pigment assemblages in South Bay were similar to those in North Bay with representation of pigments from green algae, cryptophytes, diatoms and blue-green algae (Figure 12). One difference is that unlike North Bay, fucoxanthin (diatoms and chrysophytes) and aphanizophyll (filamentous blue-green algae) were present in the pre-settlement assemblages from South Bay, albeit at low concentrations.

In post-settlement samples, pigment concentrations varied but generally indicated slight nutrient enrichment with an overall increase in algal production based on higher concentrations of chlorophyll *a* and beta-carotene from ~1850 to 1980. The highest pigment concentrations occurred ~1850 with the greatest increases observed in chlorophyll *b* (green algae) and diatoxanthin (diatoms), suggesting nutrient enrichment at that time. In ~1949, all pigments decreased in concentration with the exception of aphanizophyll. These samples were also characterized by a high sedimentation rate and low organic matter content. These patterns indicate increased sediment input from the watershed, and may have occurred due to high runoff events that likely occurred with the record high precipitation in 1951 (dates may be offset due to error in chronology), or possibly from construction activities, either of which would have diluted sediment pigment concentrations.

Beginning around 1980, in timing with the zebra-mussel invasion, the total algal abundance (chlorophyll a and beta-carotene) increased consistent with eutrophication in South Bay, which has persisted to at least 2009. A shift in community composition also occurred over that time period with a decrease in diatom pigment diatoxanthin, while other pigments including alloxanthin (cryptophytes) and fucoxanthin (diatoms and chrysophytes) increased in concentration. This indicates that the algal community has been changing to favour non-diatom algae in the last few decades.

As with the North Bay core, changes in pigment preservation have not likely caused the observed changes in concentrations as preservation of pigments has been stable over the period of record.

Figure 12. Algal Pigments in South Bay Sediment Core



5.3 Diatom Assemblages and Historical TP Concentrations

5.3.1 North Bay

The oldest fossil diatom assemblages extracted from the North Bay core (dating back to the 17th century) and the diatom-inferred TP concentrations of 13.5-14.5 ug/L (Figure 13) indicate that this bay was naturally mesotrophic. The predominant species *Aulacoseira ambigua* is an indicator of mesotrophic conditions. The diatom-inferred TP concentrations correspond well with the background TP concentrations of 13.5 ug/L for North Bay that were modeled using the Lakeshore capacity model (Gartner Lee Limited 2005), providing additional confidence that the diatom model is predicting phosphorus levels in North Bay..

From pre-settlement times until today, the fossil diatom assemblages in the North Bay core have undergone three noticeable changes. The first change occurred sometime between 1700 and 1840 and consisted of a shift from a dominance of littoral,(attached), algae to planktonic,(free-floating) algae. The ratio of littoral to planktonic diatoms decreased from 1.7 to 0.8 in this time interval. A change to a more planktonic assemblage can be caused by more open-water habitat (deeper water) or by nutrient enrichment. The diatom inferred TP did increase slightly, but not beyond levels observed in the 1600s. Pre-1800 climate and water level data are not available, so we cannot explore if the change was due to changes in these parameters. It is possible that logging activities in the watershed in the 19th century led to a minor nutrient enrichment, which was noticeable in the diatom communities but not strong enough to be detected by the diatom model of inferred phosphorus concentrations

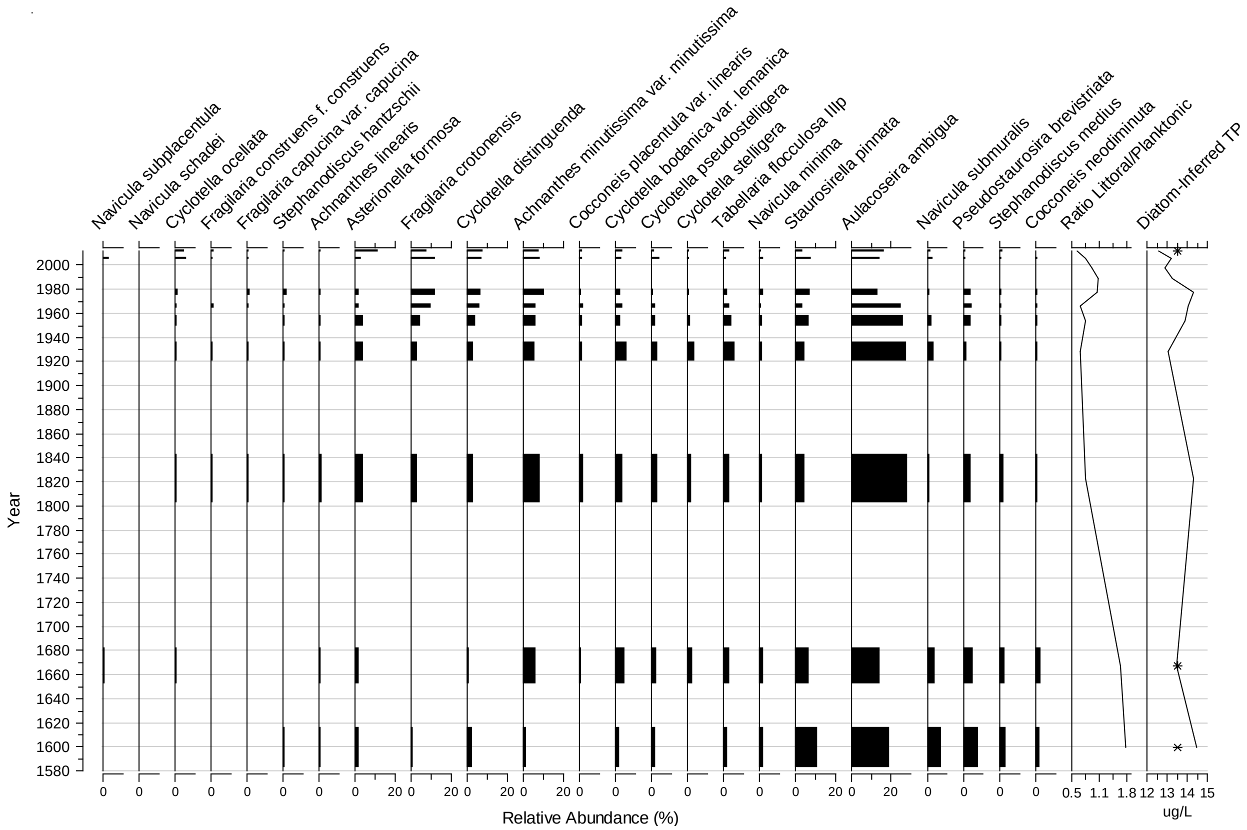
The second noteworthy change occurred in the mid-1950s, when *Fragilaria crotonensis,* a mesotrophic to eutrophic species, became more abundant and *Stephanodiscus hantzschii*, a eutrophic species, appeared. These species have been indicators of eutrophication in many lakes, including Ontario lakes (Ekdahl et al. 2007) and Great Lakes (Stoermer and Tuchman 1979, Yang et al. 1993). Diatom-inferred TP concentrations increased from 13 ug/L in the 1930s to 14 ug/L in 1950s and peaked in the late 1970s at 14.3 ug/L. While these numeric increases appear minor and well within natural variability, they are likely significant, as the diatom-inferred TP concentrations integrate conditions from a number of years, thereby “smoothing out’ natural variations. A large number of other, abundant diatom species, however, remained stable throughout this time period, such as *Asterionella formosa* and *Tabellaria flocculosa*, indicating that the nutrient enrichment was only subtle, or only occurred on a seasonal basis.

Two changes happened around 1980, with the proportion of littoral taxa increasing from 1967 to 1979 and diatom-inferred TP decreasing from 1979 to 1990. The increased abundance of littoral taxa may be the result of two causes: reduced water levels following the record-low water levels in the early 1960s and increased water clarity following the invasion of zebra mussels in the early 1980s. Zebra mussels filter particles out of the water column, thereby increase light penetration and the size of the littoral zone inhabitable for attached algae. Notably, the type of littoral taxa that increased after 1967 differed somewhat from those that made up the higher littoral proportion in pre-settlement times. The littoral taxa predominant in the pre-settlement samples consisted of small *Staurosirella* and *Pseudostaurosira* species, which are ubiquitous pioneer species that attach to any kind of substrate, including sediments. The post-1980 assemblages contained the same species, but in addition, hosted species of the genera *Navicula* and *Gomphonema*, which are mostly epiphytic diatoms, i.e., they attach to the surface of aquatic plants. These patterns were also observed in South Bay. The overall increase in littoral taxa possibly indicates an increased size of the littoral area from increased water clarity and reduced water levels, while the changes in littoral diatom assemblages indicate an increase in aquatic macrophytes after 1980.

The post-1980 TP decrease has been documented in measured data and is a phenomenon observed in a number of Muskoka lakes on the Precambrian Shield (Eimers et al. 2009). Interestingly, this decrease was not observed in South Bay, possibly due to the influence from the Severn River watershed, which drains sedimentary, non-acid sensitive geology. The diatom-inferred TP concentrations for the most recent years (12.5-13.3 ug/L for 1990 to 2012) lie well within the range of measured data from the District of Muskoka (10.6 – 13. 8 ug/L for 2002 to 2012) and data collected by Georgian Bay Forever (average: 13. 5 ug/L, HESL 2011).

The recent increase in the oligotrophic *Cyclotella ocellata* could be interpreted as reflecting lower nutrient concentrations, but it was also observed at exactly the same time in South Bay, where nutrient concentrations remained stable. Given the continued significant abundance of *Fragilaria crotonensis*, and overall increases in algal pigments that are indicative of more nutrient rich-conditions, the appearance of *C. ocellata* may be interpreted not as an indicator of lower nutrient conditions, but as an indicator of changing habitat, and therefore may have biased the diatom-inferred TP concentrations to some extent towards lower values. Post-1980 increases in *Cyclotella* species across the northern Hemisphere have occurred after 1980, including Ontario lakes, such as Lake of the Woods, and been associated with increased water column stability following climate warming trends (Rühland et al. 2008). It is highly likely that this is the case for the Georgian Bay embayments as well. As this change occurred at about the same time as the most recent changes in algal communities with chrysophytes increasing at the cost of diatoms, these may be linked to temperature and water column stability as well.

Figure 13. Diatom Assemblages, Littoral to Planktonic Ratio and Inferred TP Concentrations in North Bay



Note: The stars in the diatom-inferred TP column indicate the measured (top) TP (HESL 2011) and modeled (bottom) TP, using the District of Muskoka Water Quality Model.

5.3.2 South Bay

The pre-settlement diatom assemblage in South Bay was very similar to that of North Bay in terms of the encountered species (Figure 14). The relative abundance of several species, however, was different and the diatom-inferred TP was lower at ca. 11 ug/L, indicating oligotrophic to mesotrophic conditions. The main differences were higher abundances of *Cyclotella pseudostelligera* and *C. distinguenda* and lower abundances of *Pseudostaurosira brevistriata* and *Staurosirella pinnata* compared to North Bay, resulting in a much lower ratio of littoral to planktonic species. The diatom-inferred TP concentrations were only slightly higher than the DMM Water Quality model estimate for South Bay background of 8.4 ug/L (Gartner Lee Limited 2005).

Diatom-inferred TP increased from 11.4 to 14.4 ug/L from 1911 to 1920. The timing of this change is coincident with the construction of the Trent Severn Waterway, which may have altered hydrology and nutrient inputs to South Bay. Given that this increase is only documented for one sample and diatom-inferred TP returns to 12 ug/L in the subsequent sample (1940), the significance of this event is uncertain. A high-resolution analysis of all collected core samples would provide more insight into the continuous nutrient history.

The first major change in fossil South Bay diatoms was observed at ca. 1960, when *Aulacoseira ambigua* decreased in abundance and *Cyclotella pseudostelligera* disappeared while *Fragilaria crotonensis* increased in abundance and *Stephanodiscus hantzschii* appeared. These changes were reflected in increasing diatom-inferred TP, from around 11.5 in 1954 to 14.5 ug/L in 1980. At this time the ratio of littoral to planktonic taxa increased from 0.2 to 0.5, including the first occurrence of the epiphytic taxon *Cocconeis placentula*. The increase of littoral taxa after 1960 may be a response to the record-low water levels in Georgian Bay in the mid-1960s (Department of Fisheries and Oceans 2013).

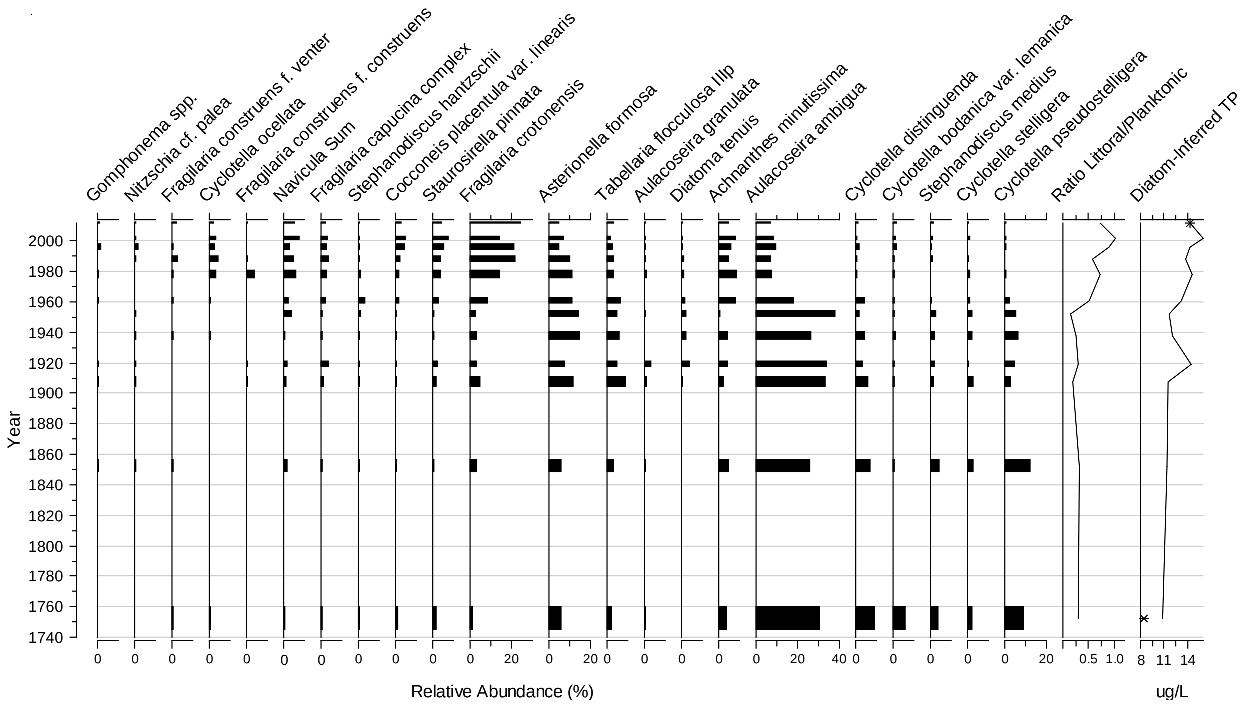
The increase of littoral taxa abundance and species richness continued after 1980, reaching the highest levels of 1 about the year 2000. A number of littoral taxa appeared for the first time, mostly from the genera *Navicula*, *Gomphonema* and *Nitzschia*. These patterns were similar to North Bay, although in South Bay all littoral species, including *Staurosirella pinnata* increased in relative abundance recently, and the species richness of littoral taxa increased, possibly indicating that the combined effect of increased light penetration and increased macrophyte cover was stronger in shaping a diverse littoral habitat for attached diatoms compared to North Bay. Alternatively, the coring site in South Bay may be closer to a littoral under-water shelf or the shoreline, increasing the likelihood of littoral diatom deposition at the coring site. Still, in both North and South Bay, we were able to distinguish two factors that had a cumulative favourable effect on littoral algae taxa, based on the lagged responses in the 1960s, likely to lower water levels, and further increases after the zebra mussel invasion in 1980.

The only planktonic, oligotrophic species that increased after 1980 was *Cyclotella ocellata*, showing the same pattern as in North Bay. This indicates that this species responds to a regional signal rather than local nutrient patterns and water sources, supporting the hypothesis that this species is related to higher water column stability from climate warming.

