Severn Sound

Environmental Association

Report on Water Quality in the Honey Harbour Area of Georgian Bay

2010

Report on Water Quality in the Honey Harbour Area of Georgian Bay

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Severn Sound Environmental Association

for the

Township of Georgian Bay

June 2010

FOREWORD

This document reports on technical investigations conducted by SSEA in the Honey Harbour area from 1998 to 2009 for the Township of Georgian Bay. The monitoring surveys were part of the Severn Sound Environmental Association Open Water Monitoring Program.

The report received technical review prior to its publication. This does not necessarily signify that the contents reflect the views and policies of the Corporation of the Township of Georgian Bay or the Ontario Ministry of the Environment, supporting the work, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Paula Madill, Sampling Technologist, SSEA conducted most of the open water field work for the survey with assistance from SSEA summer staff. Lex McPhail, SSEA Applications Specialist, and Maggie Houlden provided graphic support and assisted with GIS data analyses for this report. We also acknowledge Kristina Kostuk, former water scientist at SSEA for her assistance in data analyses.

EXECUTIVE SUMMARY

The current objectives of the SSEA monitoring in the Honey Harbour area include:

1. Identify trends in water quality, specifically with respect to temperature, oxygen, phosphorus, nitrogen, Secchi disk visibility, chlorophyll *a* and algae biomass;
2. Measure temperature and dissolved oxygen profiles for North Bay, South Bay and Honey Harbour in order to determine the temperature and oxygen regimes in the water column of the bays through the ice-free period of the season and between years;
3. Measure biovolume of total phytoplankton and of specific taxonomic groups of interest and describe patterns of change in community composition within and between years;
4. Sample zooplankton biomass, density, and species richness; Describe patterns of change in community composition; and
5. Relate changes in water quality and phytoplankton and zooplankton community composition with other factors affecting the quality of the bays.

The SSEA Honey Harbour monitoring program is accomplished through partnership with the Township of Georgian Bay, the District Municipality of Muskoka and the Ministry of the Environment, and is coordinated with the SSEA open water monitoring program in Severn Sound and with other monitoring carried out through Georgian Bay Forever. Monitoring results are shared with the Township, the District and the MOE. The District uses the nutrient and temperature/oxygen profiles on their website. Results from water quality monitoring and other SSEA work in the area from past surveys is included in reports and publications from SSEA and in university research studies.

The findings of the SSEA open water monitoring as well as analysis of historical data are summarized as follows:

- The historical record of open water nutrient monitoring up to and including 2009, does not indicate a change in the trophic status of the Honey Harbour area.
- Water clarity has fluctuated with no particular trend except during the peak infestation of zebra mussels when water clarity improved (1998)
- There is no significant increase in euphotic zone total phosphorus or a decrease in bottom water oxygen, or significant change in phytoplankton community.
- The volume-weighted hypolimnetic oxygen concentration in North Bay during late summer is not changing significantly over years of monitoring (1980 – 2010).
- Total phosphorus concentration does increase at 1 m off bottom in both North and South Bay, coinciding with the low bottom water oxygen concentration during each summer. However, this build up does not appear to affect the total phosphorus concentrations in water higher in the water column. The euphotic zone composite total phosphorus concentration does not increase over the ice-free period of the year.
- The phytoplankton community has very low biovolume of blue-green algae. The dominant groups and species of algae in the communities of North Bay and South Bay fluctuate from year to year. Subtle changes in some algae are occurring that require further monitoring and interpretation.
- These bays should be considered sensitive to significant inputs of phosphorus.

From these findings, the following recommendations are made:

- It is recommended that the monitoring program be continued each year until 2013 in order to track trends in nutrients and related indicators of trophic status, as well as other environmental stressors that could impact this busy recreational area.
- The conditions in North Bay should be further assessed with additional sampling of bottom water conditions and vertical distribution of phytoplankton. This will assist in interpretation of the nutrient status of North Bay, and also further investigate any subtle changes in the phytoplankton community and their relation to environmental stressors.
- The results of more detailed phytoplankton studies should be evaluated following the 2013 season in order to revamp the monitoring program for future years.

INTRODUCTION

Excellent overall water quality is one of Georgian Bay's greatest assets. However, human activities can jeopardize this water quality if land use planning and responsible water recreation are not made priorities among residents and governing agencies in the area. The Honey Harbour area is an excellent example of a heavily impacted region of Georgian Bay that is highly sensitive to human activities, and will continue to be vulnerable if impacts are not minimized.

PHYSICAL DESCRIPTION

The Honey Harbour area of Georgian Bay is comprised of igneous granite and meta-sedimentary gneisses of the Precambrian Shield, and is located just north of the transition between the Shield and the sedimentary rock overlain by glacial deposits to the south (SSRAP 1988, Figure 1). Soils in the Honey Harbour area are thin to non-existent, leaving areas of exposed bedrock. Numerous wetlands and small streams flow to the deeply cut, isolated bays that make up the shoreline. North Bay is a deep (~20 m), flat bottom, isolated bay with very restricted water circulation and minimal water inflow from the surrounding watershed (Figure 2 and Figure 3). South Bay has greater water circulation than North Bay, although it is still relatively isolated, and is also shallower at ~10 m. It is influenced by the Severn River via Baxter Lake. Honey Harbour is also shallow (~9 m) and has the greatest amount of circulation with Georgian Bay.

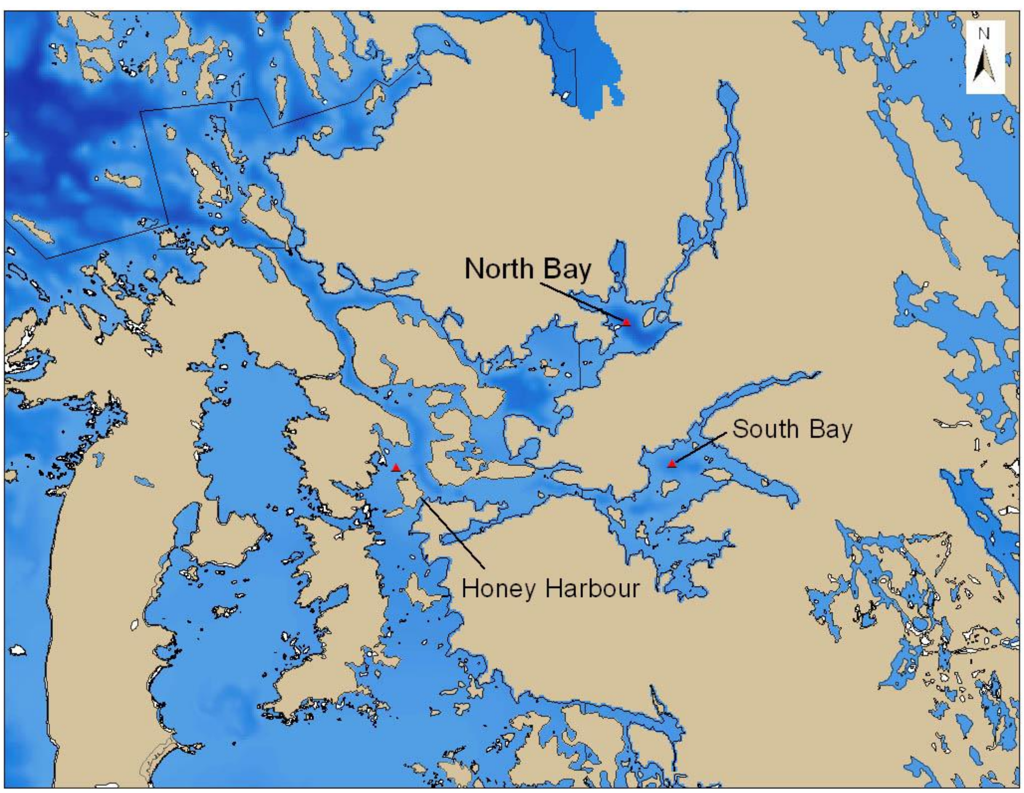

Figure 1. The Honey Harbour area of Georgian Bay and sites sampled in this study. Darker shades of blue indicate deeper waters. Note: All water depths are based on a Chart Datum of 176.1 M above sea level.

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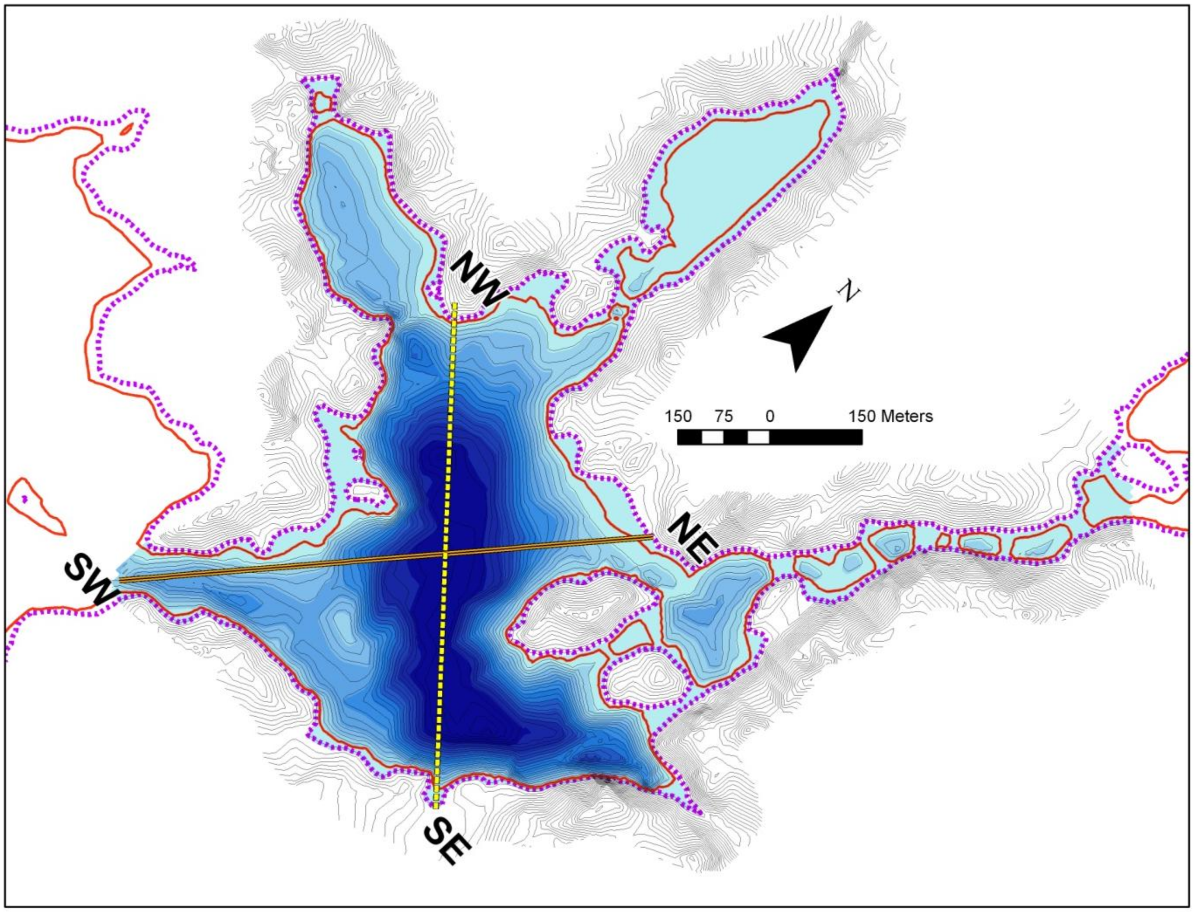