The diatom-inferred TP in South Bay remained at levels between 14 and 16 ug/L after 1980. This is in contrast to the declining TP in North Bay from 1980 to 2012. This difference shows that site-specific factors control patterns in recent TP concentrations in these two embayments. While the shorelines of both bays are well developed, the fossil chironomid assemblages indicate that South Bay has had more severe anoxia in the hypolimnion (see section 5.4.2) and therefore may have a stronger internal TP recycling mechanism that prevents a TP decline. This means that the legacy of previous nutrient loading may affect this bay for longer than it does in North Bay. In addition, the hydrology of South Bay differs with larger water inputs from the watershed and therefore likely less residence time, which has an effect on phosphorus processes as well and possibly a larger spring inflow of nutrients from the larger watershed. North Bay, on the other hand, is more susceptible to occasional mixing events from strong winds with the open water Georgian Bay, which would help keep phosphorus levels low.

The most recent diatom-inferred TP concentrations (14.3 ug/L) agree well with monitoring data (14.3 ug/L, mean TP measured by Georgian Bay Forever, 10 ug/L measured by the DMM (Figure 14)).

Figure 14. Diatom Assemblages, Littoral to Planktonic Ratio and Inferred TP Concentrations in South Bay



Note: The stars in the diatom-inferred TP column indicate the measured TP (top, Georgian Bay Forever data) and modeled TP (bottom, using the District of Muskoka Water Quality Model).

5.4 Chironomid Assemblages and Historical Oxygen Conditions

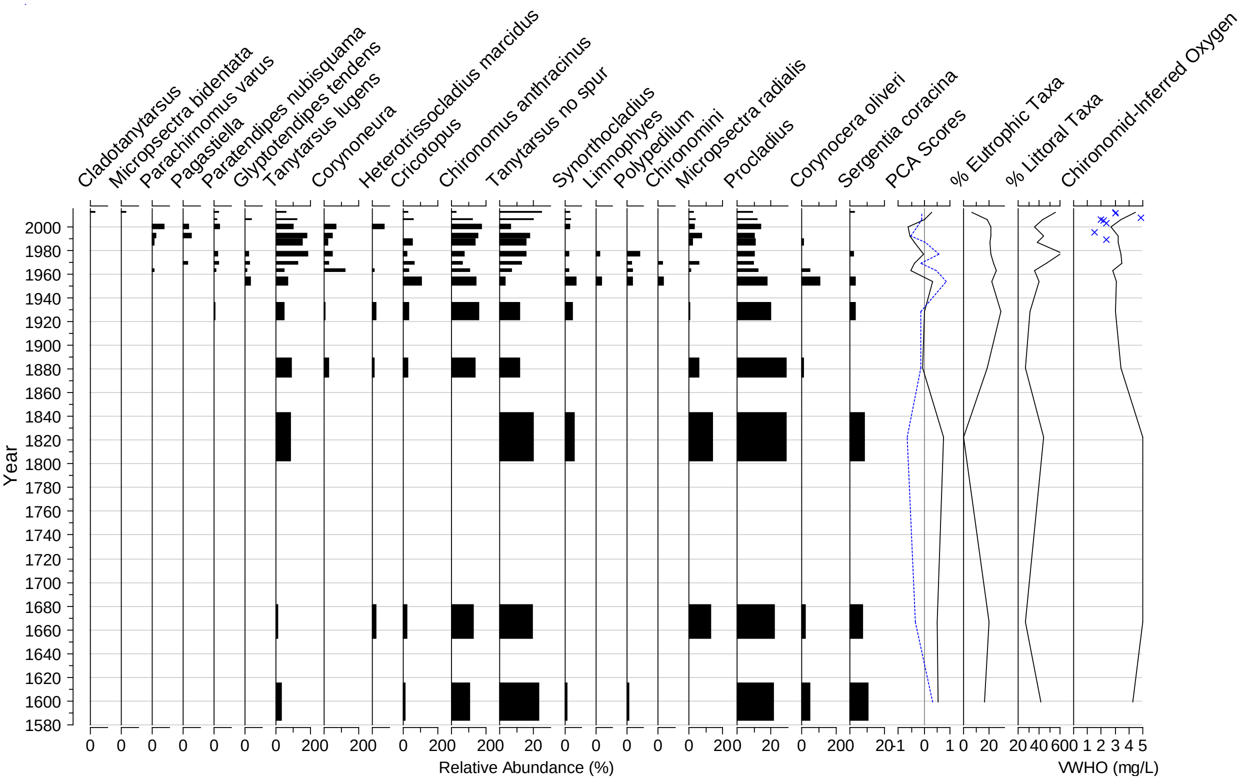
5.4.1 North Bay

The chironomid record from the North Bay core indicates that, in the 17th Century, the bay was naturally moderately productive with chironomid-inferred oxygen concentrations of 4.3-5.0 mg O_2/L (Figure 15). The assemblages were dominated by profundal taxa that are known to be tolerant of low oxygen conditions (i.e., *Procladius* and *Chironomus anthracinus*-type) and eutrophic indicators represented 16-20% of the taxa. Several littoral taxa including *Tanytarsus*, and *Sergentia coracina*-type were also well-represented comprising between 27-40% of the assemblages.

In the sediment interval representing ~1820-1860, the previously dominant profundal taxon, *Chironomus anthracinus*-type, disappeared from the record as did all eutrophic indicator taxa, and the diversity of chironomids was the lowest that was observed in all the intervals analyzed. Only 9 taxa were present in this interval, in comparison to between 14 and 26 taxa in the other intervals. The cause of this taxonomic shift is uncertain, but the loss of the dominant profundal, eutrophic and anoxia indicator suggests that lower water levels, lower nutrients or improved oxygen conditions may have occurred at that time. This is contrary, however, to the increase in open-water habitat or nutrient enrichment that was inferred from the increase in planktonic diatoms that also occurred at that time. While the change in chironomid assemblages is notable, overall, there was no change in the relative contribution of littoral and profundal taxa that would suggest a large change in water levels, or in chironomid-inferred oxygen concentration that would indicate improved oxygen conditions. A similar event occurred in the 1868-1877-sample in South Bay, but given the low resolution of analyses for this time period and limited historical knowledge, the reasons for this change remain uncertain.

In the post-settlement times from the late 1800s to ~1950, the proportion of eutrophic chironomid-indicator taxa increased indicating that the bay became more nutrient enriched. Over that time period, chironomid-inferred oxygen also declined to 3 mg O_2/L from 5 mg O_2/L in the mid 1800s. This was followed by the greatest changes in the chironomid assemblages as indicated by the fluctuations in PCA scores from ~1950 to 1980. This period is first marked by a decrease in the littoral taxon *Tanytarsus* (no spur) and the first appearance of several taxa including *Limnophes, Polypedilum*, and *Chironomini*. This community shift is coincident with the record high precipitation and water levels in the early 1950s. In the early to mid 1960s during the period of record low water levels, there was a shift to increased representation of littoral taxa such as *Tanytarsus lugens*, *Corynocera oliveri*-type, *Polypedilum*, and *Corynoneura* and a decline in the profundal taxon *Procladius.* The shifts in chironomid assemblages indicate that this indicator group is sensitive to the large variations in precipitation and water levels that occurred over that time period. The relative contribution of littoral taxa remained higher in the records from the 1960s to present relative to earlier periods in the record. Of note, the chironomid-inferred oxygen concentration has increased in the last two sediment intervals from ~2000 to present, which is consistent with the reduced total phosphorus concentration inferred from the diatoms.

Figure 15. Chironomid Assemblages, PCA scores and Inferred Hypolimnetic Oxygen in North Bay



Notes: The solid and dashed lines in the PCA scores column represent PCA axis 1 and axis 2 scores, respectively. The blue crosses in the chironomid-inferred oxygen column are measured VWHO estimated from figures presented in SSEA (2013) and Schiefer et al. (2006).

5.4.2 South Bay

The chironomid assemblages in pre-settlement times from ~1750-1800 in South Bay were similar to those in North Bay with a dominance of the profundal, low-oxygen indicators *Chironomus anthracinus*-type and *Procladius* (Figure16). These two taxa, however, occurred in greater abundances in the South Bay record and chironomid-inferred oxygen concentration was lower ranging from 1.6 to 2.3 mg O_2/L VWHO. These low oxygen concentrations indicate that South Bay has naturally low oxygen levels at end-of-summer in the hypolimnion and has likely experienced periods of anoxia prior to disturbance by human settlement. Overall, a shift to lower water levels, more eutrophic conditions and lower oxygen concentrations occured following settlement, similar to that observed in the North Bay record, with some minor differences in taxonomic shifts and the timing of those shifts.

In the early pre-settlement period until ~1920, the chironomid assemblages were stable with one notable change in the late 1800s when *C. anthracinus*-type decreased in abundance and eutrophic taxa disappeared from the record. This change is very similar to the one that was noted in North Bay between ~1820 and 1860, when *C. anthracinus*-type and eutrophic taxa were absent in the assemblages. The change in the South Bay record is later than that in the North Bay record, but this difference in timing may be due to the time intervals analyzed in the two cores and potential error in the chronology. The similarity of the taxonomic changes and their timing suggest that both bays were subject to a similar event.

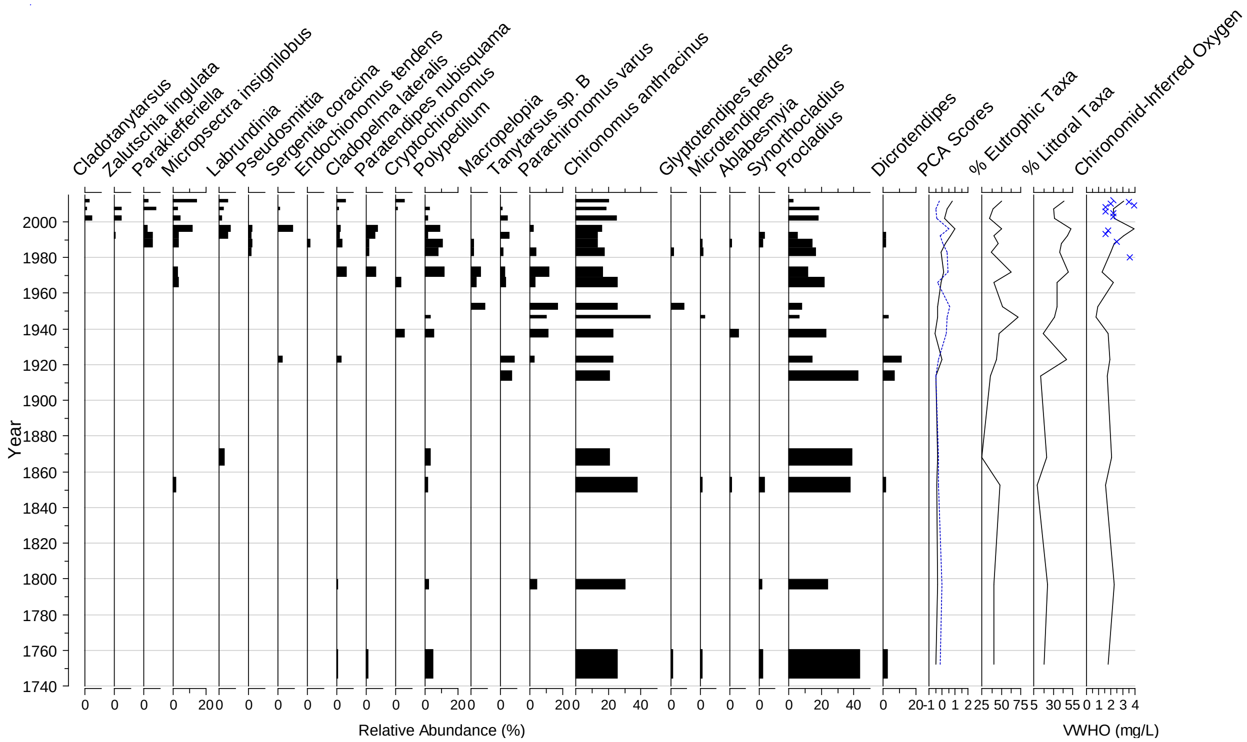
From ~1920-1950, pronounced changes in the chironomid assemblages indicate a shift to lower water levels and more productive conditions as evidenced by the increase in a large number of littoral taxa including *Dicrotendipes, Parachironomus varus, Cladopelma lateralis* and *Tanytarsus* sp. B (mendax), a decrease in the profundal taxon, *Procladius,* and greater representation of eutrophic indicators. In ~1948, the large increase in the anoxia tolerant, profundal *Chironomus anthracinus*-type, and decrease in chironomid-inferred oxygen to its lowest level in the record of 0.8 mg O_2/L VWHO would indicate pronounced anoxia. The timing of this change, however, just precedes the high precipitation event of 1951 and may reflect an increase in deepwater relative to littoral habitat with higher water levels rather than increased anoxia.

In later settlement years from ~1970 to present, changes in chironomid assemblages reflect lower water levels and likely stable oxygen levels. Several littoral taxa appear for the first time in the record or increase in abundance (*Dicrotendipes, Polypedilum, Paratendipes, Cladopelma,* and *Cladotanytarsus*) indicating overall shallower conditions and increased abundance of aquatic plants. In contrast to the North Bay record, chironomid-inferred oxygen in South Bay increased to higher levels over that time period than those inferred in pre-settlement times. It is possible, however, that the chironomid-inference model does not provide accurate estimates of oxygen over this period in South Bay. *Chironomus* and *Procladius* are taxa that can sustain periods of anoxia and have low ecological optima for oxygen in the inference model. Their decline in relative abundances, expressed as percentage of the total, however, may be more strongly related to the lower water levels indicated by the greater abundances of littoral taxa than changes in oxygen conditions. Decreases in *Chironomus* and *Procladius* abundances have been observed under relatively stable hypolimnetic oxygen conditions but general eutrophication in Lake Mendota, Wisconsin, where changes in sediment chemistry were the hypothesized causes of declines in these taxa (Lathrop 1992).

There is a possibility that some of the anoxia increase was due to more extended periods of stratification caused by warming climate. The longer the thermal stratification persists, the longer the midge taxa would be exposed to low-oxygen conditions and therefore low-oxygen taxa would be more important in the chironomid community. This hypothesis, however, is difficult to test based on the sediment data due to the confounding effect of littoral taxa in the sediment samples.

In summary, the South Bay Chironomid assemblages have responded most strongly to changes in habitat availability over the past ca. 25 years, but some minor changes also indicated some nutrient enrichment after 1940 and some periods of lower hypolimnetic oxygen levels.

Figure 16. Chironomid Assemblages, PCA scores and Inferred Hypolimnetic Oxygen in South Bay



Notes: The solid and dashed lines in the PCA scores column represent PCA axis 1 and axis 2 scores, respectively. The blue crosses in the chironomid-inferred oxygen column are measured VWHO estimated from figures presented in SSEA (2013) and Sheifer et al. (2006).

5.5 Aquatic Plant Communities

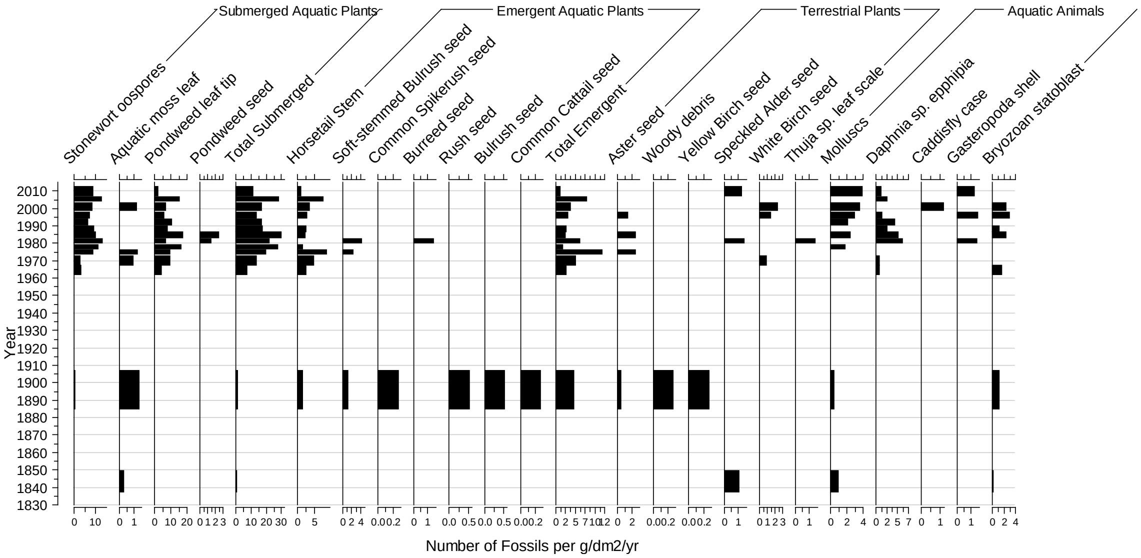
The remains of 21 specimen types (e.g., stems, leaves, seeds, shells) from 18 taxa of aquatic plants, terrestrial plants and aquatic invertebrates.were identified through macrofossil analysis of the near-shore core. Samples included remains of emergent wetland plants, submerged and floating-leaved macrophytes and terrestrial species, including trees, shrubs and herbaceous plants.

Species with similar habitat requirements were grouped together and plotted (Figure 17) to facilitate interpretation. Submerged macrophytes, such as pondweeds (*Potamogeton* sp.), macrophytic algae (Stonewort or *Chara* sp.) and aquatic mosses generally require a greater water depth than emergent species such as horsetails (*Equisetum* sp.), bullrushes (*Scirpus* sp.), spikerushes (*Eleocharis* sp.), bur-reeds (*Sparganium* sp.), cattails (*Typha* sp.) or rushes (*Juncus* sp.). There was a greater incidence of submerged vegetation in more recent samples when compared to samples from 1850 and 1910, suggesting an increase in the available dissolved nutrients in the water over time, beginning at the latest in 1965. No samples were analysed between 1910 and 1965, so the exact timing of this change cannot be inferred from the available results. There was a larger number of emergent species present in samples around 1910, which may be indicative of shallower water levels in the area at that time.

The presence of aquatic animal remains throughout the samples indicates that there has been standing water present at the site for the duration of the timeframe captured by the sediments. An increased abundance of mussels since 1980 may represent the zebra mussel invasion. There is little change in the abundance of terrestrial plant remains throughout the sediments, indicating little change in the surrounding upland vegetation.

It was also noted that samples between 1850 and 1910 had much more hydrophobic soils than samples from 1965 to 2012 (i.e. these sediments resisted dissolution in warm water, but no evidence of clay was present). These samples also had a noticeably higher sand content than the more recent samples, with a considerable portion of the sediment remains consisting of silica. High sand content in older samples and lower sand content in more recent samples, suggests an increase in sediment organic content due to the presence of increasing amounts of decaying macrophyte remains on the lake bottom.

Figure 17. Macrofossil Counts at the North Bay Near-shore Site



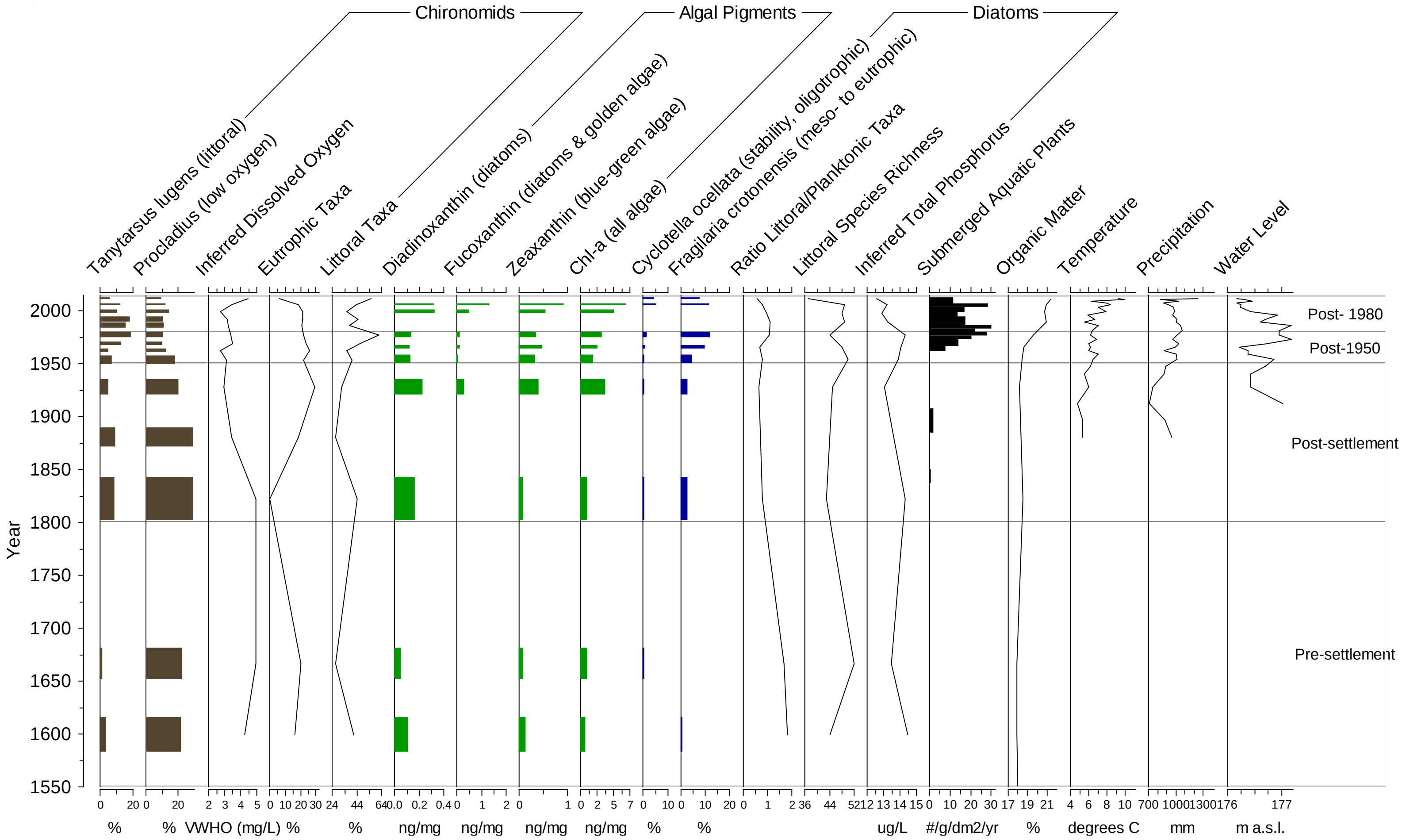
In conclusion, an increase in the presence of submerged macrophytes between 1910 and 1965 and decreasing sand concentrations in the sediment samples suggests eutrophication of the water body during this time frame. Periods of increased presence of emergent species around 1970 and in the early 2000s suggest lower water levels and retreat of the riparian habitat in the immediate area of coring.

6. Summary

6.1 North Bay Water Quality History

Sediment indicators retrieved from the North Bay core showed a variety of changes in water quality before regular monitoring activities started in the 1980s. The first noticeable, but minor change occurred during the mid-1800s, when the eutrophication indicator diatom *Fragilaria crotonensis* increased in abundance, followed by an increase in eutrophic chironomid taxa and a decrease in inferred hypolimnetic oxygen in the late 1800s (Figure 18).

Figure 18. Summary of Paleolimnological Indicators in North Bay



Notes: The time zones were based on historical data, not on any sediment data collected in this study. The unit for submerged aquatic plant is number of fossils per square decimetre and year.

The sample representing 1920-1935 showed a peak in eutrophic chironomid taxa, low inferred-DO and increased algae pigment concentrations, indicating nutrient-enriched conditions. This change coincided with a period of drought and high temperatures, possibly indicating a response to climate, but a higher-resolution study would be required to confirm any detailed relationships of sediment indicators with climate. In the subsequent sample (1950-58), the low oxygen persisted and the diatom assemblages started to show a moderate nutrient enrichment signal as well, with increases in *Fragilaria crotonensis* and diatom-inferred TP. The latter part of this period corresponds to the time when cottage development increased in the area and therefore the observed changes likely reflect a moderate increase in nutrient input from land disturbance.

Around 1980, the eutrophic diatom taxon, *F. crotonensis,* attained the highest levels recorded in North Bay, sediment organic matter content increased and submerged aquatic macrophytes became more abundant, indicating the maximum extent of nutrient enrichment at that time in North Bay. There was also a peak in littoral chironomid taxa and an increase in littoral diatom taxa, which may be related to the record-low water levels in the late 1960s and possibly increased water clarity following the zebra mussel invasion in the late 1980s. After 1980, the eutrophication indicator *F. crotonensis* maintained its relative abundance and the lower oxygen levels persisted for most of the time, except the most recent years. Low hypolimnetic oxygen is usually linked to high nutrient concentrations and measured data indicate variable hypolimnetic oxygen and TP concentrations since the early 1980s, but no trend, confirming the trends in sediment indicators. The diatom-inferred TP decreased after 1980, which is not supported by measured data. This discrepancy may either be due to a seasonal signal in the diatom assemblages that is different from that at the time of the year when *F. crotonensis* blooms, or the reconstructions are biased by the larger importance of littoral species.

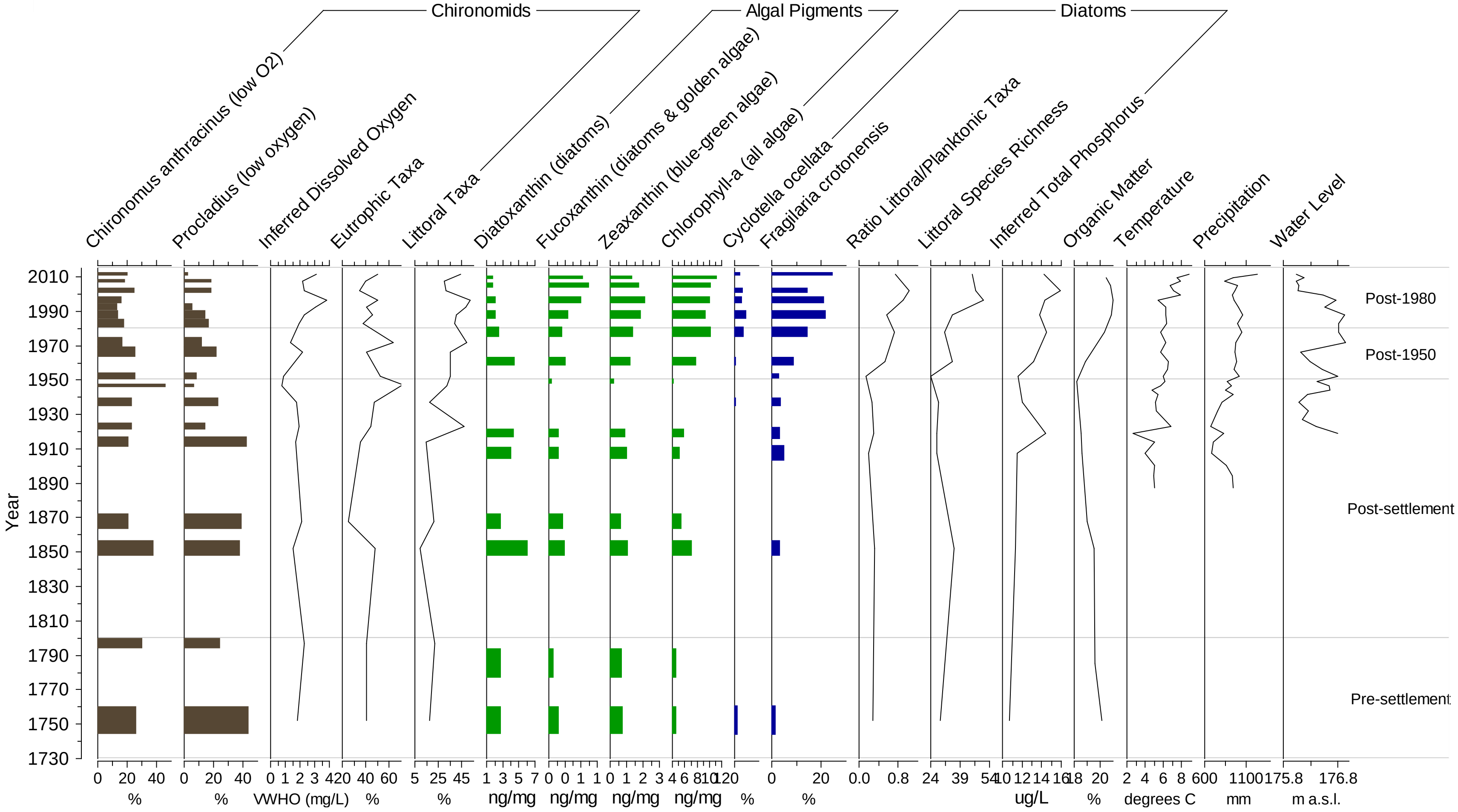
In summary, lower hypolimnetic oxygen, more abundant eutrophic diatom species as well as increased organic matter and aquatic plant abundances indicate that some nutrient enrichment has occurred in North Bay in response to shoreline development in the mid-20th century, peaking approximately in 1980. While the anoxia pattern was significant, there was comparatively little variation in diatom-inferred TP concentrations and algae assemblages since pre-settlement times, indicating that either spring and fall flushing remove recycled hypolimnetic phosphorus from the bay before it could affect algal assemblages or that a different factor, for example, prolonged stratification, played a role in anoxia patterns. Both the chironomid and diatom assemblages indicated that the availability of littoral (i.e., shallow-water) habitat has increased in North Bay since the late 1960s.

6.2 South Bay Water Quality History

The South Bay sediment record showed similar midge larvae and diatom assemblages as well as similar historical changes to that from North Bay, with some changes that were more or less pronounced (Figure 19). There was a slight increase in algal production in the mid-1800s, as indicated by increases in algal pigments and *F. crotonensis*, but no change in hypolimnetic oxygen conditions.

In the period from 1960 to 1980, *F. crotonensis* increased more, diatom-inferred TP increased by 4 ug/L and sediment organic matter increased as well, indicating increased aquatic productivity in response to nutrient enrichment. There was also a higher abundance of eutrophic chironomid taxa, and some low hypolimnetic oxygen occurrences, but these indicators were variable in the following decades.

Figure 19. Summary of Paleolimnological Indicators in South Bay



Notes: The time zones were based on historical data, not on any sediment data collected in this study.

Around 1980, the total algal abundance, including that of blue-green algae, increased, while the diatom pigment levels decreased, indicating a shift in the composition of major phytoplankton groups towards non-diatoms. Diatom-inferred TP increased to maximum values of 15 to 16 ug/L and organic matter content reached the highest historical values ca. 1990. The increase in littoral midge and diatom species after 1980 was more significant in South Bay than in North Bay.

Two minor recent changes in algae remains that occurred in both North and South Bay are notable. The oligotrophic diatom *Cyclotella ocellata* appeared around 1980 in both bays and reached the highest abundance in North Bay around 2000, possibly indicating a more stable water column associated with increased temperature. The pigment of golden algae (Chrysophytes), Fucoxanthin, has also increased since the year 2000, a change that has been observed in contemporary phytoplankton studies in Georgian Bay embayments and other Ontario lakes, but the reasons for which have not been confirmed. Given the almost simultaneous occurrence of these changes, it is possible that the increase of chrysophytes is also related to warming and water column stability.

6.3 Comparison Between North and South Bay

The water quality and aquatic biota in North and South Bay are generally very similar and have undergone similar historical changes in the past. Both Bays were naturally mesotrophic and are still today, although at different levels, as discussed below. The aquatic ecosystems of both bays have been modified by human activities in the watersheds before water quality monitoring began. A minor nutrient enrichment was recorded during the logging period in the 19th century, while a moderate nutrient enrichment after approximately 1950 likely resulted from shoreline development. An increased availability of habitat for attached algae and insects since the late 1960s, which intensified after 1980, was observed in both bays, likely reflecting a combination of lower water levels, increased water clarity and increased aquatic plant growth. The recent changes in algae communities, such as increased abundances of golden algae (Chrysophytes) and the diatom *Cyclotella ocellata*, were also observed in both bays, indicating that these changes are part of larger-scale patterns (e.g., climate change) that are independent of local factors.

Differences between North and South Bay were mainly observed in the pre-settlement nutrient status and the degree to which the water quality and biota have responded to land use activities. Based on fossil diatom assemblages, North Bay was naturally mesotrophic, with TP concentrations at ~ 13 ug/L. This naturally slightly elevated nutrient status compared to the majority of shield lakes is possibly due to the depth and potential for internal phosphorus load, plus inputs from wetlands in the northeastern part of the watershed. South Bay was at the lowest end of the mesotrophic spectrum, with diatom-inferred TP concentrations at ca. 11 ug/L. Based on fossil midge larvae, the pre-settlement volume-weighted hypolimnetic oxygen was above 4 mg/L in North Bay and around 2 mg/L in South Bay. In pre-settlement times, the larger flushing rate of South Bay may have prevented the expression of potential phosphorus recycling from deep-water anoxia in terms of productivity in the epilimnion.