Figure 2. Bathymetry map of upper North Bay showing transects used to graph the basin profile. 1 m contours are shown. Note: All water depths are based on a Chart Datum of 176.1 M above sea level. Produced by the Severn Sound Environmental Association with data supplied in part from the County of Simcoe, the Ontario Ministry of Natural Resources (© Queen's Printer 2010) and under License with members of the Ontario Geospatial Data Exchange, 2010. Depth sounding data was supplied under license by the Canadian Hydrographic Service (© CHS in right of her majesty the Queen, 2010). Not for navigational purposes.

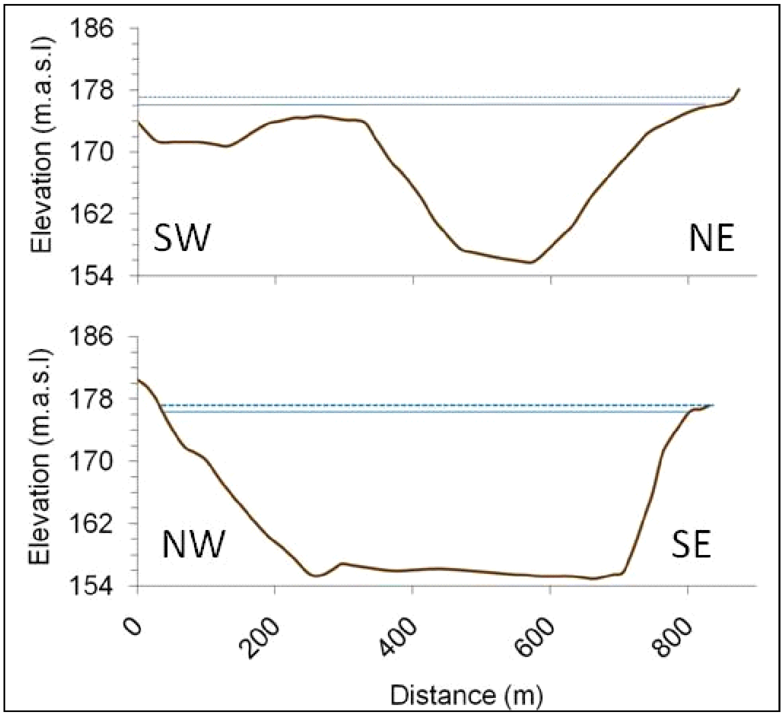

Figure 3. Transects of upper North Bay in South-West to North-East (upper panel) and North-West to South-East (lower panel) orientations. The solid and dashed blue lines indicate the water surface under high and low water levels, respectively.

ENVIRONMENTAL STRESSORS

Cottaging and boating are important aspects of the economy in Honey Harbour, however they are also the greatest source of environmental stress on the area. As road access increased, the number of seasonal and full time residences also increased dramatically. In addition to private residences, there are marinas and campground facilities that service the large number of boaters that visit the area. Activities associated with cottaging and boating can increase the amount of nutrients (phosphorus and nitrogen) entering the bays of Honey Harbour, mainly from septic systems, and detergent and fertilizer use by cottagers, and from grey and black water discharge from boats. Due to the varying residence times in the different bays, anthropogenic nutrient input has varying effects on localized water quality. The more isolated the bay, the more vulnerable it is to both natural and cultural eutrophication. The morphometry, or shape, of some bays, such as the deep U shape of North Bay, also make them prone to natural eutrophication by promoting thermal stratification and impeding bottom water circulation. Increased nutrient input from human activities has the potential to speed up this eutrophication process.

STUDY OBJECTIVES

The Severn Sound Environmental Association (SSEA) monitors three open water stations in the Honey Harbour area for water quality and plankton communities, in addition to stations in the southern portion of Severn Sound. This report summarizes and interprets data collected by

SSEA from 1998 to 2009, as well as data collected by other agencies dating back to 1981. Our study objectives are as follows:

1. Identify trends in water quality, specifically with respect to phosphorus, nitrogen, Secchi disk visibility, and chlorophyll *a*;
2. Describe temperature and dissolved oxygen profiles for North Bay, and determine patterns in metalimnetic and hypolimnetic oxygen depletion
3. Describe sediment characteristics and quality, with reference to relevant sediment quality guidelines.
4. Identify trends in biovolume of total phytoplankton and of specific taxonomic groups of interest such as cyanobacteria and *Microcystis spp*.; Describe patterns of change in community composition;
5. Identify trends in zooplankton biomass, density, and species richness; Describe patterns of change in community composition; and
6. Relate changes in water quality with changes in phytoplankton and zooplankton community composition.

We will conclude with recommendations on future monitoring needs and potential for collaboration in data collection.

METHODS

OPEN WATER SAMPLING PROGRAM

Three sites were sampled in the Honey Harbour area: Honey Harbour (HH), inner/upper North Bay (NB) and South Bay (SB). Sampling locations were based on stations originally sampled by the Ministry of Environment (MOE) from 1981 to 1995, which were then taken over by SSEA in 1998 (Figure 4). Sampling occurred biweekly during the ice-free season, generally from May to October (Table 1). As a reference to conditions in the open waters of Severn Sound, SSEA station P4 was used for 1981-1998 and station M5 was used for 2003-2009.

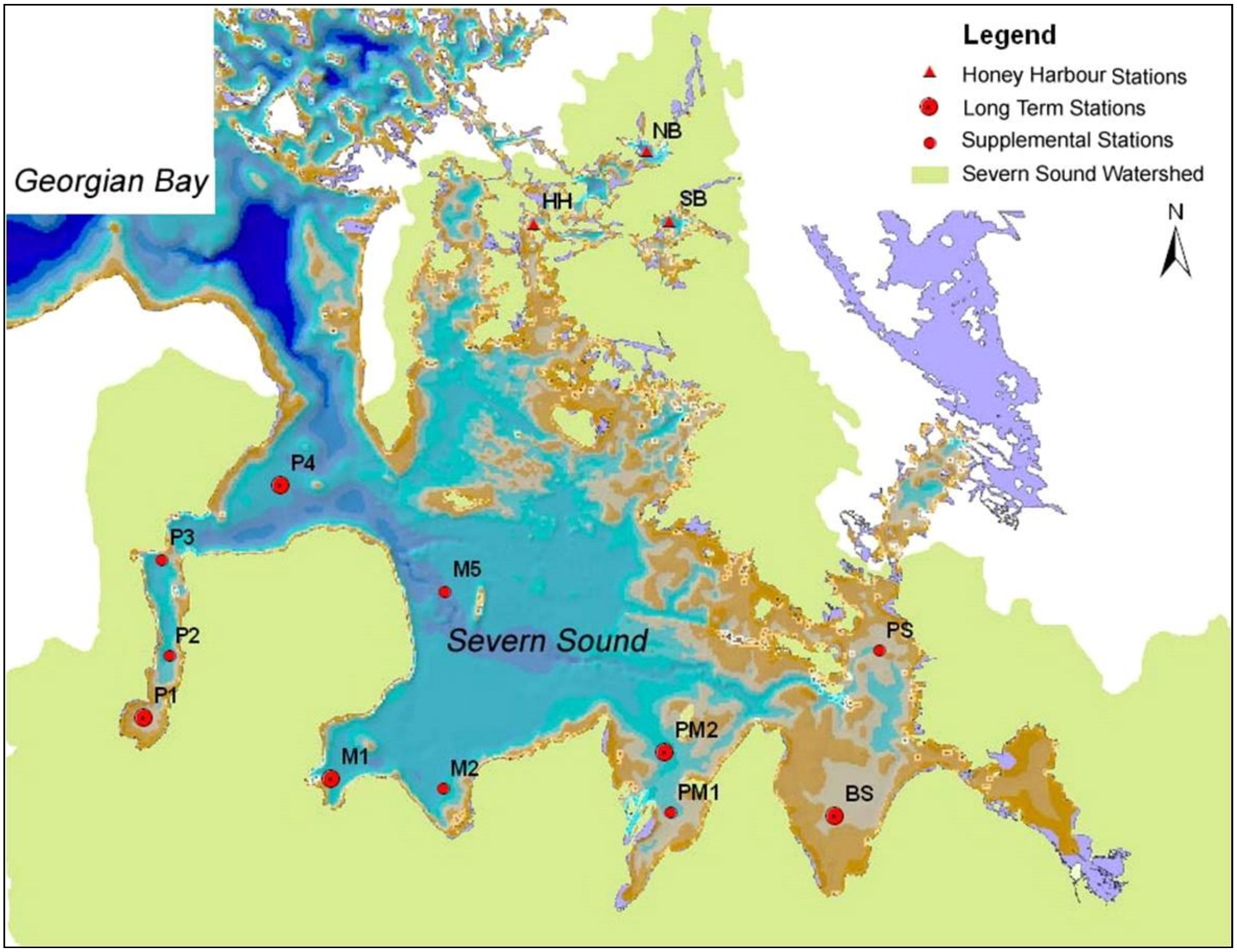

Figure 4. Open water stations monitored by SSEA.