While North Bay bottom-water oxygen levels have been lower since the logging period, the algae communities and nutrient concentrations changed only slightly over the entire period of record. In South

Bay, oxygen conditions deteriorated only shortly around 1950 and improved recently, while algae assemblages showed a stronger nutrient-enrichment response since the 1960s. These discrepancies indicate that North and South Bay display different sensitivities to nutrient enrichment from the watershed. One main reason for that is likely the much larger watershed of South Bay that would continuously provide nutrient-enriched waters to South Bay. Although South Bay has a higher flushing rate than North Bay, which can reduce sensitivity to eutrophication from local sources by dilution, , this is probably not the only process in South Bay. The South Bay watershed also includes some drainage from the Severn River, which drains some off-shield areas of more intewnroisive land use and is hence more enriched. which contains enriched waters from This has likely contributed to the historical eutrophication of South Bay, in addition to local shoreline development.

The differing hydrology may be the reason for another, different, process that results in higher sensitivity of South Bay to nutrient enrichment than North Bay. Conductivity surveys have shown that South Bay is continuously dominated by Severn River influx, with limited or no mixing with Georgian Bay open waters. North Bay, on the other hand, was shown to receive large inputs of lower-conductivity, lower-nutrient Georgian Bay waters during a windy period in 2006. Assuming that this water exchange was not an isolated incidence, such events can significantly dilute any nutrient inputs from the watershed or from sediment recycling and thereby reduce the sensitivity of North Bay to nutrient enrichment. More detailed, year-round conductivity surveys of both bays, but in particular of North Bay, would provide more insight into the mixing patterns with the Georgian Bay open waters and better define the importance of this mechanism for embayment nutrient status.

7. Conclusion

The analysis of sediment cores retrieved from North and South Bay, two sheltered bays on the eastern coast of Georgian Bay, has provided a historical perspective on water quality at these two sites. The multiple lines of evidence used to reconstruct past water quality included lead-210 sediment chronologies, algal pigments, diatom assemblages, diatom-inferred TP, chironomid assemblages, chironomid-inferred bottom-water oxygen, aquatic macrofossils and sediment organic matter.

The main conclusions of this study were as follows:

- Before European settlement, North Bay (TP 13 ug/L) and South Bay (TP 11 ug/L) were mesotrophic, while South Bay had naturally more anoxia than North Bay;
- With the onset of watershed deforestation in the 19th century, minor shifts in algae and midge larvae communities were observed in both bays, consistent with slight nutrient enrichment;
- The largest changes in diatom algae and midge larvae communities as well as overall algae production were observed in the 1950s/1960s and were indicative of additional nutrient enrichment. These were likely related to cottage development and watershed alterations, with a stronger effect seen in South Bay than in North Bay;

- Significant shifts in algae and midge larvae assemblages to more littoral communities in the late 1960s and again after 1980 indicate increased availability of shallow water habitat, likely due to reduced water levels, increased water clarity and increased aquatic macrophyte abundance;
- A minor, but consistent diatom algae change after 1980 indicated increased water column stability, possibly related to climate warming, and coincided with the increased abundance of chrysophyte algae, a regionally reported phenomenon.
- The more pronounced nutrient enrichment of South Bay is likely due to the influence of the Severn River watershed and the more limited water exchange with the Georgian Bay open waters compared to North Bay in addition to shoreline development.
- Overall, water quality in North and South Bays appears to be influenced by upstream influences (i.e., the Severn River for South Bay) and exchange with Georgian Bay (North Bay) as well as by local shoreline disturbance.
- The aquatic biota have responded as strongly to changes in habitat in the past ca. 30 years as to any water quality changes since pre-settlement times.

The Georgian Bay embayment sediment study filled an important data gap by describing conditions predating the water quality monitoring programs that started in 1980. This places existing water quality measurements into context with the natural background conditions and historic changes. By matching observed patterns in the sediment cores with known historical land use activities, and by comparing the records of the two hydrologically different bays, we gained insight into the timing and causes of water quality changes. We also identified differing sensitivity to nutrient enrichment between the bays. These pieces of information put the currently collected monitoring data into a long-term perspective and help direct future monitoring and stewardship efforts.

The results presented here were inferred from three sediment cores that were interpreted at a coarse temporal resolution. Increasing the spatial and temporal resolution by, for example, sampling more sites and analysing cores in finer sections would improve the power of the interpretation. Comparison of the upper and lower sections of the cores in this study provided a good comparison between historic and current conditions in South Bay and North Bay. Analysis of cores taken from uninhabited embayments would provide better resolution of the relative roles of shoreline development and other factors such as water levels and climate change in the changes observed in the North and South Bay cores since 1950.

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Appendix A. Lead-210 Results

North Bay Nearshore Core Lead-210 Data

Section of Core		Total Dry	Cum Dry	%	Sample	209 Po	Po Sample Extracted			Date Po Counted			Time	Counting	209 Po	210 Po	209 Po	210 Po
Top	Bottom	Weight	Weight	Moisture	Weight	Weight		Date					Since	Time	Counts	Counts		
					used								Extractn					
(cm)	(cm)	(g)	(g)		(mg)	(mg)	(year)	(month)	(day)	(year)	(month)	(day)	(day)	(sec.)			cps	cps
0	0.5	3.56	3.56	91%	600	100	12	11	4	12	11	15	11	63423	1071	2483	0.017	0.039
0.5	1	1.91	5.47	85%			12	11	4	12	11							
1	1.5	2.82	8.29	84%	569	101	12	11	4	12	11	16	12	84035	1490	2804	0.018	0.033
1.5	2	2.37	10.66	84%			12	11	4	12	11							
2	2.5	2.45	13.12	83%	558	101	12	11	4	12	11	16	12	84039	1341	1789	0.016	0.021
2.5	3	2.24	15.36	83%			12	11	4	12	11							
3	3.5	2.62	17.98	77%	619	100	12	11	4	12	11	16	12	84042	1347	1349	0.016	0.016
3.5	4	2.62	20.60	82%			12	11	4	12	11							
4	4.5	2.91	23.52	81%	557	98	12	11	4	12	11	16	12	84044	1384	905	0.016	0.011
4.5	5	2.72	26.24	82%			12	11	4	12	11							
5	5.5	3.81	30.05	79%	537	102	12	11	4	12	11	21	17	181567	2934	1868	0.016	0.010
5.5	6	4.19	34.24	75%			12	11	4	12	11							
6	6.5	5.18	39.42	72%	557	102	12	11	4	12	11	18	14	151234	3046	1153	0.020	0.008
6.5	7	4.51	43.93	74%			12	11	4	12	11							
7	7.5	5.37	49.30	71%	504	101	12	11	4	12	11	18	14	151271	2521	764	0.017	0.005
7.5	9	11.31	60.61	71%			12	11	4	12	11							
9	9.5	6.14	66.75	71%	658	100	12	11	4	12	11	18	14	151303	2522	1010	0.017	0.007
9.5	11	22.03	88.78	72%			12	11	4	12	11							
11	11.5	7.11	95.89	64%	591	100	12	11	4	12	11	19	15	94700	1996	289	0.021	0.003
11.5	13	20.64	116.53	66%			12	11	4	12	11							
13	13.5	7.18	123.71	64%	622	100	12	11	4	12	11	22	18	58650	487	75	0.008	0.001
13.5	14	7.46	131.17	63%			12	11	4	12	11							
14	14.5	5.92	137.09	64%	623	101	12	11	4	12	11	19	15	94673	1781	265	0.019	0.003
14.5	15	5.76	142.85	68%			12	11	4	12	11							
15	16	11.91	154.76	69%	545	102	12	11	4	12	11	19	15	94678	1828	271	0.019	0.003
16	17	12.63	167.39	68%			12	11	4	12	11							
17	18	11.55	178.94	71%	463	100	12	11	4	12	11	19	15	94634	1675	184	0.018	0.002
18	19	16.51	195.45	58%			12	11	4	12	11							
19	20	12.28	207.72	70%	522	96	12	11	4	12	11	21	17	181579	3020	450	0.017	0.002

North Bay Nearshore Core Lead-210 Data

Section of Core		Carrier Yield (%)	210 Po Meas (Bq/g)	Pb-210 (Bq/g)	Precisn 1 STD (%)	Interpolate Pb-210 (Bq/g)	Pb-210xs (Bq/g)	Pb-210xs in the core (Bq/cm2)	Mass Pb-210xs (Bq)	Age at top of sectn (year)	CRS Sedimnt Accum Rate (g/m2/yr)	STD 210 xs (Bq)	CV on 210 xs (%)	CV in SAR (%)	STD in date (years)
Top (cm)	Bottom (cm)														
0	0.5	57.777	0.434	0.459	3.656	0.459	0.428	1.525	9.264	2013	174	0.017	3.952	5.9	0.0
0.5	1					0.429	0.398	0.760	7.739	2007	157	0.002	0.544	Interpolated	
1	1.5	60.065	0.376	0.399	3.206	0.399	0.368	1.038	6.979	2003	153	0.013	3.525	5.4	0.5
1.5	2					0.344	0.313	0.741	5.940	1998	153	0.002	0.693	Interpolated	
2	2.5	54.056	0.271	0.288	3.612	0.288	0.257	0.631	5.199	1994	163	0.011	4.132	6.2	1.1
2.5	3					0.241	0.210	0.471	4.568	1990	175	0.002	1.032	Interpolated	
3	3.5	54.839	0.182	0.193	3.852	0.193	0.162	0.426	4.098	1986	203	0.008	4.775	7.0	1.8
3.5	4					0.165	0.134	0.352	3.672	1983	220	0.002	1.612	Interpolated	
4	4.5	57.494	0.129	0.137	4.275	0.137	0.106	0.310	3.319	1980	251	0.006	5.879	8.6	2.8
4.5	5					0.143	0.112	0.305	3.009	1976	217	0.002	1.938	Interpolated	
5	5.5	54.205	0.136	0.148	2.960	0.148	0.117	0.446	2.704	1973	186	0.005	4.172	6.2	2.5
5.5	6					0.116	0.085	0.356	2.258	1967	214	0.002	2.551	Interpolated	
6	6.5	67.561	0.078	0.084	3.458	0.084	0.053	0.273	1.903	1962	291	0.004	6.854	9.9	5.0
6.5	7					0.078	0.048	0.214	1.629	1957	276	0.002	4.558	Interpolated	
7	7.5	56.456	0.068	0.073	4.130	0.073	0.042	0.228	1.415	1952	269	0.004	8.785	12.6	7.6
7.5	9					0.073	0.042	0.480	1.187	1946	225	0.002	5.106	Interpolated	
9	9.5	57.031	0.068	0.073	3.724	0.073	0.043	0.261	0.708	1930	134	0.003	8.204	11.8	9.7
9.5	11					0.052	0.021	0.455	0.447	1915	174				
11	11.5	72.115	0.028	0.030	6.294	0.030	-0.001	-0.008	-0.008	1907	106			Background	
11.5	13					0.030	0.000	0.000							
13	13.5	28.410	0.028	0.030	12.404	0.030	0.000								
13.5	14					0.030	0.000								
14	14.5	63.728	0.027	0.029	6.584	0.029	0.000								
14.5	15					0.031	0.000								
15	16	64.765	0.031	0.034	6.509	0.034	0.000								
16	17					0.031	0.000								
17	18	60.560	0.027	0.029	7.766	0.029	0.000								
18	19					0.031	0.000								
19	20	59.277	0.031	0.034	5.053	0.034	0.000								

North Bay Deep-Water Core Lead-210 Data

Section of Core		Total Dry	Cum Dry	%	Sample	209 Po	Po Sample Extracted			Date Po Counted			Time	Counting	209 Po	210 Po	209 Po	210 Po
Top	Bottom	Weight	Weight	Moisture	Weight	Weight		Date					Since	Time	Counts	Counts		
					used								Extractn					
(cm)	(cm)	(g)	(g)		(mg)	(mg)	(year)	(month)	(day)	(year)	(month)	(day)	(day)	(sec.)			cps	cps
0	0.5	1.17	1.17	94%	627	99	12	11	17	12	11	28	11	110764	2182	9048	0.0197	0.0817
0.5	1	0.64	1.81	95%														
1	1.5	1.66	3.47	90%	609	99	12	11	17	12	12	2	15	169677	4387	11922	0.0259	0.0703
1.5	2	1.37	4.84	91%														
2	2.5	1.51	6.35	90%	627	98	12	11	17	12	11	29	12	62051	1219	4875	0.0196	0.0786
2.5	3	1.87	8.22	89%														
3	3.5	2.17	10.39	87%	498	99	12	11	17	12	11	29	12	62051	1183	3626	0.0191	0.0584
3.5	4	1.83	12.22	89%														
4	4.5	2.09	14.31	87%	508	99	12	11	17	12	11	29	12	62057	1205	3556	0.0194	0.0573
4.5	5	0.23	14.53	99%														
5	5.5	2.44	16.97	86%	628	100	12	11	17	12	12	2	15	169663	3164	10081	0.0186	0.0594
5.5	6	2.08	19.04	88%														
6	6.5	2.43	21.48	87%	326	101	12	11	17	12	11	29	12	47142	867	917	0.0184	0.0195
6.5	7	2.40	23.88	85%														
7	7.5	2.42	26.30	86%	453	98	12	11	17	12	11	29	12	47186	1110	1078	0.0235	0.0228
7.5	9	7.15	33.45	85%														
9	9.5	6.27	39.72	87%	434	100	12	11	17	12	11	29	12	47208	1024	612	0.0217	0.013
9.5	11	7.94	47.66	86%														
11	12	5.41	53.07	87%	571	101	12	11	17	12	11	29	12	47237	888	689	0.0188	0.0146
12	13	5.41	58.47	85%														
13	14	5.85	64.32	86%	539	101	12	11	17	12	11	30	13	62195	1211	461	0.0195	0.0074
14	15	5.37	69.70	85%														
15	16	5.80	75.50	84%	533	101	12	11	17	12	11	30	13	62174	1122	351	0.018	0.0056
16	17	4.94	80.44	86%														
17	18	7.56	88.00	79%	538	101	12	11	17	12	11	30	13	62153	1123	254	0.0181	0.0041
18	19	7.68	95.67	79%														
19	20	5.82	101.50	85%	344	100	12	11	17	12	11	30	13	62071	1410	172	0.0227	0.0028
20	21	4.58	106.07	87%														
21	22	5.48	111.55	83%	521	100	12	11	17	12	11	27	10	40700	795	163	0.0195	0.004
22	23	5.68	117.23	86%														
23	24	6.69	123.91	82%	351	100	12	11	17	12	11	27	10	40677	807	119	0.0198	0.0029
24	25	8.38	132.29	76%														
25	26	7.55	139.84	80%	574	99	12	11	17	12	11	27	10	40642	826	194	0.0203	0.0048

North Bay Deep-Water Core Lead-210 Data

Section of Core		Carrier	210 Po	Pb-210	Precisn	Interpolate	Pb-210xs	Pb-210xs	Mass	Age	CRS	STD	CV	CV	STD
Top	Bottom	Yield	Meas		1 STD	Pb-210		in the	Pb-210xs	at top	Sedimnt	210 xs	on 210 xs	in SAR	in date
								core		of sectn	Accum				
											Rate				
(cm)	(cm)	(%)	(Bq/g)	(Bq/g)	(%)	(Bq/g)	(Bq/g)	(Bq/cm2)	(Bq)	(year)	(g/m2/yr)	(Bq)	(%)	(%)	(years)
0	0.5	68.083	0.736	0.7778	2.385	0.778	0.730	0.851	18.145	2013	200.14	0.02	2.58	4.16	0
0.5	1					0.657	0.609	0.392	17.294	2011	228.69	0.00	0.53	Interpolated	
1	1.5	89.356	0.4966	0.5355	1.7659	0.535	0.488	0.809	16.902	2010	279.02	0.01	2.05	3.52	0.0804
1.5	2					0.641	0.593	0.816	16.093	2009	218.46	0.00	0.55	Interpolated	
2	2.5	68.587	0.7027	0.7463	3.2023	0.746	0.699	1.053	15.277	2007	176.10	0.02	3.45	5.27	0.292
2.5	3					0.737	0.689	1.287	14.224	2005	166.20	0.00	0.47	Interpolated	
3	3.5	65.89	0.685	0.7275	3.3483	0.728	0.680	1.478	12.936	2002	153.24	0.02	3.61	5.49	0.5975
3.5	4					0.707	0.660	1.206	11.458	1998	139.93	0.00	0.49	Interpolated	
4	4.5	67.108	0.6465	0.6866	3.3333	0.687	0.639	1.334	10.252	1994	129.21	0.02	3.62	5.49	1.0089
4.5	5					0.651	0.603	0.136	8.918	1990	119.08	0.00	0.54	Interpolated	
5	5.5	63.807	0.5703	0.6149	2.0378	0.615	0.567	1.382	8.782	1989	124.67	0.01	2.28	3.80	0.8863
5.5	6					0.503	0.456	0.946	7.400	1984	130.84	0.00	0.71	Interpolated	
6	6.5	62.303	0.3684	0.3912	4.737	0.391	0.344	0.836	6.454	1979	151.26	0.02	5.47	8.00	2.659
6.5	7					0.321	0.274	0.657	5.618	1975	165.46	0.00	1.19	Interpolated	
7	7.5	82.13	0.2362	0.2508	4.2761	0.251	0.203	0.493	4.962	1971	196.57	0.01	5.51	8.05	3.3572
7.5	9					0.208	0.160	1.145	4.469	1967	224.82	0.00	2.03	Interpolated	
9	9.5	74.216	0.1548	0.1644	5.1094	0.164	0.117	0.733	3.324	1958	229.04	0.01	7.70	11.08	6.0489
9.5	11					0.164	0.117	0.926	2.591	1950	178.97	0.00	2.78	Interpolated	
11	12	63.683	0.1543	0.1639	5.0769	0.164	0.116	0.629	1.665	1936	115.29	0.01	7.68	11.04	8.4818
12	13					0.125	0.077	0.418	1.036	1920	108.08	0.00	4.20	Interpolated	
13	14	65.96	0.0802	0.0856	5.4726	0.086	0.038	0.223	0.618	1904	130.81	0.01	14.97	21.26	23.112
14	15					0.078	0.031	0.166	0.396	1889	103.29	0.00	10.52	Interpolated	
15	16	61.133	0.0666	0.0711	6.1158	0.071	0.024	0.137	0.230	1872	78.41	0.01	22.98	32.56	45.766
16	17					0.061	0.014	0.067	0.093	1843	55.26	0.00	24.00	Interpolated	
17	18	61.209	0.0477	0.051	6.948	0.051	0.003	0.026	0.026	1802	60.91	0.00	139.64	197.49	416.06
18	19														
19	20	77.722	0.0399	0.0426	8.0766									Background	
20	21														
21	22	66.833	0.0442	0.0465	8.5982										
22	23														
23	24	67.88	0.0472	0.0497	9.8196										
24	25														
25	26	70.24	0.0455	0.0479	7.9783										

South Bay Lead-210 Data

Section of Core		Total Dry	Cum Dry	%	Sample	209 Po	Po Sample Extracted			Date Po Counted			Time	Counting	209 Po	210 Po	209 Po
Top	Bottom	Weight	Weight	Moisture	Weight	Weight		Date					Since	Time	Counts	Counts	
					used								Extractn				
(cm)	(cm)	(g)	(g)		(mg)	(mg)	(year)	(month)	(day)	(year)	(month)	(day)	(day)	(sec.)			cps
0	1	2.41	2.41	96%	653	101	12	11	9	12	11	22	13	58646	671	1786	0.011
1	2	3.39	5.80	90%													
2	3	3.37	9.17	90%	556	100	12	11	9	12	11	27	18	40723	573	1164	0.014
3	4	3.44	12.61	90%													
4	5	3.46	16.07	89%	538	96	12	11	9	12	11	23	14	112094	1412	3040	0.013
5	6	2.51	18.58	93%													
6	7	3.99	22.58	88%	383	99	12	11	9	12	11	23	14	112119	1541	2158	0.014
7	8	4.18	26.76	88%													
8	9	4.61	31.36	87%	434	96	12	11	9	12	11	23	14	112124	2273	3127	0.020
9	10	4.13	35.49	87%													
10	11	4.83	40.33	86%	672	98	12	11	9	12	11	23	14	112134	1820	3433	0.016
11	12	4.51	44.84	87%													
12	13	4.85	49.68	86%	524	99	12	11	9	12	11	24	15	76159	1284	1433	0.017
13	14	4.70	54.38	85%													
14	15	5.03	59.41	84%	634	99	12	11	9	12	11	24	15	76200	1182	939	0.016
15	16	6.22	65.63	83%													
16	17	5.56	71.19	83%	612	99	12	11	9	12	11	24	15	76214	1181	658	0.015
17	18	5.25	76.44	84%													
18	19	5.71	82.14	83%	596	99	12	11	9	12	11	24	15	76200	1186	589	0.016
19	20	5.43	87.57	84%													
20	21	5.92	93.49	81%	442	96	12	11	9	12	11	25	16	77865	1018	465	0.013
21	22	6.63	100.11	82%													
22	23	6.38	106.49	81%	457	97	12	11	9	12	11	25	16	77879	1319	510	0.017
23	24	5.46	111.95	83%													
24	25	6.34	118.29	82%	312	99	12	11	9	12	11	25	16	77899	1602	382	0.021
25	26	6.76	125.06	82%													
26	27	6.25	131.30	82%	374	102	12	11	9	12	11	25	16	77913	1330	383	0.017
27	28	5.81	137.12	83%													
28	29	6.60	143.72	81%	470	101	12	11	9	12	11	26	17	99446	1455	462	0.015
29	30	6.26	149.98	81%													
30	31	6.42	156.40	81%	375	100	12	11	9	12	11	26	17	99467	1749	456	0.018
31	32	6.13	162.53	81%													
32	33	6.66	169.19	81%	561	100	12	11	9	12	11	26	17	99488	1735	586	0.017
33	34	5.56	174.74	84%													
34	35	6.87	181.61	80%	596	100	12	11	9	12	11	26	17	99506	1737	655	0.017

Section of Core		210 Po	Carrier	210 Po	Pb-210	Precisn	Interpolate	Pb-210xs	Pb-210xs	Mass	Age	CRS	STD	CV	CV	STD
Top	Bottom		Yield	Meas		1 STD	Pb-210		in the	Pb-210xs	at top	Sedimnt	210 xs	on 210 xs	in SAR	in date
									core		of sectn	Accum				
(cm)	(cm)	cps	(%)	(Bq/g)	(Bq/g)	(%)	(Bq/g)	(Bq/g)	(Bq/cm2)	(Bq)	(year)	(g/m2/yr)	(Bq)	(%)	(%)	(years)
0	1	0.030	38.760	0.463	0.494	4.528	0.494	0.426	1.024	20.296	2013	384.2	0.023	5.34	7.813	0.000
1	2						0.472	0.403	1.367	19.271	2011	384.9	0.004	0.99	Interpolated	
2	3	0.029	48.143	0.411	0.450	5.103	0.450	0.381	1.285	17.904	2008	378.5	0.023	6.11	8.871	0.358
3	4						0.456	0.388	1.336	16.620	2006	345.1	0.004	1.03	Interpolated	
4	5	0.027	44.895	0.432	0.463	3.221	0.463	0.395	1.365	15.284	2003	311.8	0.015	3.91	5.884	0.537
5	6						0.450	0.381	0.958	13.919	2000	293.9	0.004	1.05	Interpolated	
6	7	0.019	47.501	0.407	0.437	3.335	0.437	0.368	1.470	12.961	1998	283.7	0.015	4.10	6.137	0.886
7	8						0.402	0.333	1.393	11.491	1994	277.7	0.004	1.20	Interpolated	
8	9	0.028	72.251	0.342	0.367	2.756	0.367	0.298	1.376	10.097	1990	272.5	0.011	3.64	5.528	1.242
9	10						0.349	0.281	1.159	8.722	1985	250.1	0.004	1.42	Interpolated	
10	11	0.031	56.666	0.309	0.332	2.900	0.332	0.263	1.273	7.563	1981	231.4	0.010	3.96	5.943	1.888
11	12						0.294	0.225	1.015	6.290	1975	225.0	0.004	1.78	Interpolated	
12	13	0.019	58.267	0.237	0.256	3.843	0.256	0.187	0.907	5.275	1969	227.1	0.011	5.67	8.263	3.582
13	14						0.203	0.134	0.632	4.368	1963	261.7	0.004	2.97	Interpolated	
14	15	0.012	53.610	0.139	0.150	4.371	0.150	0.082	0.412	3.736	1958	367.7	0.008	9.40	13.444	7.320
15	16						0.130	0.061	0.381	3.324	1954	436.9	0.004	6.53	Interpolated	
16	17	0.009	53.554	0.101	0.109	4.865	0.109	0.041	0.226	2.943	1950	582.0	0.007	16.33	23.179	14.400
17	18						0.105	0.036	0.190	2.717	1948	606.1	0.004	11.08	Interpolated	
18	19	0.008	53.791	0.093	0.100	5.041	0.100	0.031	0.180	2.527	1946	646.7	0.006	20.44	28.975	19.421
19	20						0.110	0.042	0.227	2.348	1943	451.2	0.004	9.54	Interpolated	
20	21	0.006	46.596	0.112	0.121	5.597	0.121	0.052	0.310	2.120	1940	326.3	0.008	15.01	21.325	15.498
21	22						0.110	0.042	0.278	1.811	1935	348.0	0.004	9.54	Interpolated	
22	23	0.007	59.740	0.092	0.100	5.214	0.100	0.031	0.201	1.533	1929	392.4	0.007	20.88	29.598	24.601
23	24						0.096	0.028	0.150	1.332	1925	389.3	0.004	14.51	Interpolated	
24	25	0.005	71.074	0.085	0.092	5.694	0.092	0.024	0.150	1.182	1921	402.3	0.007	27.89	39.487	36.126
25	26						0.094	0.025	0.172	1.032	1917	327.0	0.004	15.74	Interpolated	
26	27	0.005	57.261	0.088	0.096	5.799	0.096	0.027	0.170	0.860	1911	254.9	0.007	25.18	35.663	36.278
27	28						0.090	0.021	0.123	0.690	1904	263.4			Interpolated	
28	29	0.005	49.564	0.077	0.084	5.340	0.084	0.015	0.099	0.567	1897	304.0			2.000	2.302
29	30						0.084	0.016	0.099	0.468	1891	238.3			Interpolated	
30	31	0.005	60.163	0.078	0.085	5.258	0.085	0.017	0.107	0.369	1884	178.9			2.000	2.579
31	32						0.079	0.011	0.067	0.262	1873	193.7			Interpolated	
32	33	0.006	59.668	0.068	0.074	4.778	0.074	0.005	0.035	0.196	1863	302.7			2.000	2.987
33	34						0.076	0.007	0.039	0.161	1857	183.1			Interpolated	
34	35	0.007	59.726	0.071	0.077	4.585	0.077	0.009	0.062	0.122	1848	109.4			2.000	3.293

Section of Core		Total Dry	Cum Dry	%	Sample	209 Po	Po Sample Extracted			Date Po Counted			Time	Counting	209 Po	210 Po	209 Po
Top	Bottom	Weight	Weight	Moisture	Weight	Weight		Date					Since	Time	Counts	Counts	
					used								Extractn				
(cm)	(cm)	(g)	(g)		(mg)	(mg)	(year)	(month)	(day)	(year)	(month)	(day)	(day)	(sec.)			cps
35	36	6.80	188.41	82%													
36	37	6.73	195.13	82%	529	100	13	5	16	13	5	26	10	140353	2409	746	0.017
37	38	6.01	201.15	82%	623	100	13	5	16	13	5	26	10	140478	2415	920	0.017
38	39	6.80	207.94	82%													
39	40	6.87	214.81	82%	484	100	13	2	4	13	2	9	5	60926	1439	387	0.024
41217					368	100	12	11	4	12	11	21	17	181561	3162	6385	0.017
					388	102	12	11	4	12	11	21	17	181550	2607	5351	0.014
41222					356	100	12	11	9	12	11	22	13	58664	714	1478	0.012
					417	100	12	11	9	12	11	22	13	58669	968	2276	0.016
41230					439	100	12	11	17	12	11	28	11	110809	2347	5874	0.021
					345	99	12	11	17	12	11	28	11	110790	2465	4388	0.022

Section of Core		210 Po	Carrier	210 Po	Pb-210	Precisn	Interpolate	Pb-210xs	Pb-210xs	Mass	Age	CRS	STD	CV	CV	STD
Top	Bottom		Yield	Meas		1 STD	Pb-210		in the	Pb-210xs	at top	Sedimnt	210 xs	on 210 xs	in SAR	in date
									core		of sectn	Accum				
(cm)	(cm)	cps	(%)	(Bq/g)	(Bq/g)	(%)	(Bq/g)	(Bq/g)	(Bq/cm2)	(Bq)	(year)	(g/m2/yr)	(Bq)	(%)	(%)	(years)
35	36						0.073	0.005	0.033	0.060	1825	100.4			Interpolated	
36	37	0.005	58.726	0.066	0.069	4.190	0.069	0.001	0.005	0.027	1800	320.1			2.000	
37	38	0.007	58.820	0.069	0.072	3.874	0.072	0.004	0.023	0.023	1794	48.4			2.000	
38	39															
39	40	0.006	80.812	0.062	0.064	5.726	0.064									
41217		0.035	59.587	0.617	0.672	2.175										
		0.029	48.168	0.607	0.661	2.388										
41222		0.025	41.643	0.654	0.698	4.558										
		0.039	56.452	0.634	0.677	3.837										
41230		0.053	72.469	0.641	0.677	2.442										
		0.040	76.895	0.574	0.607	2.517										

Appendix B. Complete Pigment Data

									Chl-C2			**Pheophorbide-a**		
	DEPTH						fi0l		Retention T	Intercept	Slope	Retention T	Intercept	Slope
Sample	Top of	Bottom of				organic	extraction	volume	11.2	-1.4E+07	91910691	16.5 min	81.6	9121.49
Name	interval	interval	LOI 950	LOI 550	dry mass	mass	volume	injected	Fluor453	conc		pda410	conc	
	cm	cm	%	%	g	ug	ml	ml	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.
NB0.5-1	0.5	1	3.3	21.3	0.43	91564	4	0.25	220227	0.158	0.000028	119040	13.0416	0.0023
NB2-2.5	2	2.5	2.8	20.9	0.44	91344	5	0.25	9870403	0.263	0.000058	96662	10.5882	0.0023
NB3-3.5	3	3.5	3.2	20.7	0.59	122450	4	0.25	7628877	0.239	0.000031	88205	9.6611	0.0013
NB4.5-5	4.5	5	2.9	20.9	0.61	126405	4	0.25	6280378	0.224	0.000028	46239	5.0603	0.0006
NB6-6.5	6	6.5	2.6	19.6	0.63	123995	4	0.25	4896955	0.209	0.000027	43922	4.8063	0.0006
NB7.5-8	7.5	8	2.2	18.6	0.55	102365	4	0.25	3474248	0.194	0.000030	36533	3.9962	0.0006
NB9-9.5	9	9.5	2.4	18.4	0.75	137826	5	0.25	3274644	0.192	0.000028	36133	3.9524	0.0006
NB11-12	11	12	2.7	18.1	1.00	181529	5	0.25	8890161	0.253	0.000028	64969	7.1137	0.0008
NB16-17	16	17	3.2	18.6	1.01	188107	5	0.25	2319921	0.181	0.000019	17196	1.8763	0.0002
NB22-23	22	23	2.3	17.9	1.05	187250	5	0.25	2564154	0.184	0.000020	8550	0.9284	0.0001
NB 24-25	24	25	2.3	17.9	0.69	123897	5	0.25	1371124	0.171	0.000028	0	-0.0089	0.0000
NB27-28	27	28	2.0	18.0	1.10	197434	5	0.25	2525105	0.183	0.000019	0	-0.0089	0.0000
SB1-2	1	2	2.4	20.5	0.82	168603	5	0.25	10233527	0.267	0.000032	118218	12.9514	0.0015
SB3-4	3	4	2.5	20.8	0.92	190708	5	0.25	9371779	0.258	0.000027	145062	15.8944	0.0017
SB6-7	6	7	2.6	21.0	0.96	201652	5	0.25	8367671	0.247	0.000024	106240	11.6383	0.0012
SB8-9	8	9	3.1	20.9	0.93	194053	5	0.25	6868748	0.231	0.000024	71501	7.8298	0.0008
SB10-11	10	11	3.0	20.4	0.88	178124	5	0.25	7712057	0.240	0.000027	106420	11.6580	0.0013
SB13-14	13	14	2.8	18.9	0.85	160831	5	0.25	6673513	0.229	0.000028	73172	8.0130	0.0010
SB15-16	16	17	2.8	18.2	0.93	168909	5	0.25	6457723	0.226	0.000027	20357	2.2228	0.0003
SB24-25	24	25	2.6	18.5	0.94	174219	5	0.25	5439362	0.215	0.000025	40958	4.4813	0.0005
SB26-27	26	27	2.2	18.6	0.94	174242	5	0.25	5263811	0.213	0.000024	43277	4.7356	0.0005
SB31-32	31	32	2.6	19.0	0.96	182459	5	0.25	6881081	0.231	0.000025	33300	3.6418	0.0004
SB33-34	33	34	2.6	19.5	0.94	183698	5	0.25	5464202	0.215	0.000023	46708	5.1117	0.0006
SB37-38	37	38	2.7	19.6	0.92	179738	5	0.25	6136985	0.223	0.000025	21023	2.2958	0.0003
SB39-40	39	40	2.8	20.1	0.90	180285	5	0.25	1758954	0.175	0.000019	49160	5.3805	0.0006