Table 1. Stations sampled by MOE and SSEA, and number of samples taken per year at Honey Harbour stations and open water reference stations.

Year	Sampling Organization	HH	NB	SB	P4	M5	Year	Sampling Organization	HH	NB	SB	P4	M5
1981	MOE		7	7	5		1996					9	
1982					8		1997	MOE		1		10	
1983					8		1998	SSEA	12	12	12	12	
1984	MOE		3	3	8		1999	SSEA				13	
1985					9		2000	SSEA				12	
1986					11		2001	SSEA				12	
1987					6		2002	SSEA				11	
1988					10		2003	SSEA	8	8	8	8	8
1989	MOE		6	6	10		2004	SSEA				12	12
1990					11		2005	SSEA	13	13	13	13	12
1991					10		2006	SSEA				12	12
1992					11		2007	SSEA				13	13
1993	MOE	8	7		11		2008	SSEA	11	11	11	12	12
1994					10		2009	SSEA	13	13	13	13	13
1995	MOE		8		9								

FIELD SAMPLING

Water samples were collected using two 1 L glass bottles fitted with integrator caps and deployed to the bottom of the euphotic zone (twice the Secchi disk depth; Locke and Scott 1986). Unfiltered samples were dispensed into double rinsed PET jars, or borosilicate glass tubes in the case of phosphorus, for nutrient (nitrate+nitrite (TNO_3), ammonia+ammonium (TNH_3), total Kjeldahl nitrogen (TKN), and total phosphorus (TP)), chlorophyll *a*, and phytoplankton analysis. Samples for chlorophyll *a* were stored in opaque bottles and phytoplankton samples were preserved with Lugol's solution. All samples were kept on ice and shipped to the laboratory within 48 h.

In addition to routine sampling, phytoplankton and water chemistry samples were taken separately in the epilimnion, metalimnion and hypolimnion at NB and SB on July 25 2005 by the MOE. From July 29 to the end of the season in 2008, phosphorus analysis was done on water samples taken 1 m off bottom at NB and SB. In 2009, full nutrient analysis was done on water samples taken 1 m off bottom at NB and SB.

Zooplankton samples were collected using various nets over the years (long net in 1998 and Wisconsin net in 2003-2009), all with 80 μm mesh. The net was towed vertically from 1 m off bottom to the surface at a slow and constant rate. Samples were preserved with a buffered 4% formalin solution.

Temperature, conductivity, dissolved oxygen, and pH were measured with an YSI 640 multi-parameter probe at 1 m intervals beginning at the surface to 1 m off bottom. Water clarity was measured using a 20 cm Secchi disk lowered over the shaded side of the sampling vessel.

Environment Canada in cooperation with SSEA collected sediment cores from the Honey Harbour area in 2002 (Figure 5). The quality of surficial portions of the cores (top 4 cm) are summarized in the results section to assist in the interpretation of the water quality status of the Honey Harbour area. The cores were collected from deeper areas of Honey Harbour (8 to 20 m water depth).

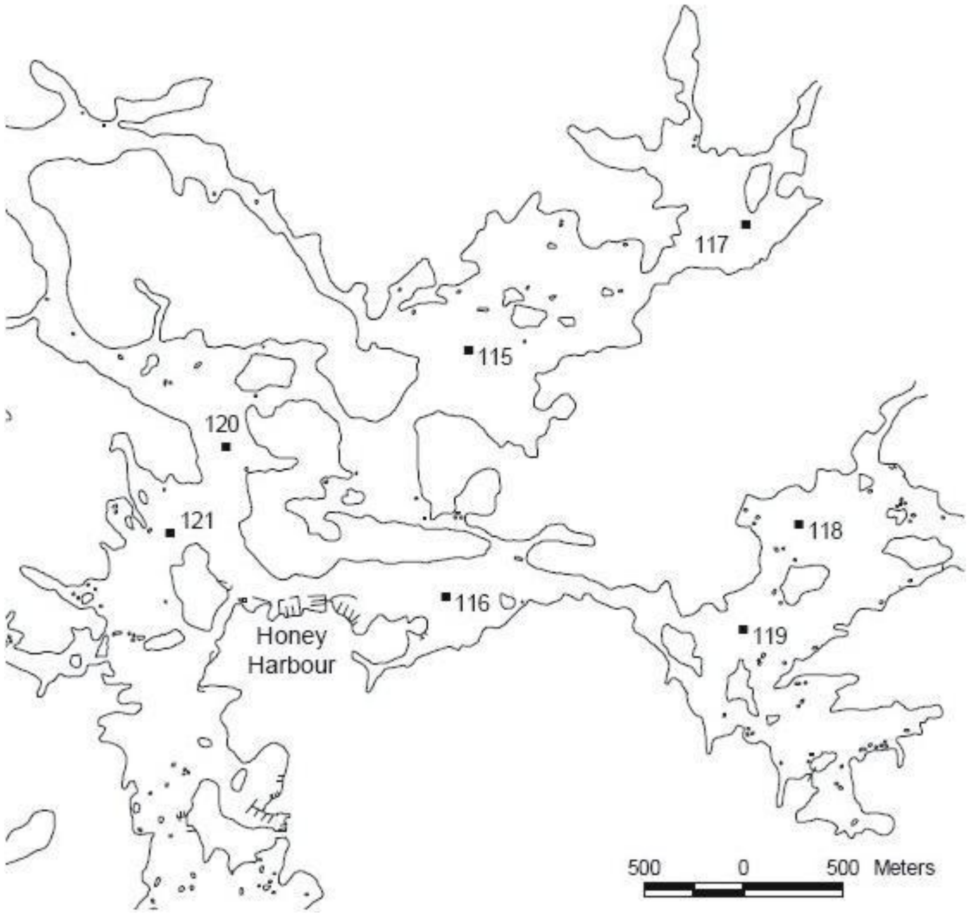

Figure 5. Honey Harbour sediment core locations, March 2002. Stations 117, 118 and 121 correspond to SSEA stations NB, SB and HH, respectively.

LABORATORY ANALYSES

Water samples were analyzed for all parameters using standard MOE analytical methods at the MOE Rexdale Laboratory (MOE 1974). From 2000 onward, the MOE Dorset Laboratory performed all phosphorus analyses using lower detection limits.

Phytoplankton samples were settled at the MOE Rexdale lab and then identified to genus or species by an MOE approved private contractor. Biovolume was obtained for each taxa using standard analytical methods (Nicholls et al. 1977, Hopkins and Standke 1992). For P4 from 1997-2006 and 2008-2009, aliquots from samples taken over the entire season were combined and counted to give an annual average (pooled sample). In 2007, each biweekly samples was counted (individuals). For M5, 2003-2009 samples were counted as individuals. For NB and SB for 1998 and 2003, samples were pooled, and from 2005-2009 samples were counted as individuals. Finally for HH, samples from 1998-2009 were pooled, except for 2005 for which samples were counted as individuals.

Zooplankton analysis was also carried by a private contractor. Analytical methods were consistent with MOE procedures for identification, enumeration and biomass estimation using the ZEBRA software system and the R3 counting method (Allen et al. 1994, Gemza 1995).

STATISTICAL ANALYSES

Prior to analysis, data were checked for outliers using Grubb's test, and for normality using Shapiro-Wilk's test. Where tests required normality (e.g. ANOVA, correlation), data were log transformed. Bivariate statistical analyses included *t*-tests, Tukey tests, ANOVA and correlation-based trend analysis, which were performed with SAS JMP® 6 software (SAS Institute Inc., 2005). Analyses were considered to be significant at *p* values less than 0.5.

RESULTS AND DISCUSSION

TEMPERATURE AND DISSOLVED OXYGYEN

Temperature and dissolved oxygen (DO) are two fundamental variables in water bodies and are both important indicators of water quality. DO measures the amount of oxygen dissolved in the water, and determines the how much of water column is useable habitat. Coldwater fish, like lake trout for example, cannot withstand concentrations below 5 mg/L and must seek suitable habitat that meets their temperature and oxygen requirements. Temperature plays an important role in regulating growth of both plants and animals, and timing of fish migration and spawning.

Measurements of DO and temperature at regular depth intervals yield profiles that indicate whether a system is well mixed or stratified into thermal layers, called the epilimnion, metalimnion and hypolimnion. The metalimnion, or thermocline, is the region of rapid temperature change, 1°C/m or more, that prevents the surface and bottom layers from mixing. Generally, due to greater water circulation from wind and currents, the water column at P4 and M5 does not stratify except briefly under very calm conditions. Shallow waters and increased water circulation prevent strong stratification at HH as well. SB is also shallow, however this station as well as NB are both sheltered from wind and currents, and thus stratify into three distinct layers each year. Large temperature difference, and resulting density difference, between the epilimnion and hypolimnion, prevent these layers from mixing, thereby isolating the bottom waters from atmospheric oxygen. Coupled with high rates of decomposition, this isolation of the hypolimnion can lead to oxygen depletion in the bottom waters.

NB and SB regularly experience such hypolimnetic oxygen depletion. In addition, a zone of anoxic waters develops within the metalimnion late in the season at NB. Isopleths and isotherms (graphs connecting points with the same DO or temperature values throughout the sampling season) are used to visually examine yearly patterns in the location and duration of anoxic waters.

. Generally, stratification began at NB in late May to early June, and broke down by late September to early October (Figure 6). The sampling program did not covered the earliest and latest part of the ice-free season, and so did not capture turnover events, however these likely occurred in the spring in early April and in the fall in late November. The seasonal changes in thickness and location of the three thermal layers have been fairly consistent. In early summer, the thermocline was up to 10 m thick, and by late summer shrank to 5 m or less. The lower bounds of the thermocline was generally between 8-10 m deep.