Note:

ng/ug org.: nanogram of pigment per microgram of organic sediment matter

	Pheophorbide-a FLUOR			Fucoxanthin			Aphanizophyll			Diadinoxanthin		
	Retention T	Intercept	Slope	Retention T	Intercept	Slope	Retention T	Intercept	Slope	Retention T	Intercept	Slope
Sample	16.5 min	-64863.5	2000363	19.45 min	253.59	8747.9	20.36	-2754.72	9146.95	25.85	-1507.91	12508.05
Name	Fluor 440	conc		PDA450	conc		PDA480 or 51	conc		PDA450	conc	
	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.
NB0.5-1	41816803	20.94	0.0037	57174	6.51	0.00114	0	0	0	11666	1.05	0.00018
NB2-2.5	34042679	17.05	0.0037	53548	6.09	0.00133	23159	0.0030	6.67E-07	17122	1.49	0.00033
NB3-3.5	29970716	15.02	0.0020	36167	4.11	0.00054	10960	0.0017	2.27E-07	30227	2.54	0.00033
NB4.5-5	22701772	11.38	0.0014	13150	1.47	0.00019	4235	0.0010	1.28E-07	19951	1.72	0.00022
NB6-6.5	20329996	10.20	0.0013	9996	1.11	0.00014	0	0.0000	0	11840	1.07	0.00014
NB7.5-8	15885782	7.97	0.0012	7605	0.84	0.00013	0	0.0000	0	8397	0.79	0.00012
NB9-9.5	14628905	7.35	0.0011	4573	0.49	0.00007	3207	0.0009	1.31E-07	9898	0.91	0.00013
NB11-12	17556296	8.81	0.0010	26178	2.96	0.00033	0	0.0000	0	24592	2.09	0.00023
NB16-17	30641918	15.35	0.0016	0	0.00	0.00000	0	0.0000	0	18104	1.57	0.00017
NB22-23	5031175	2.55	0.0003	0	0.00	0.00000	0	0.0000	0	4937	0.52	0.00006
NB 24-25	0	0.03	0.0000	0	0.00	0.00000	0	0.0000	0	7196	0.70	0.00011
NB27-28	0	0.03	0.0000	0	0.00	0.00000	0	0.0000	0	12541	1.12	0.00011
SB1-2	45448323	22.75	0.0027	64008	7.29	0.00086	12029	0.0018	2.19E-07	12573	1.13	0.00013
SB3-4	45222621	22.64	0.0024	84876	9.67	0.00101	22187	0.0029	3.09E-07	45794	3.78	0.00040
SB6-7	37829168	18.94	0.0019	71780	8.18	0.00081	19335	0.0026	2.61E-07	54484	4.48	0.00044
SB8-9	31321161	15.69	0.0016	41562	4.72	0.00049	19094	0.0026	2.69E-07	44415	3.67	0.00038
SB10-11	39974961	20.02	0.0022	27312	3.09	0.00035	11276	0.0018	1.99E-07	36605	3.05	0.00034
SB13-14	29311241	14.69	0.0018	31119	3.53	0.00044	2025	0.0008	9.61E-08	28303	2.38	0.00030
SB15-16	15940137	8.00	0.0009	6450	0.71	0.00008	11820	0.0018	2.16E-07	3756	0.42	0.00005
SB24-25	24594352	12.33	0.0014	20211	2.28	0.00026	0	0.0000	0	13575	1.21	0.00014
SB26-27	19608490	9.83	0.0011	19046	2.15	0.00025	11906	0.0018	2.11E-07	32913	2.75	0.00032
SB31-32	22909546	11.49	0.0013	29776	3.37	0.00037	6489	0.0013	1.37E-07	9877	0.91	0.00010
SB33-34	23780320	11.92	0.0013	33257	3.77	0.00041	0	0.0000	0	12459	1.12	0.00012
SB37-38	18616518	9.34	0.0010	10636	1.19	0.00013	0	0.0000	0	29018	2.44	0.00027
SB39-40	20496089	10.28	0.0011	20968	2.37	0.00026	2642	0.0008	9.31E-08	41800	3.46	0.00038

	Alloxanthin			**Diatoxanthin**			**Zeaxanthin**			**Lutein**		
	Retention T	Intercept	Slope	Retention T	Intercept	Slope	Retention T	Intercept	Slope	Retention T		Slope
Sample	26.6 min	-963.44	13441.93	27.5 min	6318.5	8140.199	28.44 min	-1631.355	11346.588	28.63 min	4383.19	11820.59
Name	PDA450	conc		PDA450	conc		PDA450	conc		PDA450	conc	
	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.
NB0.5-1	399694	29.81	0.0052	42191	4.41	0.0008	16645	1.61	0.00028	78577	6.28	0.0011
NB2-2.5	435140	32.44	0.0071	130287	15.23	0.0033	46092	4.21	0.00092	194859	16.11	0.0035
NB3-3.5	525812	39.19	0.0051	105065	12.13	0.0016	45761	4.18	0.00055	206966	17.14	0.0022
NB4.5-5	380616	28.39	0.0036	207038	24.66	0.0031	66091	5.97	0.00076	218214	18.09	0.0023
NB6-6.5	312259	23.30	0.0030	77994	8.81	0.0011	29473	2.74	0.00035	139431	11.42	0.0015
NB7.5-8	254385	19.00	0.0030	112673	13.07	0.0020	33236	3.07	0.00048	132226	10.82	0.0017
NB9-9.5	204944	15.32	0.0022	82257	9.33	0.0014	24540	2.31	0.00033	75248	6.00	0.0009
NB11-12	510319	38.04	0.0042	91265	10.44	0.0011	40017	3.67	0.00040	216385	17.93	0.0020
NB16-17	124958	9.37	0.0010	22941	2.04	0.0002	8316	0.88	0.00009	51776	4.01	0.0004
NB22-23	124761	9.35	0.0010	19356	1.60	0.0002	8757	0.92	0.00010	45780	3.50	0.0004
NB 24-25	63535	4.80	0.0008	18370	1.48	0.0002	8280	0.87	0.00014	26525	1.87	0.0003
NB27-28	150070	11.24	0.0011	43709	4.59	0.0005	16548	1.60	0.00016	68342	5.41	0.0005
SB1-2	696008	51.85	0.0062	136954	16.05	0.0019	128811	11.50	0.00136	271081	22.56	0.0027
SB3-4	855915	63.75	0.0067	149240	17.56	0.0018	192263	17.09	0.00179	346279	28.92	0.0030
SB6-7	799736	59.57	0.0059	184011	21.83	0.0022	244361	21.68	0.00215	437469	36.64	0.0036
SB8-9	635645	47.36	0.0049	181139	21.48	0.0022	206518	18.34	0.00189	406580	34.03	0.0035
SB10-11	542152	40.40	0.0045	195081	23.19	0.0026	142067	12.66	0.00142	330680	27.60	0.0031
SB13-14	430754	32.12	0.0040	304340	36.61	0.0046	112739	10.08	0.00125	304379	25.38	0.0032
SB15-16	191812	14.34	0.0017	78034	8.81	0.0010	23736	2.24	0.00026	71078	5.64	0.0007
SB24-25	401614	29.95	0.0034	317539	38.23	0.0044	91541	8.21	0.00094	200504	16.59	0.0019
SB26-27	411204	30.66	0.0035	299947	36.07	0.0041	104224	9.33	0.00107	228338	18.95	0.0022
SB31-32	350061	26.11	0.0029	214503	25.57	0.0028	67399	6.08	0.00067	157771	12.98	0.0014
SB33-34	426076	31.77	0.0035	463888	56.21	0.0061	113542	10.15	0.00111	244616	20.32	0.0022
SB37-38	385648	28.76	0.0032	212001	25.27	0.0028	72856	6.56	0.00073	194385	16.07	0.0018
SB39-40	458177	34.16	0.0038	211247	25.17	0.0028	80978	7.28	0.00081	217935	18.07	0.0020

	Chl-b			Chl-b FLUO			Echinenone			Chl-a		
	Retention T	Intercept	Slope	Retention T	Intercept	Slope	Retention T	Intercept	Slope	Retention T	Intercept	Slope
Sample	32.79 min	-3151.87	7731.58	32.9 min	-7275267.5	109059852	33.09 min	7456.18	10389.44	34.38 min	857.48	5181.33
Name	PDA 460	conc		Fluor 459	conc		PDA460	conc		PDA430	conc	
	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.
NB0.5-1	29382	4.21	0.0007	135991057	1.31	0.00023	53365	4.42	0.0008	136524	26.18	0.0046
NB2-2.5	47435	6.54	0.0014	142311898	1.37	0.00030	99342	8.84	0.0019	159877	30.69	0.0067
NB3-3.5	67707	9.16	0.0012	212960580	2.02	0.00026	115290	10.38	0.0014	193737	37.23	0.0049
NB4.5-5	44468	6.16	0.0008	4337922	0.11	0.00001	110593	9.93	0.0013	90857	17.37	0.0022
NB6-6.5	34343	4.85	0.0006	104356958	1.02	0.00013	71439	6.16	0.0008	127374	24.42	0.0032
NB7.5-8	27788	4.00	0.0006	71324364	0.72	0.00011	66833	5.72	0.0009	82753	15.81	0.0025
NB9-9.5	33062	4.68	0.0007	54811792	0.57	0.00008	84619	7.43	0.0011	69406	13.23	0.0019
NB11-12	61803	8.40	0.0009	238996442	2.26	0.00025	137295	12.50	0.0014	173861	33.39	0.0037
NB16-17	24125	3.53	0.0004	37621419	0.41	0.00004	56083	4.68	0.0005	51220	9.72	0.0010
NB22-23	18818	2.84	0.0003	40872553	0.44	0.00005	52886	4.37	0.0005	47060	8.92	0.0010
NB 24-25	10063	1.71	0.0003	26610947	0.31	0.00005	29559	2.13	0.0003	27175	5.08	0.0008
NB27-28	24112	3.53	0.0004	43541943	0.47	0.00005	26233	1.81	0.0002	53305	10.12	0.0010
SB1-2	99726	13.31	0.0016	465031883	4.33	0.00051	192855	17.84	0.0021	247367	47.58	0.0056
SB3-4	83558	11.22	0.0012	475611656	4.43	0.00046	250817	23.42	0.0025	357035	68.74	0.0072
SB6-7	109985	14.63	0.0015	477276396	4.44	0.00044	206410	19.15	0.0019	291252	56.05	0.0056
SB8-9	125449	16.63	0.0017	392827899	3.67	0.00038	218872	20.35	0.0021	277164	53.33	0.0055
SB10-11	115086	15.29	0.0017	364749441	3.41	0.00038	205807	19.09	0.0021	213179	40.98	0.0046
SB13-14	83558	11.22	0.0014	189539408	1.80	0.00022	130688	11.86	0.0015	161251	30.96	0.0038
SB15-16	24438	3.57	0.0004	60647309	0.62	0.00007	73386	6.35	0.0008	72421	13.81	0.0016
SB24-25	81585	10.96	0.0013	92086346	0.91	0.00010	184409	17.03	0.0020	149720	28.73	0.0033
SB26-27	92361	12.35	0.0014	104293747	1.02	0.00012	179837	16.59	0.0019	130880	25.09	0.0029
SB31-32	49895	6.86	0.0008	92254214	0.91	0.00010	119899	10.82	0.0012	112489	21.54	0.0024
SB33-34	122291	16.22	0.0018	109599031	1.07	0.00012	182660	16.86	0.0018	198935	38.23	0.0042
SB37-38	61522	8.36	0.0009	84037856	0.84	0.00009	132346	12.02	0.0013	99140	18.97	0.0021
SB39-40	66311	8.98	0.0010	76846234	0.77	0.00009	122825	11.10	0.0012	100934	19.31	0.0021

	Chl-a FLUO			Pheophytin-A			Pheophytin-A FLUO			A-carotene		
	Retention T	Intercept	Slope	Retention T		Slope	Retention T	Intercept	Slope	Retention T	Intercept	Slope
Sample	34.46 min	-935433.5	18250005	36.36min	-6899.94	7310.98	36.45min	608615.53	1457197.1	37.26 min	-3665	13250
Name	Fluor440	conc		pda410	conc		Fluor 440	conc		PDA450	conc	
	area	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.	are	ng/ml	ng/ug org.	area	ng/ml	ng/ug org.
NB0.5-1	1.318E+09	72.30	0.013	430127	59.78	0.010	169155374	115.67	0.020	8016	0.88	0.0002
NB2-2.5	1.287E+09	70.59	0.015	486997	67.56	0.015	173338708	118.54	0.026	89248	7.01	0.0015
NB3-3.5	1.429E+09	78.38	0.010	590280	81.68	0.011	170900531	116.86	0.015	160880	12.42	0.0016
NB4.5-5	904487145	49.61	0.006	583833	80.80	0.010	181234055	123.95	0.016	166593	12.85	0.0016
NB6-6.5	865792378	47.49	0.006	454794	63.15	0.008	127386066	87.00	0.011	123053	9.56	0.0012
NB7.5-8	600563236	32.96	0.005	378380	52.70	0.008	102175891	69.70	0.011	52536	4.24	0.0007
NB9-9.5	523293198	28.72	0.004	357744	49.88	0.007	99560254	67.91	0.010	69751	5.54	0.0008
NB11-12	1.739E+09	95.36	0.011	612198	84.68	0.009	198898655	136.08	0.015	166590	12.85	0.0014
NB16-17	444378042	24.40	0.003	321949	44.98	0.005	82391462	56.12	0.006	32904	2.76	0.0003
NB22-23	476394406	26.16	0.003	250651	35.23	0.004	97520835	66.51	0.007	17997	1.63	0.0002
NB 24-25	279056036	15.34	0.002	168749	24.03	0.004	54857915	37.23	0.006	7140	0.82	0.0001
NB27-28	505241619	27.74	0.003	301185	42.14	0.004	103881850	70.87	0.007	34337	2.87	0.0003
SB1-2	1.746E+09	95.72	0.011	768198	106.02	0.013	254276459	174.08	0.021	142652	11.04	0.0013
SB3-4	1.797E+09	98.53	0.010	1017052	140.06	0.015	246049721	168.43	0.018	202213	15.54	0.0016
SB6-7	1.865E+09	102.23	0.010	952609	131.24	0.013	266093380	182.19	0.018	253920	19.44	0.0019
SB8-9	1.668E+09	91.47	0.009	940360	129.57	0.013	220958615	151.21	0.016	299630	22.89	0.0024
SB10-11	1.683E+09	92.29	0.010	845167	116.55	0.013	250881771	171.75	0.019	105326	8.23	0.0009
SB13-14	1.172E+09	64.27	0.008	755285	104.25	0.013	204524309	139.94	0.017	184891	14.23	0.0018
SB15-16	631153516	34.64	0.004	358638	50.00	0.006	131735964	89.99	0.011	28059	2.39	0.0003
SB24-25	946883881	51.94	0.006	705103	97.39	0.011	199179487	136.27	0.016	233682	17.91	0.0021
SB26-27	828612927	45.45	0.005	701749	96.93	0.011	165291038	113.01	0.013	234827	18.00	0.0021
SB31-32	914001949	50.13	0.005	643899	89.02	0.010	185763757	127.06	0.014	131825	10.23	0.0011
SB33-34	1.212E+09	66.46	0.007	825560	113.86	0.012	217397559	148.77	0.016	362553	27.64	0.0030
SB37-38	772238294	42.37	0.005	596073	82.47	0.009	152100372	103.96	0.012	179263	13.81	0.0015
SB39-40	774874879	42.51	0.005	590999	81.78	0.009	149007493	101.84	0.011	149436	11.55	0.0013
	Note:											
	A-carotene and B-carotene could not be spectrally distinguished from each other. As B-carotene is generally much higher, we interpreted it as B-carotene (with some A-carotene).											

	B-carotene		
	Retention T	Intercept	Slope
Sample	37.26 min	3779.99	11537.25
Name	PDA450	conc	
	area	ng/ml	ng/ug org.
NB0.5-1	8016	0.37	6.42E-05
NB2-2.5	89248	7.41	1.62E-03
NB3-3.5	160880	13.62	1.78E-03
NB4.5-5	166593	14.11	1.79E-03
NB6-6.5	123053	10.34	1.33E-03
NB7.5-8	52536	4.23	6.61E-04
NB9-9.5	69751	5.72	8.30E-04
NB11-12	166590	14.11	1.55E-03
NB16-17	32904	2.52	2.68E-04
NB22-23	17997	1.23	1.32E-04
NB 24-25	7140	0.29	4.70E-05
NB27-28	34337	2.65	2.68E-04
SB1-2	142652	12.04	1.43E-03
SB3-4	202213	17.20	1.80E-03
SB6-7	253920	21.68	2.15E-03
SB8-9	299630	25.64	2.64E-03
SB10-11	105326	8.80	9.88E-04
SB13-14	184891	15.70	1.95E-03
SB15-16	28059	2.10	2.49E-04
SB24-25	233682	19.93	2.29E-03
SB26-27	234827	20.03	2.30E-03
SB31-32	131825	11.10	1.22E-03
SB33-34	362553	31.10	3.39E-03
SB37-38	179263	15.21	1.69E-03
SB39-40	149436	12.62	1.40E-03

Appendix C. Complete Diatom Data

	Top of interval (cm)										
Diatom Taxon	0	2	3	4.5	6	7.5	9	11	16	22	24
Achnanthes cf. lacus vulcani					2						
Achnanthes cf. ventralis				2						1	
Achnanthes clevei		2	1	1	1		2	7	1	10	10
Achnanthes conspicua		1								1	
Achnanthes daonensis			1								
Achnanthes exigua	1	3		3	3	1	1	2		2	8
Achnanthes joursacense							1	1	2	1	
Achnanthes laevis	1	2		1	2	1	1			1	
Achnanthes lanceolata spp. frequentissima		2	1	3	3			2	1	7	11
Achnanthes lanceolata ssp. biporama							2				
Achnanthes lanceolata ssp. rostrata	1	1	1	2	3	2	2	4	4	1	
Achnanthes laterostrata		2			1		1	1		1	1
Achnanthes levanderi			1	1	2		2		1	1	1
Achnanthes linearis	2		5	1	1		3	3	5	1	2
Achnanthes minutissima var. inconspicua				5	6		2	2	2	1	
Achnanthes minutissima var. minutissima	29	29	13	35	32	22	22	20	25	20	6
Achnanthes ostrupii							1			2	
Achnanthes peragalli				1						2	
Achnanthes pusilla											
Achnanthes sp.	2			3	0		4				2
Achnanthes subatomiodes	5	1		1	4	4	2	2	1		1
Amphipleura pellucida							1				
Amphora cf. aequalis		1									
Amphora cf. montana									1		
Amphora cf. veneta									1		
Amphora fogediana				1		3					
Amphora inariensis				2			1			5	3
Amphora libyca		3			1					2	
Amphora ovalis			1				1				
Amphora pediculus	4		6		3		2	4	1	2	6
Anomoeoneis vitrea	1	1	1	3	1		1		1		1
Asterionella formosa	43	11	18	9	7	8	15	14	13	6	8
Aulacoseira ambigua	61	49	30	35	41	85	92	95	86	45	69
Aulacoseira granulata		1	2		2	3	4	1		2	1
Aulacoseira islandica				3		3				3	
Caloneis hyalina			2								
Caloneis permagna			1			1	1	2			
Cocconeis neodiminuta		2		2	2	1	1	1	2	8	7
Cocconeis placentula var. linearis	5	5	5	6	3	7	6	5	7	4	
Cyclotella bodanica	14	11	6	11	8	13	9	20	11	15	7
Cyclotella comensis	4	1	2	1	2						
Cyclotella distinguenda	30	26	33	36	22	21	14	11	9	3	9
Cyclotella ocellata	17	19	16	15	5	3	1	1	1	1	
Cyclotella pseudostelligera	6	14	1	2	1	8	8	10	9	9	7
Cyclotella stelligera	2	1	2		1		6	13	6	8	

Cymbela falaisensis										2	
Cymbella amphicephala				1							
Cymbella caespitosa					1						
Cymbella cesatii								1			
Cymbella cistula						1					
Cymbella gracile								1			
Cymbella microcephala			3	3			1		2		
Cymbella minuta										1	
Cymbella silesiaca			2		1			1			
Cymbella sp.		1		2							
Diatoma tenuis							1		2		
Diploneis finnica				1							
Diploneis marginestriata		2	1	4	1		1	1		4	5
Diploneis oblongella				1					1		
Diploneis parma	1	1			4	2		3	1		3
Diploneis sp.											1
Entemoneis cf. alata			1	1		2	1				1
Epithemia adnata				1	1						
Epithemia cistula	2									2	2
Epithemia turgida				1		1					
Eunotia bilunaris		2	1	1		3		1		1	2
Eunotia cf. arcus		1									
Eunotia cf. implicata											1
Eunotia constricta		1									
Eunotia formica	1									1	
Eunotia incisa	2	3	2	2		3	1			1	1
Eunotia minor						1				1	
Eunotia sp.	4		2		1					2	1
Fragilaria capucina var. capucina	3	1	2	3	5	3		1	1		
Fragilaria capucina var. gracilis	1	1	1		2	1	3	2	1		
Fragilaria capucina var. mesolepta	1					1		1			
Fragilaria capucina var. rumpens								2			
Fragilaria construens var. construens	5	1	6			6		2	1		
Fragilaria construens var. binodis			2								
Fragilaria crotonensis	29	41	30	25	38	34	16	10	9		2
Fragilaria exigua						1					
Fragilaria lepostauron			1								
Fragilaria nanana				1							
Fragilaria neoproducta						1					
Fragilaria parasitica			2						1	2	
Fragilaria spp.			6			1					
Fragilaria tenera			1		1		1				
Fragilaria ulna var. acus											
Fragilaria ulna var. ulna	1	1	1	1	1			1		2	
Frustulia rhomboides								1			
Gomphonema acuminatum		1					1				
Gomphonema angustatum		1									

Gomphonema angustum	2		3	2	2		2	1	5	2	1
Gomphonema clevei											
Gomphonema gracile		3			3	2					
Gomphonema grovei											
Gomphonema spp.	2		2	7	2	2	4		6		
Gyrosigma acuminatum	3	1	1	1	4	2	1	1		7	10
Navicula capitata		1									
Navicula cari		1									
Navicula cf. accomoda	1										
Navicula cf. bryophila	1										
Navicula cf. crucicola							1				
Navicula cf. digitulus										2	
Navicula cf. kotschyi							1				
Navicula cf. kuelbsii	4			1						3	
Navicula cf. pusilla									1		
Navicula cf. submolesta		1		1							
Navicula cocconeiformis			1	1				1			2
Navicula cryptocephala	5	1			1	2			2	1	
Navicula cryptotenella	3	1	2	3	4	2	3	4	4	3	3
Navicula elginensis			1			2		1			
Navicula helensis					1	1	2	1		4	1
Navicula jaernefeldtii					1	2	1	2		1	2
Navicula joubaudii			1								
Navicula menisculus						1				2	1
Navicula minima	2	7	2	4	6	2	5	5	5	6	8
Navicula minuscula											
Navicula minusculoides				2							
Navicula mutica					2				1	2	
Navicula peregrine	2	1				1			1	1	
Navicula praeterita								1			
Navicula psedolanceolata var. densilineata				2							
Navicula pseudoscutiformis	1	2				1	2		2		3
Navicula pseudoventralis					4		1			4	2
Navicula pupula		1	1	3	1	1			1	3	2
Navicula radiosa	2	1	2	2	2	1	1	2	2	1	
Navicula rhynchocephala		2			1	2	2		3	4	4
Navicula schadei			5	10							
Navicula schoenfeldtii			1								
Navicula seminulum	5			2		1					1
Navicula spp.		2	2	2		2	3	2	4		9
Navicula subminuscula			1	2				2		2	
Navicula Submuralis	7	10	7	9	4		7	11	2	13	26
Navicula subplacentula		10								1	
Navicula subrotundata			1								
Navicula subtilissima											1
Neidium binodis		1									
Neidium dubium									1		

Nitzschia angustatula									1		
Nitzschia cf. palea	4					3	2	2			
Nitzschia dissipata		1					1				
Nitzschia gracilis			3								
Nitzschia perminuta		1				2	4				
Nitzschia pura		1									
Nitzschia radicula			1								
Nitzschia sp.	2		1			1	2				
Nitzschia linearis var. subtilis	2	3		1			1	1		1	
Niztschia amphibia					1			2	1	2	1
Pinnularia						1					3
Pinnularia biceps var. Pusilla								1			
Rhopalodia gibba								2			
Stauroneis anceps									1		
Stauroneis nobilis var. Gracile					1						
Stauroneis phoenicenteron		1									1
Stauroneis smithii									2		1
Staurosira brevistriata	2	2	8	7	12	16	13	5	12	16	27
Staurosirella pinnata	13	27	27	22	23	12	24	16	14	22	39
Stephanodiscus hantzschii	4		1		6	3	4	2	2		1
Stephanodiscus medius	5	3		5	3	4	3	4	7	8	11
Stephanodiscus minutulus					1						
Stephanodiscus niagarae				3	1	3	1	3	1	2	1
Surirella angusta						1	1				
Surirella spp.						1					
Tabellaria flocculosa IIIp	11	6	9	10	6	10	14	19	10	10	8
Tabellaria flocculosa str. III							1				
Tabellaria flocculosa var. Linearis					2	1	1		1		
Tabellaria quadriseptata											
Unidentified	7	6	2	2	1	7	4	2		9	5
Total	368	343	298	337	310	339	347	342	301	316	353

	Top of interval (cm)											
Diatom Taxa	0	4	6	8	10	13	15	20	24	26	33	39
Achnanthes cf. lanceolata var. dubia						1						
Achnanthes cf. levanderi				2		1						
Achnanthes cf. oestrupii											1	
Achnanthes cf. ventralis				3								
Achnanthes clevei		1	1	3	1				1	1		2
Achnanthes delicatula									1			1
Achnanthes exigua	2	1	1			2	1				1	3
Achnanthes joursacense	1	2						2				
Achnanthes lacus vulcani	2								2			
Achnanthes laevis											1	
Achnanthes lanceolata ssp. frequentissima		1									2	
Achnanthes lanceolata ssp. rostrata		3	4		2			2	1			2
Achnanthes laterostrata					1							
Achnanthes linearis	2	1			3	3			1	1	4	1
Achnanthes minutissima var. inconspicua	1	2		3		1		3			1	2
Achnanthes minutissima var. minutissima	18	30	20	17	30	28	2	15	15	8	16	13
Achnanthes pusilla					1							
Achnanthes saccula	1										1	
Achnanthes sp.	1		1	1								
Achnanthes subatomoides											1	
Achnanthes suchlandtii										1		
Achnathes chlidanos												2
Achnenthes consipcua		1										
Amphipleura pellucida		1						1				
Amphora fogediana								1				
Amphora inariensis			1									
Amphora lybica	1				1						2	
Amphora pediculus	4	2	1	1							2	
Anomoeoneis vitrea				1	2	3	1	2		1		
Asterionella formosa	17	25	16	34	39	38	45	50	24	37	19	20
Aulacoeira ambigua status alpha							5	2				
Aulacoseira ambigua	24	31	32	25	27	60	117	87	108	104	80	97
Aulacoseira disc view				1	2							
Aulacoseira granulata	3	2	1	4	5		2		11	5	2	4
Aulacoseira islandica				2			1				3	
Bacillaria paradoxa	2											
Caloneis permagna				2		1		1				
Caloneis silicula		1										
Caloneis spp.	1											
Cocconeis neodiminuta												1
Cocconeis neothumensis		1										
Cocconeis placentula var. linearis	11	18	15	9	7	6	1	1	2	2	2	5
Cyclostephanos tholiformis		3						5				
Cyclotella bodanica	7	6	6	2	4	2	2	5	3	3	4	19
Cyclotella comensis	2	2	2	5	3							

Cyclotella distinguenda	6	3	7	3	4	15	7	16	12	19	23	29
Cyclotella michiganiana				1								
Cyclotella ocellata	8	12	10	16	13	1		1				4
Cyclotella pseudostelligera	3	2	1				18	22	17	10	39	29
Cyclotella stelligera	1	5		4	9	13	8	9	2	9	10	9
Cymbella caespitosa												1
Cymbella hebridica												1
Cymbella microcephala	1	3	1					2			2	2
Cymbella silesiaca		2	1	2	1	1	1			1		
Cymbella spp.	1							2				
Diatoma tenuis	4	4	2	5	6	6	8	8	13	3		
Diploneis marginestriata		1					1			1	2	2
Diploneis parma		1							1			
Entemoneis sp.										1		
Epithemia adnata			1									
Eunotia formica			1									
Eunotia incisa											1	2
Eunotia sp.			2	1								
Fragilaria capcuina var. vaucheriae			1									
Fragilaria capucina var. capucina	4	2	6	8	3		1	2	9	2	2	3
Fragilaria capucina var. gracilis	4	4	4	3	7	7	2	1	4	3	2	
Fragilaria capucina var. mesolepta		6		2		2		1				
Fragilaria capucina var. rumpens		2										
Fragilaria constricta	1		1									
Fragilaria construens var. construens	3			4	15				2	2		
Fragilaria construens var. venter	8		4	10	2	2		4			1	2
Fragilaria crotonensis	83	51	67	72	49	29	9	12	11	16	11	5
Fragilaria exigua	1							2				
Fragilaria nanana								2				
Fragilaria parasitica		3				1		1	1			
Fragilaria robusta			1									
Fragilaria spp.			2									
Fragilaria tenera	2	1		5	1	2	3	2	2	3	5	
Fragilaria ulna var. acus				4	5	1	2	4	4	2		
Fragilaria ulna var. ulna	2	2	1	5	4	4	2				1	
Gomphonema affine	1											
Gomphonema angustatum				2								
Gomphonema angustum	2	1	3			2			1	1		
Gomphonema cf. pseudoaugur							1					
Gomphonema clevei					1	1						
Gomphonema gracile			1			1	2		1		3	1
Gomphonema grovei					1							
Gomphonema parvulum	1		1									
Gomphonema spp.	6		6		3	2			2	2	1	
Gomphonema truncatum	1		2									
Gyrosigma acuminatum		2	1		3	1	2				1	
Gyrosigma obscurum			2									

Gyrosigma parkerii							1			1		
Naivula cf. pseudoanglica		1										
Navicula arvensis	2		1									1
Navicula capitata						1						
Navicula cari				1								
Navicula cf. bryophila					1							
Navicula cf. kuelbsii	1					1						
Navicula cocconeiformis	1	2				2				1	1	
Navicula cryptocephala		3	3		2	4	2	3	2	3	4	4
Navicula cryptotenella	3	7	4	3	10	6	1			1	1	
Navicula disjuncta			1								3	
Navicula elginensis						1		2				
Navicula heimansii												2
Navicula lacustris									1			
Navicula laevissima		1						1				1
Navicula menisculus	3	1	1	1								
Navicula minima	4				5				1		1	2
Navicula minuscula				1								
Navicula pseudoscutiformis			1							1		
Navicula pupula	1	3				3			1			
Navicula radiosa	2	7	4	3	1				3	2	1	
Navicula rhynchocephala	6	5		1	2		1		1		1	1
Navicula schoenfeldtii	1		1									
Navicula seminulum		1	1	9		1	3					
Navicula spp.		2			2	1	5	2			3	2
Navicula submuralis	8	6	1	2	6		3		3	2		
Navicula subrhynchocephala			3								1	
Navicula subtilissima				1			1					
Navicula viridula var. rostellata	1											
Neidium binodis						2						
Neidium dubium			1									
Nitaschia laevidensis		2					1					
Nitaschia paleacea										1		
Nitaschia radicula		2						1			1	
Nitzschia acicularis								1				
Nitzschia amphibia											1	
Nitzschia angustata			1									
Nitzschia angustatula				1								
Nitzschia bacillum	1											
Nitzschia bremensis			1									
Nitzschia cf. agnita											1	
Nitzschia cf. sigma	1					1			1			
Nitzschia cf. sublinearis											1	
Nitzschia constricta				1								
Nitzschia dissipata		1	1			1		2	1	1		
Nitzschia frustulum		1	1					2				
Nitzschia linearis var. subtilis	2	1	4			1	3	2	2			