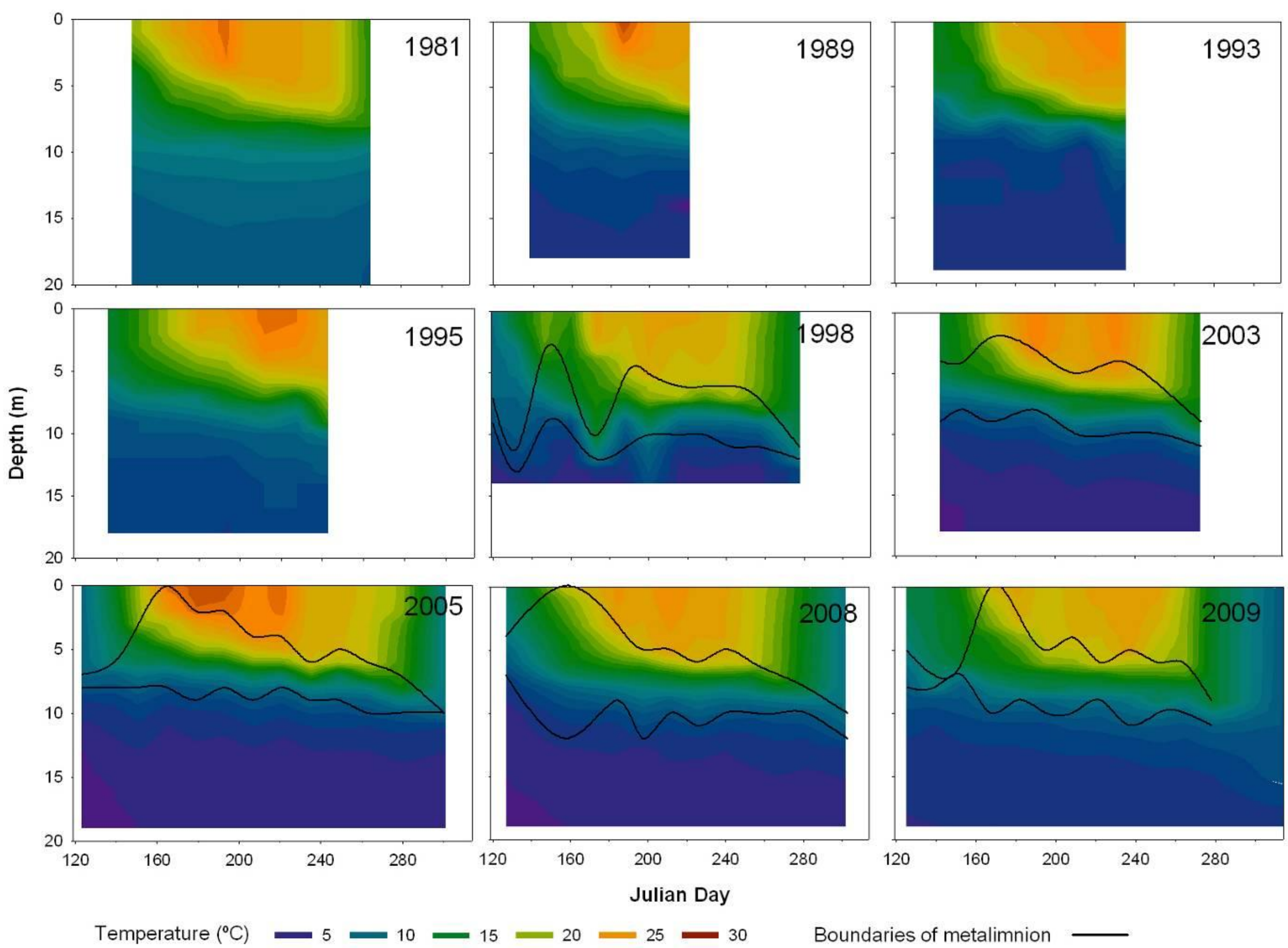

Figure 6. Temperature isotherms for NB from 1981-2009 for the ice free season. Black lines show the boundaries of the metalimnion. In 1998, there was not enough instrument cable to allow for temperature measurements past 14 m depth.

The vertical and temporal extent of the hypolimnetic and metalimnetic oxygen minima at NB has also been fairly consistent (Figure 7). Hypolimnetic oxygen at 1 m off bottom fell below 5 mg/L by late May each sampling year, and did not recover during the sampling period (Figure 8). Although sampling did not continue into the fall months until 2005, the beginnings of anoxic zones in the metalimnion have been detected since 1981. Distinct metalimnetic minima have been detected from 1995-2009. Metalimnetic oxygen fell to <5 mg/L by late July each year, and did not recover until mid-October. This low oxygen zone was up to 5 m thick in the early part of the summer, and by late summer, DO remained below 5 mg/L to the lake bottom. This means that coldwater fish species would have been restricted to the epilimnion, where temperatures were too warm for survival. Decomposing algae that become entrained in the thermocline due to mixing resistance may be the cause of this metalimnetic minima, and will be further explored in the phytoplankton section of this report.

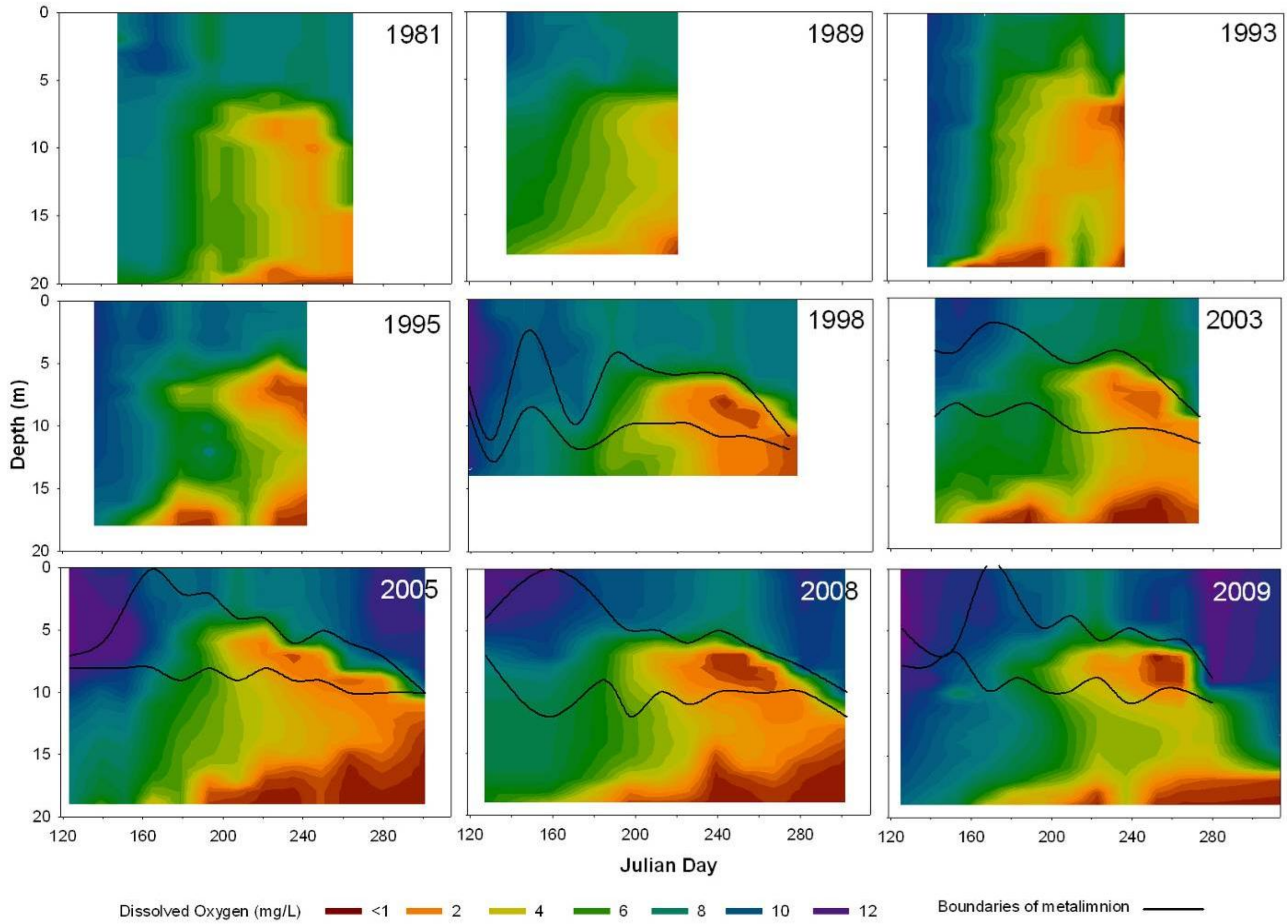

Figure 7. DO isopleths for NB from 1981-2009 for the ice free season. Black lines show the boundaries of the metalimnion. In 1998, there was not enough instrument cable to allow for DO measurements past 14 m depth.