Nitzschia macilenta									1			
Nitzschia palea	1	4	7	1			1	3	3	2	2	
Nitzschia perminuta	4		1	1		2		1	1	1		
Nitzschia recta					4	2						
Nitzschia sp.	1		2	2	4	5	1				2	2
Pseudostaurosira brevistriata		3	4	1	3	2		5		2		
Rhopalodia gibba		1										
Stauroneis anceps							1					1
Stauroneis recondita			1									
Stauroneis smithii	1			2								
Staurosira leptostauron	2	2	1									1
Staurosirella pinnata	16	27	19	14	15	11	1	3	9	6	1	7
Stephanodiscus hantzschii	4	4	3	2	8	18	5	1	7	7	6	2
Stephanodiscus medius	7	6	1	5		4	9	8	9	7	14	13
Stephanodiscus niagarae	2	1	1		2		1	1		2	1	1
Surirella angusta		1			2							
Surirella roba			1									
Tabellaria flocculosa III	1									1		
Tabellaria flocculosa IIIp	13	8	10	12	13	23	16	21	17	29	12	9
Tabellaria flocculosa IV		1										
Tabellaria flocculosa var. Linearis							1				1	
Tabellaria quadriseptata				1								
Unidentified	4	2	3	2	3	2	2				1	2
Total	336	347	314	329	338	330	303	327	314	308	306	313

Appendix D. Complete Chironomid Data

Appendix D1 Chironomid Relative Abundances for North Bay Core

	Top of Interval (cm)													
Chironomid Taxa	0	2	3	4	5	6	7	8	9	11	14	16	22	24
Chironomini	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	3.6	0.0	0.0	0.0	0.0	0.0
Chironomus anthracinus	3.2	12.4	17.9	15.8	14.4	8.1	6.7	11.0	14.5	16.4	14.1	0.0	13.3	10.9
Chaetocladius	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	1.6	2.9	0.0	0.0
Cladopelma lateralis	0.0	2.1	3.6	2.6	0.0	0.0	0.0	1.8	0.0	1.3	0.0	0.0	0.0	1.8
Cladotanytarsus	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corynocera oliveri	0.0	0.0	0.0	0.0	1.4	0.0	0.0	5.5	10.9	0.0	1.6	0.0	2.7	5.5
Corynoneura	0.0	0.0	7.1	5.3	2.9	5.4	3.3	12.8	0.0	1.3	3.1	0.0	0.0	0.0
Cricotopus	3.2	6.2	0.0	0.0	5.8	2.7	6.7	3.7	10.9	3.8	3.1	0.0	2.7	1.8
Cryptochironomus	0.0	0.0	0.0	2.6	0.0	2.7	0.0	1.8	0.0	0.0	1.6	0.0	0.0	1.8
Dicrotendipes	3.2	0.0	3.6	0.0	1.4	0.0	3.3	3.7	0.0	2.5	1.6	0.0	0.0	1.8
Diplocladius	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Endochironomus impar	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	1.3	0.0	0.0	1.3	0.0
Glyptotendipes barbipes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	1.3	0.0	0.0	0.0	0.0
Glyptotendipes tendens	0.0	4.1	0.0	0.0	0.0	2.7	3.3	1.8	3.6	0.0	0.0	0.0	0.0	0.0
Harnischia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Heterotrissocladius grimshawi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
Heterotrissocladius marcidus	0.0	0.0	7.1	0.0	0.0	0.0	0.0	1.8	0.0	2.5	1.6	0.0	2.7	0.0
Labrundinia	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0
Lauterborniella	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Limnophyes	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0
Macropelopia	0.0	0.0	0.0	0.0	1.4	2.7	0.0	3.7	0.0	0.0	0.0	0.0	0.0	1.8
Metriocnemus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0
Microchironomus	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropsectra bidentata	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropsectra insignilobus	6.3	4.1	0.0	0.0	2.9	0.0	0.0	0.0	3.6	0.0	1.6	0.0	0.0	0.0
Micropsectra radialis	3.2	4.1	3.6	7.9	2.9	0.0	6.7	1.8	0.0	1.3	6.3	14.7	13.3	0.0
Microtendipes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0
Nanocladius branchiolus	6.3	0.0	0.0	2.6	2.9	0.0	0.0	1.8	0.0	1.3	0.0	0.0	0.0	0.0
Orthocladius	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pagastiella	0.0	0.0	3.6	5.3	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paracladopelma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Paratanytarsus	6.3	0.0	0.0	2.6	0.0	2.7	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0
Parachirnomus varus	0.0	0.0	7.1	2.6	1.4	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Parachironomus vitiosus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Paratendipes nubisquama	3.2	2.1	3.6	0.0	0.0	2.7	3.3	1.8	0.0	1.3	0.0	0.0	0.0	0.0
Pentaneurini	0.0	2.1	0.0	2.6	0.0	0.0	3.3	0.0	0.0	2.5	0.0	0.0	0.0	0.0
Phaenopsectra	0.0	0.0	0.0	0.0	1.4	2.7	0.0	1.8	0.0	0.0	0.0	0.0	0.0	1.8
Phaenopsectra flavipes	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	5.9	0.0	0.0
Polypedilum	0.0	0.0	0.0	0.0	0.0	8.1	3.3	3.7	3.6	0.0	0.0	0.0	0.0	1.8
Procladius	9.5	12.4	14.3	10.5	11.5	10.8	10.0	12.8	18.2	20.1	29.7	29.4	22.7	21.8
Protanypus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.8
Psectrocladius sordidellus	3.2	0.0	3.6	0.0	4.3	0.0	0.0	2.8	3.6	3.1	3.1	0.0	0.0	0.0
Pseudochironomus	1.6	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	2.9	0.0	0.0
Pseudosmittia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	3.1	0.0	1.3	0.0
Sergentia coracina	3.2	0.0	0.0	0.0	0.0	2.7	0.0	0.0	3.6	3.8	0.0	8.8	8.0	10.9

Stempellina	0.0	2.1	0.0	2.6	2.9	0.0	3.3	1.8	0.0	5.0	0.0	0.0	5.3	0.0
Stenochironomus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Stichtochironomus	3.2	0.0	0.0	0.0	0.0	2.7	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Synorthocladius	3.2	4.1	3.6	0.0	0.0	2.7	0.0	2.8	7.3	5.0	0.0	5.9	0.0	1.8
Tanytarsus B	0.0	0.0	0.0	0.0	8.6	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tanytarsus C	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tanytarsus lugens	6.3	12.4	10.7	18.4	15.8	18.9	13.3	5.5	7.3	5.0	9.4	8.8	1.3	3.6
Tanytarsus no spur	25.4	20.6	7.1	18.4	15.8	16.2	13.3	7.3	3.6	12.6	12.5	20.6	20.0	23.6
Tanytarsus with spur	3.2	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	1.3	0.0	0.0	1.3	1.8

Appendix D-2 Chironomid Relative Abundance in South Bay Core

	Top of Interval (cm)																	
Chironomid Taxa	0	2	4	6	7	8	9	11	12	15	17	20	23	25	31	33	36	39
Ablabesmyia	0	0	0	0	0	1.869	0	0	0	0	0	5.882	0	0	0	1.923	0	0
Allopsectrocladius	0	0	0	0	0	0	0	0	0	0	0	5.882	0	0	0	0	0	0
Chaetocladius	0	0	0	0	0	0	0	0	3.704	0	0	0	0	0	0	0	0	0.847
Chironomini	2.941	0	0	2.381	0	0	0	0	0	0	0	5.882	0	0	3.571	0	0	0
Chironomus anthracinus	20.59	19.05	25.58	16.67	13.59	14.02	18.28	16.92	25.93	26.09	46.43	23.53	23.53	21.43	21.43	38.46	30.86	26.27
Chironomus plumosus	0	0	0	0	0	1.869	2.151	0	0	0	0	0	0	0	0	0	0	1.695
Cladopelma lateralis	5.882	1.587	0	2.381	1.942	3.738	0	6.154	0	0	0	0	2.941	0	0	0	1.235	0.847
Cladotanytarsus	2.941	1.587	4.651	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corynoneura	8.824	3.175	0	0	1.942	1.869	0	3.077	11.11	0	0	0	2.941	0	3.571	0	2.469	0
Cricotopus	5.882	3.175	8.14	7.143	3.883	5.607	10.75	3.077	0	13.04	3.571	0	2.941	7.143	3.571	3.846	0	0
Cryptochironomus	5.882	1.587	0	0	0	0	0	0	3.704	0	0	5.882	0	0	0	0	0	0
Cryptotendipes	0	0	0	0	0	0	0	0	0	0	3.571	0	0	0	0	0	0	0
Dicrotendipes	0	0	0	0	1.942	1.869	0	0	0	0	3.571	0	11.76	7.143	0	1.923	0	3.39
Diplocladius	0	0.794	0	0	0	0	0	0	1.852	0	0	0	0	0	0	0	0	0
Endochironomus impar	0	0	0	0	1.942	0	0	0	0	0	3.571	0	2.941	0	0	0	0	0
Endochionomus tendens	0	0	0	0	0	1.869	0	0	0	0	0	0	0	0	0	0	0	0
Glyptotendipes	0	1.587	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyptotendipes tendes	0	0	0	0	0	0	2.151	0	0	8.696	0	0	0	0	0	0	0	1.695
Guttipelopia	0	0	2.326	0	0	0	2.151	0	0	0	0	0	0	0	0	0	0	0
Heterotrissocladius grimshawi	0	0	0	2.381	0	0	0	0	0	0	0	0	0	0	0	0	0	1.695
Hetero marcidus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.938	0.847
Hetero subpilosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.571	0	2.469	0
Labrundinia	5.882	3.175	2.326	7.143	5.825	0	0	0	0	0	0	0	0	0	3.571	0	0	0
Limnophyes	2.941	0	0	2.381	0	0	0	0	0	0	0	0	0	0	0	0	1.235	0
Macropelopia	0	0	0	0	0	1.869	2.151	6.154	3.704	8.696	0	0	0	0	0	0	0	0
Micropsectra bidentata	0	1.587	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micropsectra insignilobus	14.71	3.175	4.651	11.9	3.883	3.738	0	3.077	3.704	0	0	0	0	0	0	1.923	0	0
Micropsectra radialis	0	0	0	0	3.883	0	0	0	0	0	0	5.882	0	0	0	0	0	0
Microtendipes	0	0	0	0	0	1.869	2.151	0	0	0	3.571	0	0	0	0	1.923	0	1.695
Monodiamesa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.469	0
Monopelopia	2.941	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nanocladius branchiolus	0	3.175	2.326	0	0	0	0	0	1.852	0	0	0	0	0	3.571	0	0	0

Oliverdia	0	0	2.326	0	0	0	0	0	0	0	0	0	2.941	0	0	0	0	0
Orthocladius	0	0	0	0	0	0	0	0	0	0	0	0	0	7.143	0	0	0	0
Pagastiella	0	1.587	0	0	0	0	0	0	0	0	3.571	0	0	0	0	0	0	0
Parachironomus varus	0	0	0	2.381	0	0	4.301	12.31	3.704	17.39	10.71	11.76	2.941	0	0	0	4.938	0
Paracladius	0	0	0	0	0	0	0	0	0	0	0	0	2.941	0	0	1.923	0	0
Paracladopelma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.469	0
Parakiefferiella	2.941	7.937	0	2.381	5.825	5.607	0	0	0	0	0	0	0	0	0	0	0	0
Parakiefferiella triqueta	0	0	0	0	0	0	0	0	0	8.696	0	0	0	0	0	0	0	0
Parametriocnemus	0	1.587	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paratendipes nubisquama	0	0	0	7.143	5.825	1.869	2.151	6.154	0	0	0	0	0	0	0	0	0	1.695
Paratanytarsus	0	0	0	0	0	1.869	0	0	0	0	3.571	0	0	0	0	0	0	0
Pentaneurini	0	0	2.326	0	1.942	3.738	4.301	0	0	0	3.571	5.882	0	0	3.571	0	2.469	1.695
Polypedilum	0	3.175	2.326	9.524	1.942	11.21	8.602	12.31	0	0	3.571	5.882	0	0	3.571	1.923	2.469	5.085
Procladius	2.941	19.05	18.6	0	5.825	14.95	17.2	12.31	22.22	8.696	7.143	23.53	14.71	42.86	39.29	38.46	24.69	44.07
Psectrocladius sordidellus	8.824	6.349	10.47	11.9	11.65	5.607	10.75	0	7.407	0	3.571	0	14.71	0	0	1.923	4.938	1.695
Pseudochironomus	0	0.794	0	0	1.942	0.935	0	0	0	0	0	0	0	0	0	0	0	0.847
Pseudosmittia	0	0	0	2.381	1.942	2.804	2.151	0	0	0	0	0	0	0	0	0	0	0
Sergentia coracina	0	1.587	0	9.524	0	0	0	0	0	0	0	0	2.941	0	0	0	0	0
Stempellina	2.941	3.175	2.326	0	1.942	2.804	2.151	12.31	3.704	0	0	0	0	7.143	0	0	0	0
Stempellinella	2.941	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stichtochironomus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.469	0
Synorthocladius	0	0	0	0	3.883	2.804	0	0	0	0	0	0	0	0	0	3.846	2.469	2.542
Tanypus	0	1.587	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanytarsus chinyensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.923	0	0
Tanytarsus lugens	0	1.587	0	2.381	3.883	0	6.452	3.077	0	0	0	0	0	0	3.571	0	0	3.39
Tanytarsus no spur	0	1.587	2.326	0	5.825	3.738	0	0	3.704	8.696	0	0	0	0	7.143	0	2.469	0
Tanytarsus with	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.469	0
Tanytarsus sp. B	0	1.587	4.651	0	5.825	0	2.151	3.077	3.704	0	0	0	8.824	7.143	0	0	0	0
Thienemaniella	0	0	0	0	0	1.869	0	0	0	0	0	0	0	0	0	0	2.469	0
Zalutschia lingulata	0	4.762	4.651	0	0.971	0	0	0	0	0	0	0	0	0	0	0	0	0
Zavrelia	0	0	0	0	0	0	0	0	0	0	0	0	2.941	0	0	0	0	0
Zavrelimyia	0	0	0	0	1.942	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix E. Complete Macrofossil Data

Appendix E Raw Macrofossil Counts from North Bay Near-Shore Core

		Sample (cm)													
		0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	11	15
Submerged	Chara sp. oospores	7	5	7	5	3	7	4	9	6	7	3	4	2	
	Aquatic moss leaf			1							1	1		5	1
	Potamogeton sp. leaf tip	2	6	6	4	5	6	7	5	9	8	10	5		
	Potamogeton sp. seed							1	1						
Emergent	Equisetum sp. stem	1	3	3	2		2	1		1	7	5	3	6	
	Scirpus validus seed								3		2			5	
	Eleocharis palustris seed													1	
	Sparganium sp. seed								1						
	Juncus sp. seed													2	
	Scirpus sp. seed													2	
	Typha latifolia seed													1	
Terrestrial	Aster sp. seed				1			1			2			2	
	Woody debris													1	
	Betula alleghaniensis seed													1	
	alnus rugosa seed	1							1						3
	Betula papyrifera seed			2	1							1			
	Thuja sp. leaf scale								1						
Aquatic invertebrates	Mollusca	3		3	2	1		1		1				2	3
	Daphnia sp. epphipia	1	1		1	2	2	2	4			1	1		
	Caddisfly case			1											
	Gasteropoda shell	1			1				1						
	Bryozoan statoblast			2	2		1	1					2	5	1