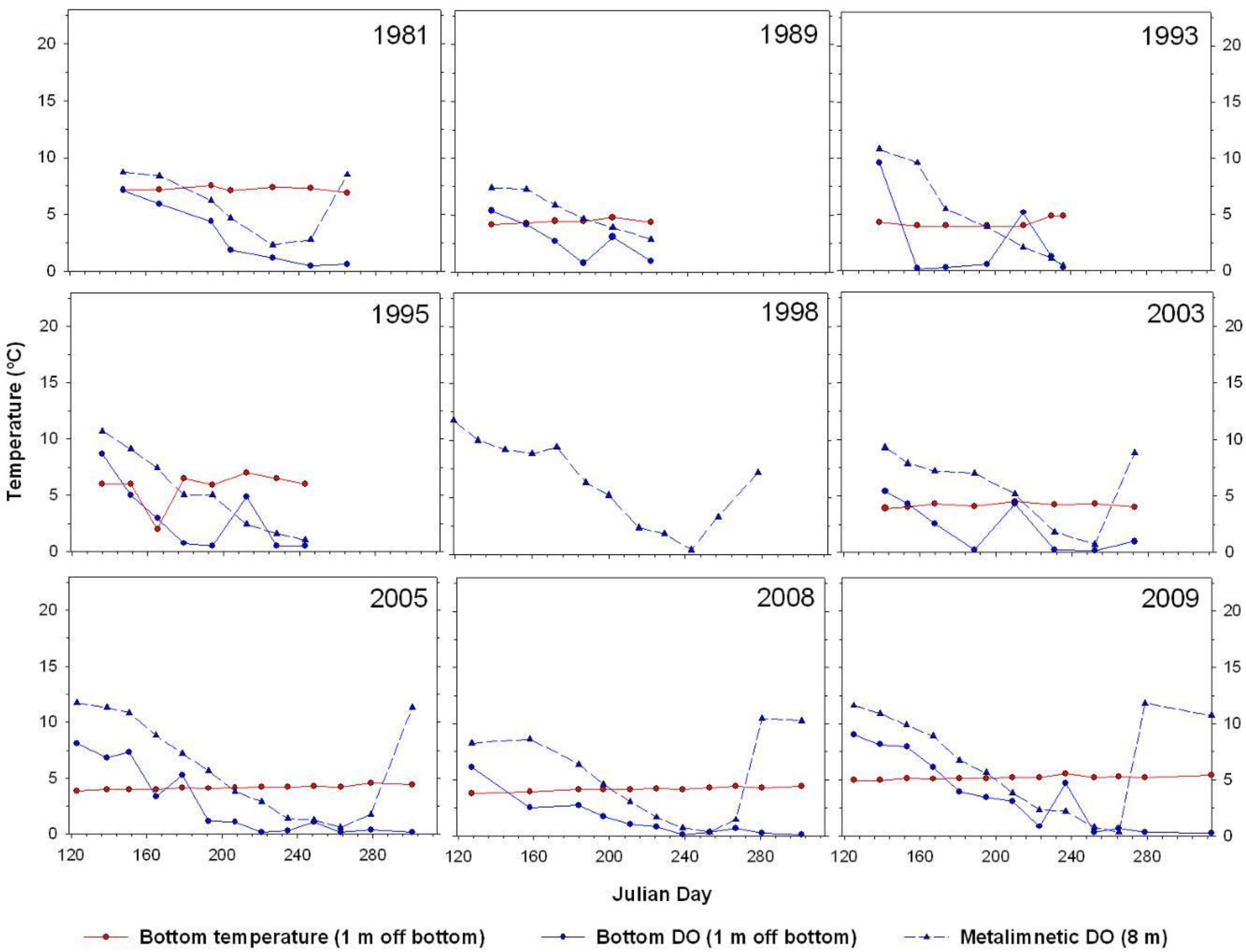

Figure 8. Temperature and DO taken at NB at 1 m off bottom and DO taken at 8 m depth (the average depth of the metalimnetic minimum) from 1981-2009. In 1998, there was not enough instrument cable to allow for temperature or DO measurements past 14 m depth.

To determine whether DO and temperature in the hypolimnion at NB have changed over time, volume weighted hypolimnetic oxygen (VWHO) and temperature (VWHT) calculations were made that take into account the variations in volume of the hypolimnion from year to year. This allows for inter-annual comparisons. DO concentrations in the hypolimnion have remained steady over time, averaging 2.4 mg/L (Figure 9A). Most cold and cool water fish, including lake trout and walleye, require concentrations above 4-5 mg/L to survive and reproduce. Temperatures in the hypolimnion have decreased, although not significantly, and averaged 4.8 °C (Figure 9B). Although the hypolimnion is cold enough to support coldwater fish populations, the low DO makes this region unsuitable as habitat.

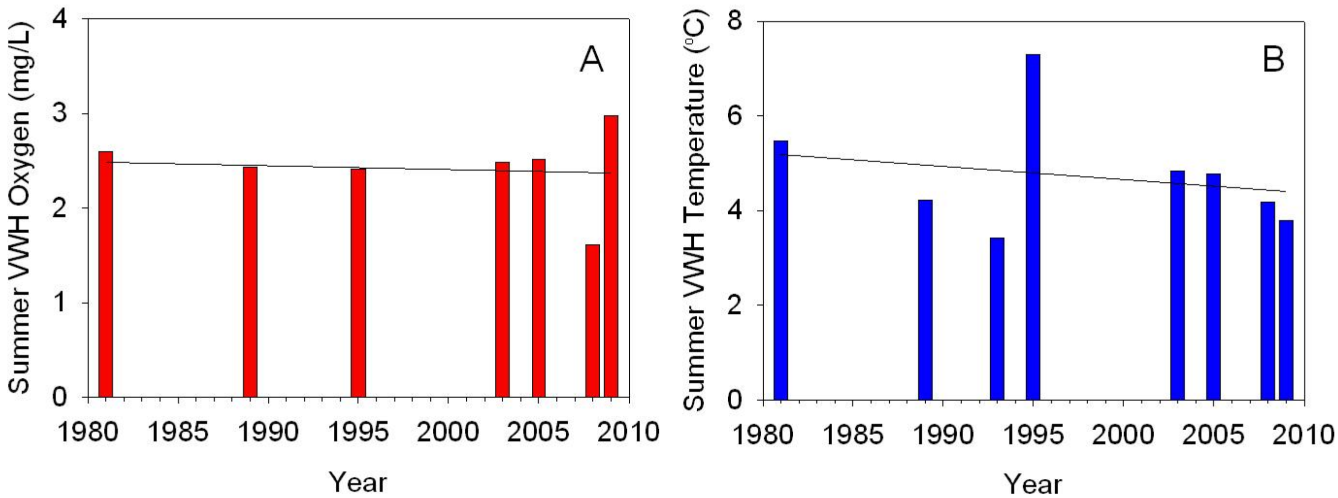

Figure 9. Summer volume weighted hypolimnetic oxygen (A) and temperature (B) for NB from 1981-2009. Trend lines shown indicate no significant trends.

Although they are spatially close together, NB and SB are very different from each other in terms of thermal structure and DO. There was slightly more variation in the timing of onset and breakdown in summer stratification at SB as well as in the thermal structure during the stratified period, likely because it is a shallower site that is more influenced by mixing from wind and water currents (Figure 10). For example, in late summer of 1998, a mixing event caused the water column to become isothermal (same temperature) for a short time, until surface heating re-established the thermal layers. Spring turnover likely occurred around the same time as at NB, although fall turnover occurred earlier, around mid-October. Compared to NB, the hypolimnion was much thinner and warmer, while the epilimnion was generally the same thickness, although cooler overall. This may be a result of the influence of the Severn River via Baxter Lake.

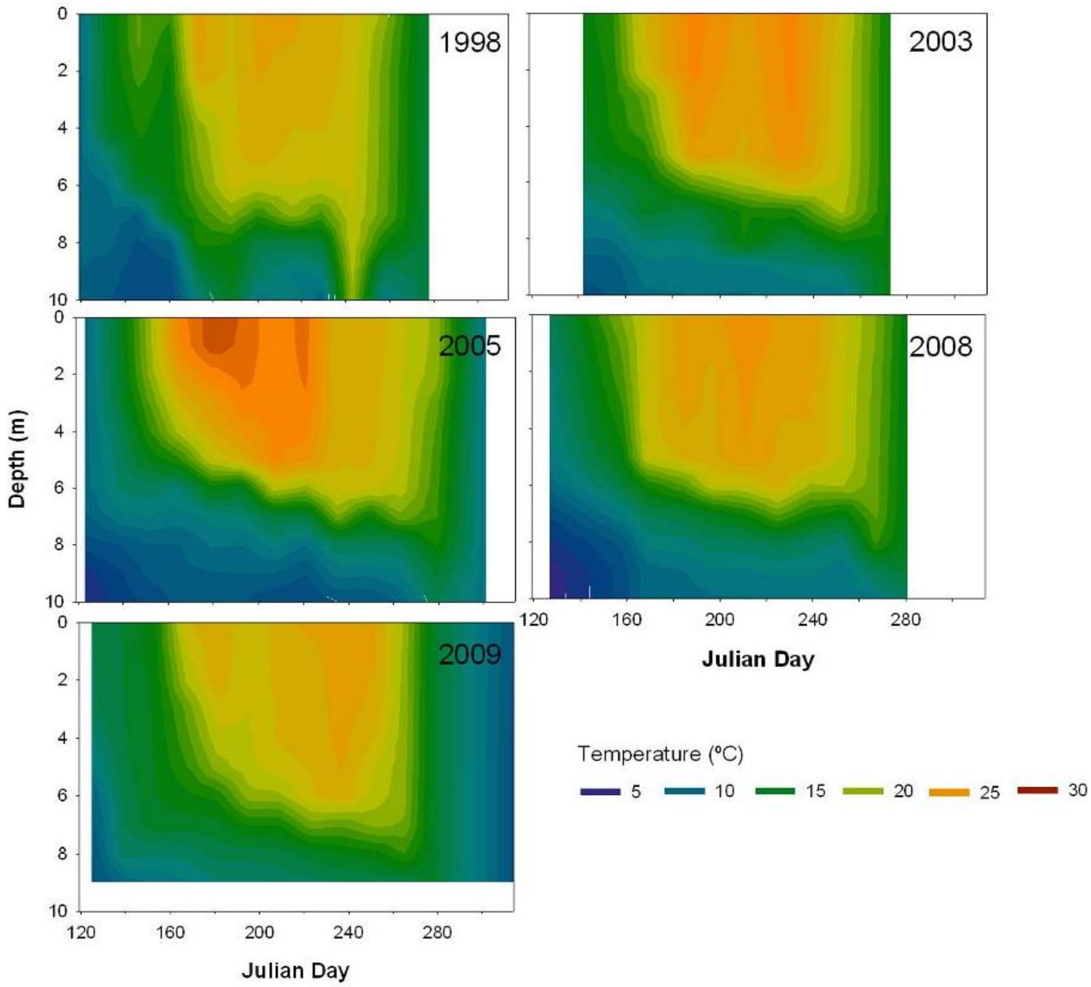

Figure 10. Temperature isotherms for SB from 1981-2009 for the ice free season.

In contrast to NB, there were no metalimnetic minima at SB (Figure 11). Also, hypolimnetic minima did not persist as late into the season, although they were as low as at NB. DO at 1 m off bottom dropped below 5 mg/L by late May and recovered by early October (Figure 12). Temperatures at 1 m off bottom averaged 10 °C. As at NB, the entire hypolimnion was unsuitable habitat for coldwater fish during the summer months due to low oxygen.

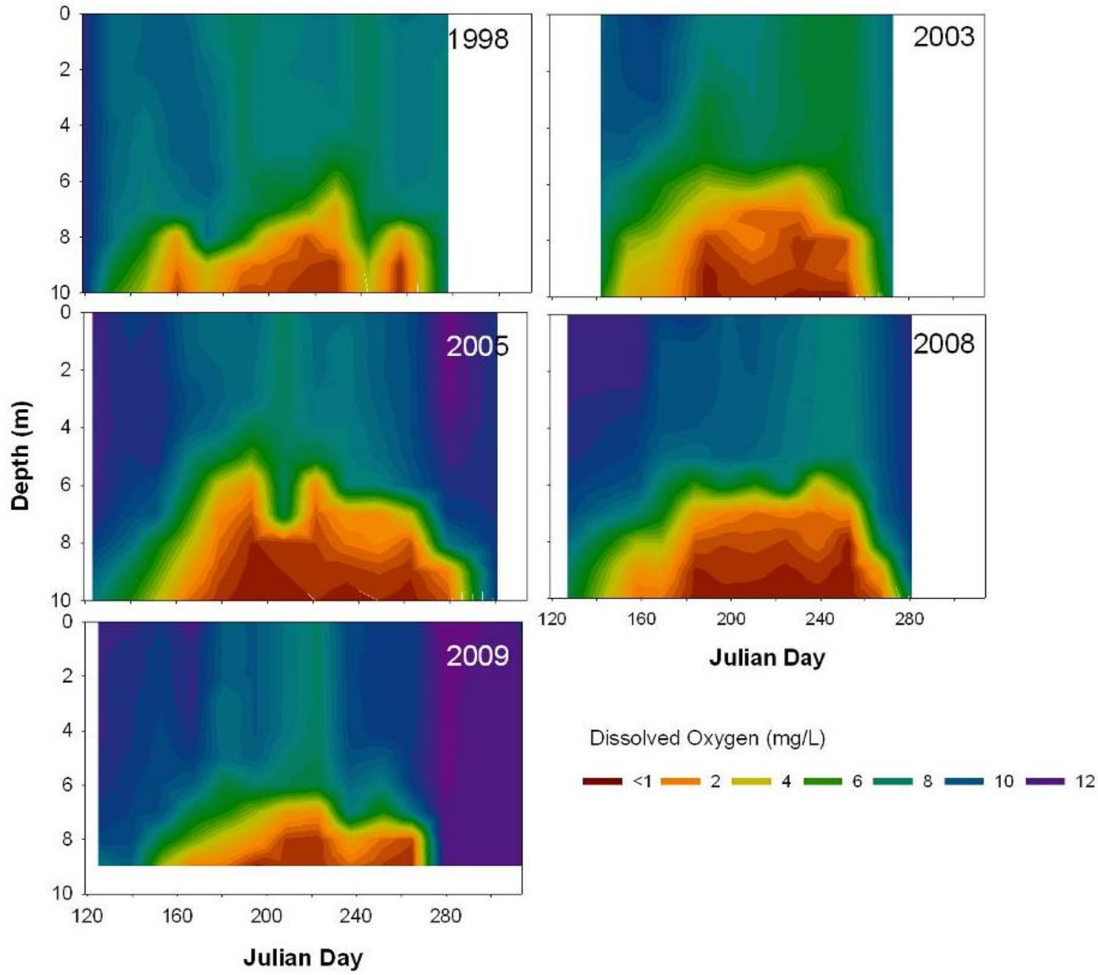

Figure 11. DO isopleths for SB from 1981-2009 for the ice free season.

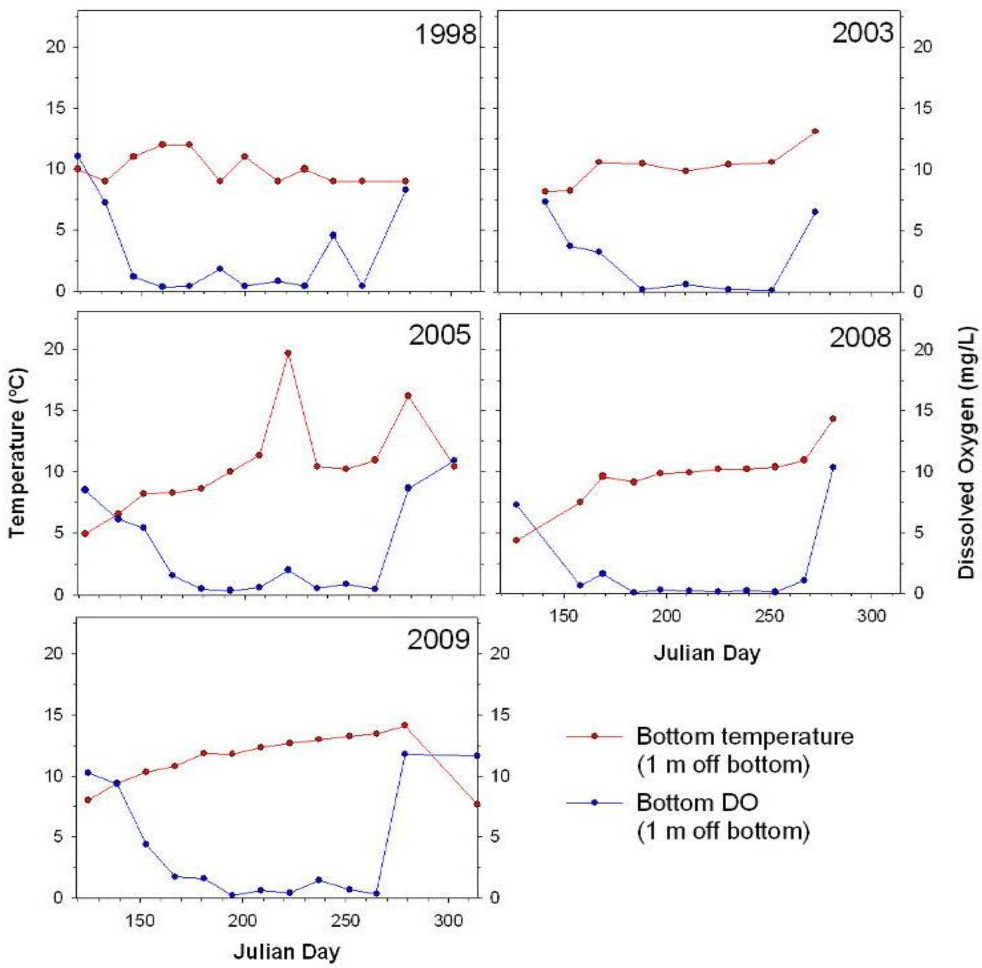

Figure 12. Temperature and DO taken at SB at 1 m off bottom from 1998-2009.

WATER QUALITY

Phosphorus

Phosphorus is essential for macrophyte and algal growth, and is the limiting nutrient in most freshwaters in Ontario. Total phosphorus (TP) measures both the dissolved and particulate fractions of phosphorus, the latter of which includes algae cells and small zooplankters. Over the period of 1981-2009, mean annual TP at NB declined, although not significantly (Figure 13). Significant decreases were seen at SB, HH and P4 (p <0.0001; 0.06; and <0.0001, respectively). There was no significant change at M5. By 1998, all sites except SB met the Severn Sound Remedial Action Plan (RAP) phosphorus delisting objective of 15 µg/L; SB met the target by 2003. Concentrations at HH were below this objective during the entire study period. The amount of seasonal variation in TP as measured by the standard deviation decreased significantly during the study period at all stations but M5 (p< 0.01).

Compared to the open water sites, the TP concentrations at NB and SB were significantly greater than at M5 and P4 (p<0.05), while at HH concentrations were significantly lower than M5 (p=0.03) and not significantly different than P4.

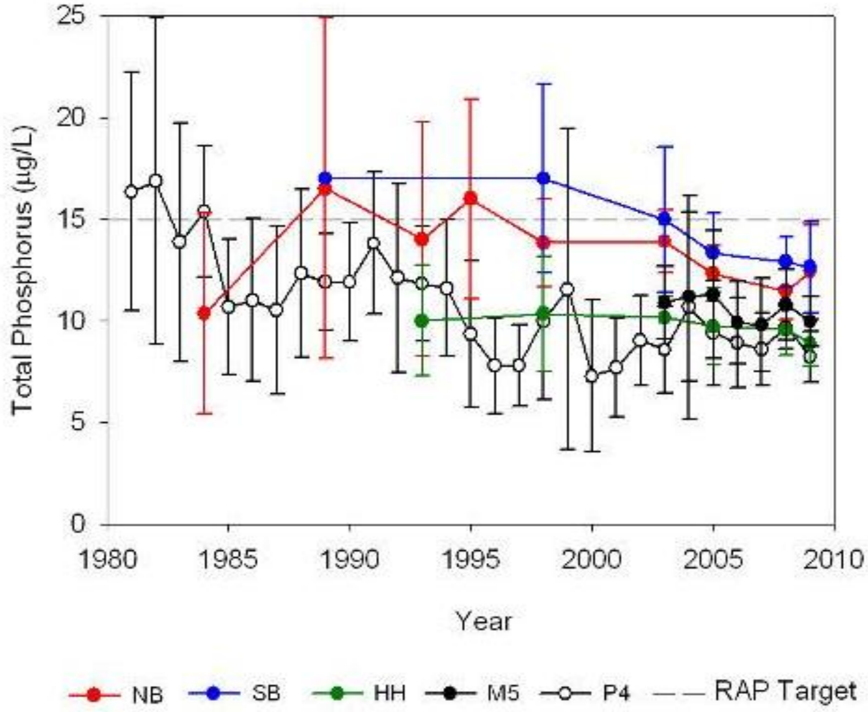

Figure 13. Trends in mean annual total phosphorus concentrations for Honey Harbour and open water stations. Error bars are ± 1 standard deviation. The RAP delisting objective of 15 µg/L is also shown by the dashed line.

Looking at the seasonal values for TP, there appear to be no discernible seasonal patterns at any of the Honey Harbour or open water reference stations (Figure 14).

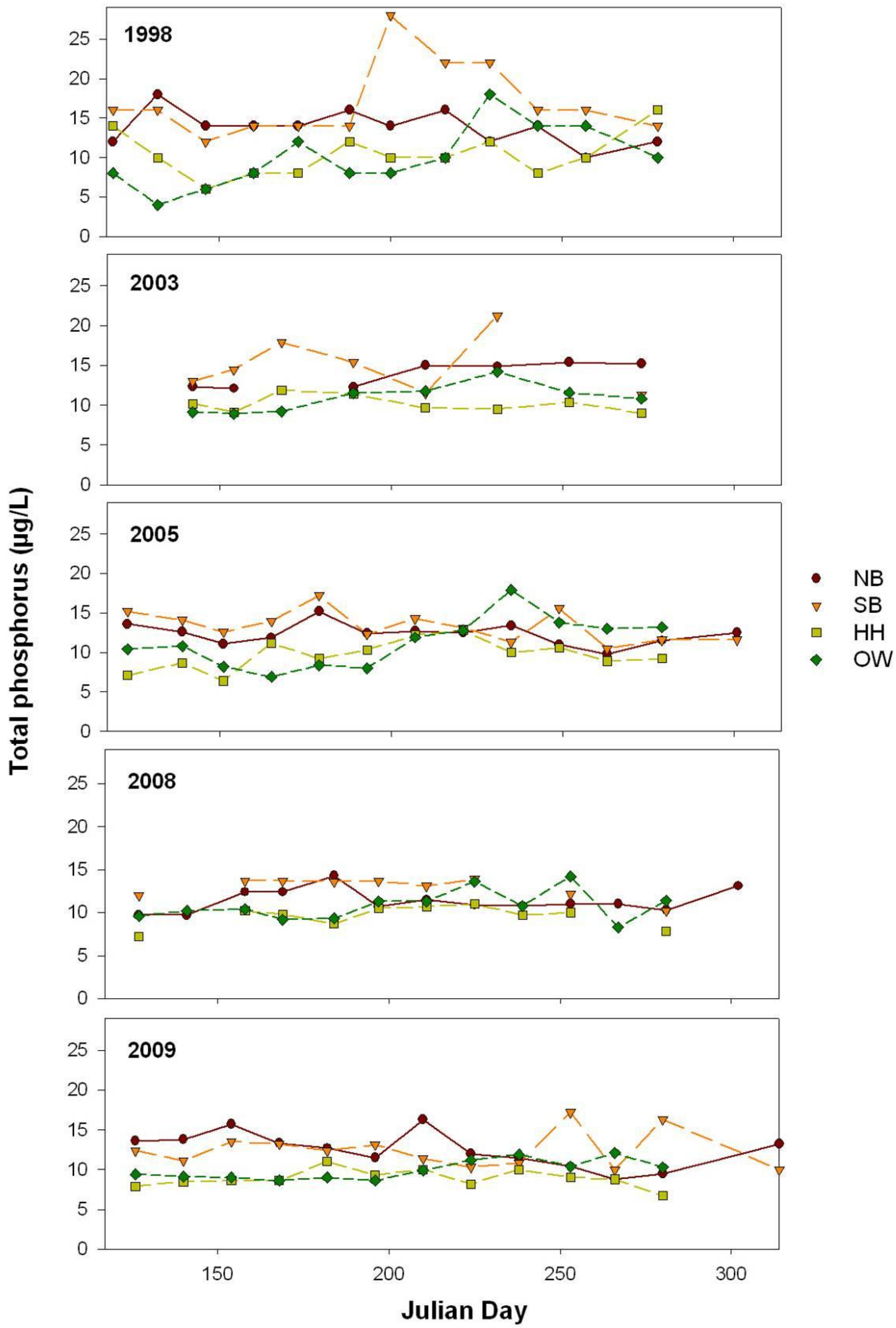

Figure 14. Seasonal trends in TP over the ice-free period from 1998-2009 for Honey Harbour stations and open water stations (P4 for 1998, and M5 for 2003-2009).

In late July 2005, samples were taken in the epilimnion (surface to top of the thermocline composite), mid-metalimnion, upper hypolimnion and bottom waters (1 m off bottom) at NB and SB. TP decreased slightly from the epilimnetic to hypolimnetic waters of NB, then increased to 325 µg/L at 1 m off bottom (Figure 15, top panel). At SB, the increase in the bottom waters was less dramatic, to 132 µg/L. The bottom water DO at the time of sampling was 1.06 and 0.6 mg/L, respectively. Similar results were found in the bottom waters of NB in 2008 and 2009, with mean TP values during the anoxic period (DO < 1 mg/L) of 246 and 86 µg/L, respectively (Figure 15, middle and bottom left-hand panels). In the bottom waters of SB in 2008 and 2009, mean TP values during the hypoxic period were 306 and 44 µg/L, respectively (Figure 15, middle and bottom right-hand panels). These high bottom water TP values occur due to the release of P from nutrient rich sediments. Each year in late summer, the bottom waters of NB and SB become anoxic, a condition which greatly increases the amount of P released from sediments. This was further evidenced by the hydrogen sulfide smell observed on several sampling dates during the anoxic periods in 2008 and 2009, an indicator of anaerobic decomposition and reducing conditions.

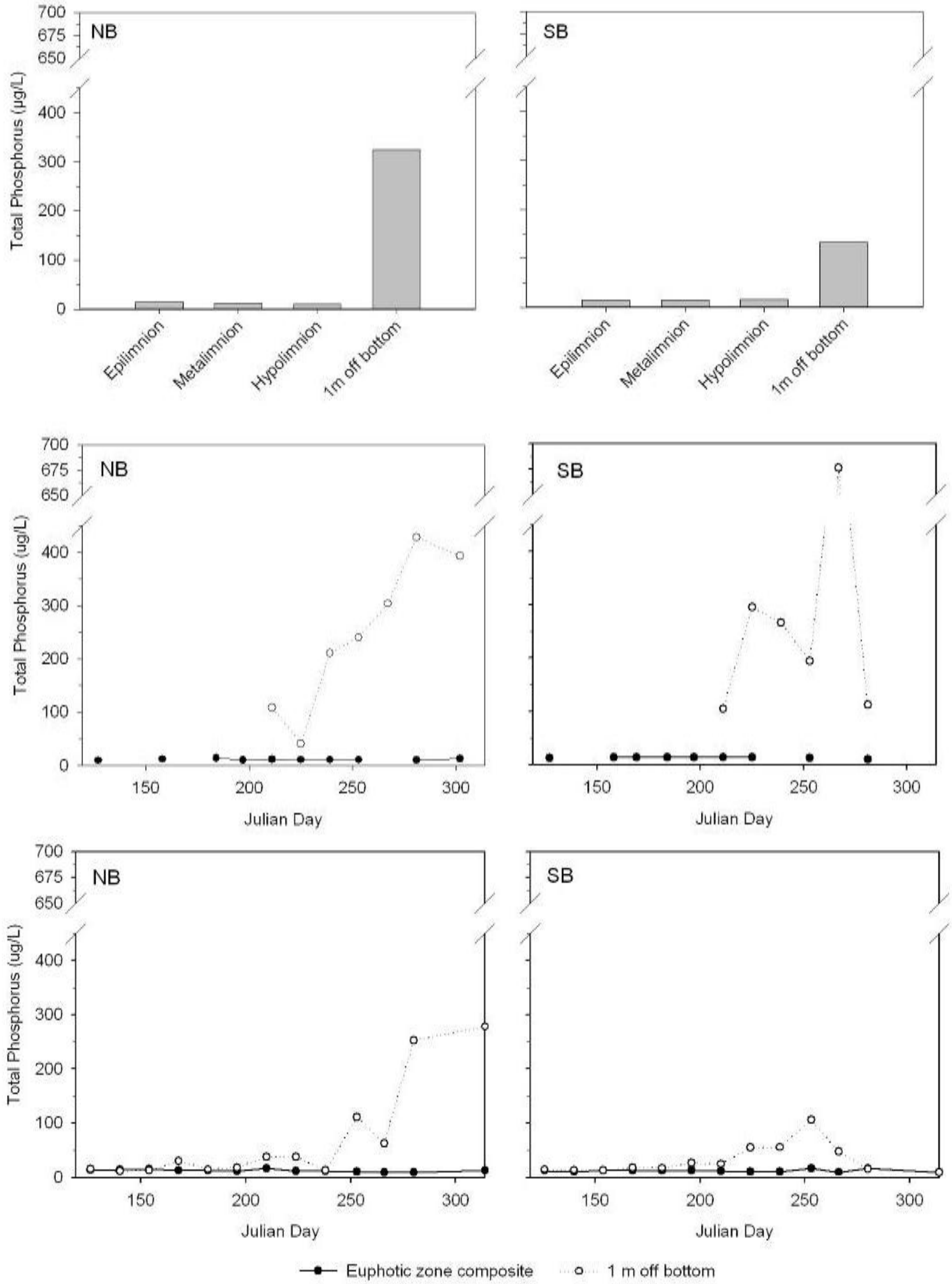

Figure 15. TP concentration in euphotic zone, metalimnion, hypolimnion and bottom water samples at NB and SB for July 25 2005 (top), and in euphotic zone and bottom water samples for the ice-free season of 2008 (middle) and 2009 (bottom). Note the scale break for TP.

Secchi Disk Visibility

Secchi disk visibility (SDV) is a measure of water clarity. Suspended solids in the water column, either algae or inorganic sediments, as well as tannins from wetland drainage can contribute to reduced water clarity. During the summer, algal blooms are generally the greatest contributor to poor water clarity. SDV did not change significantly over the long term at any of the Honey Harbour sites over the study period (Figure 16). Of the open water sites, SDV increased significantly at P4 (p=0.006), with a marked increase occurring in 1994. This coincided with the zebra mussel invasion in Severn Sound, as well as upgrades to several sewage treatment plants that discharge to Severn Sound (SSRAP, 2002). At the Honey Harbour sites, SDV was not less than the RAP delisting objective of 3 m prior to 2003, with the exception of NB in 1995. Since 2003 however, water clarity has been declining, particularly at HH where the SDV objective has only been met once since 2003. Compared to the open water sites, the water clarity at HH was significantly lower than at P4 (p=0.02).

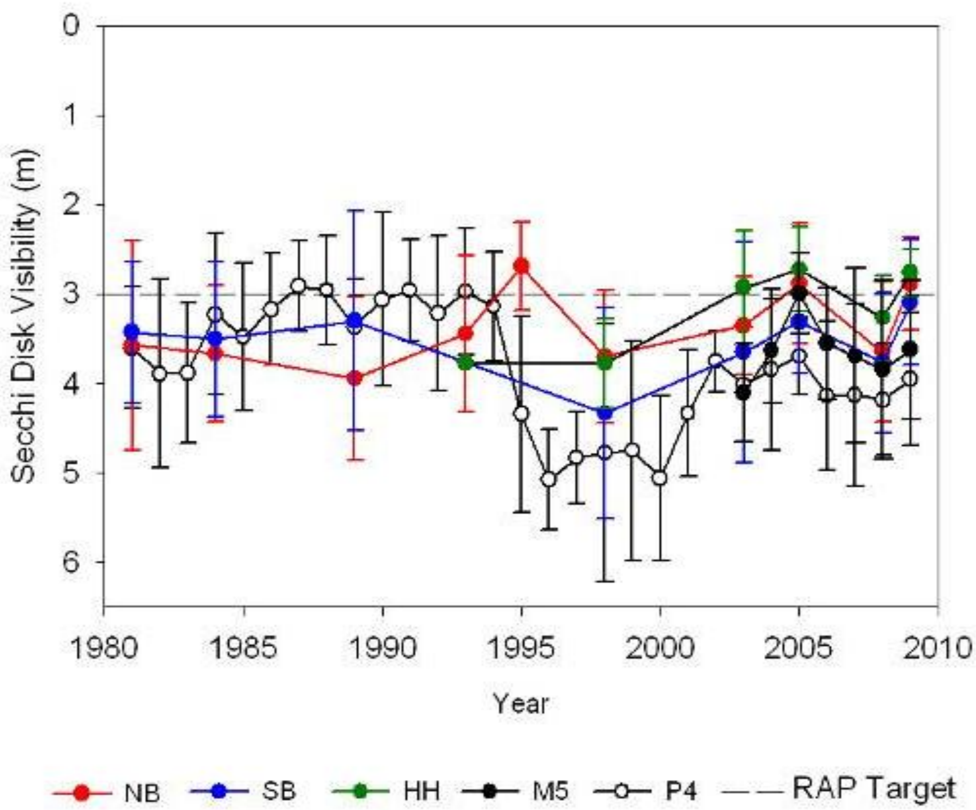

Figure 16. Trends in mean annual Secchi disk visibility for Honey Harbour and open water stations. Error bars are ± 1 standard deviation. The RAP delisting objective of 3 m is also shown.

Similar to TP, there have been no consistent seasonal patterns in SDV (Figure 17).

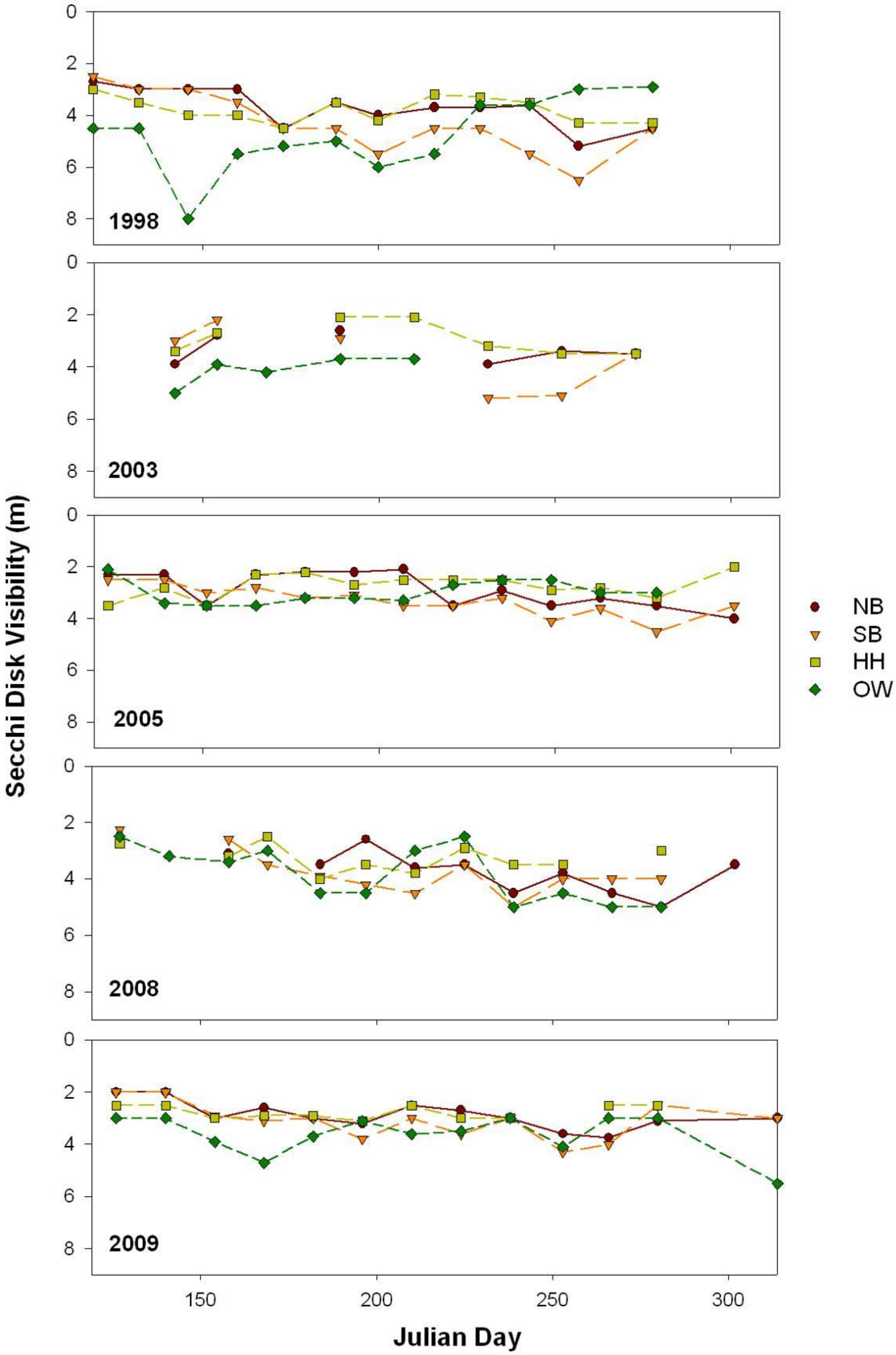

Figure 17. Seasonal trends in SDV over the ice-free period from 1998-2009 for Honey Harbour stations and open water stations (P4 for 1998, and M5 for 2003-2009).

Chlorophyll *a*

Chlorophyll *a* is a photosynthetic pigment found in algae and aquatic plants. The relatively consistent relationship between algal density and chlorophyll *a*, allows for its use as an indicator of the amount of algae in water column. Concentrations decreased significantly at HH (p=0.015), SB (p=0.058), P4 (p<0.0001) and M5 (p=0.002) over the study period (Figure 18). Only NB had significantly greater concentrations than M5 (p=0.03). Chlorophyll *a* at all of the stations have been below the RAP objective of 5 µg/L since 1993.

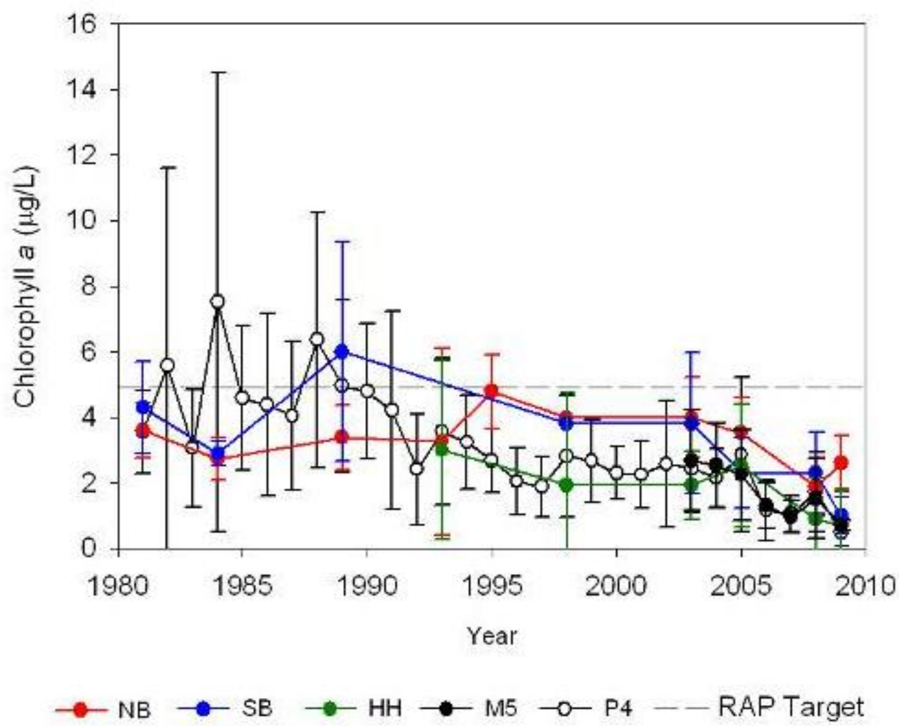

Figure 18. Trends in mean annual chlorophyll *a* for Honey Harbour and open water stations. Error bars are ± 1 standard deviation. The RAP delisting objective of 5 µg/L is also shown by the dashed line.

When chlorophyll *a* concentrations were examined seasonally, it was apparent that despite high variability, most sites experience a modest to strong peak between mid-July to early September.

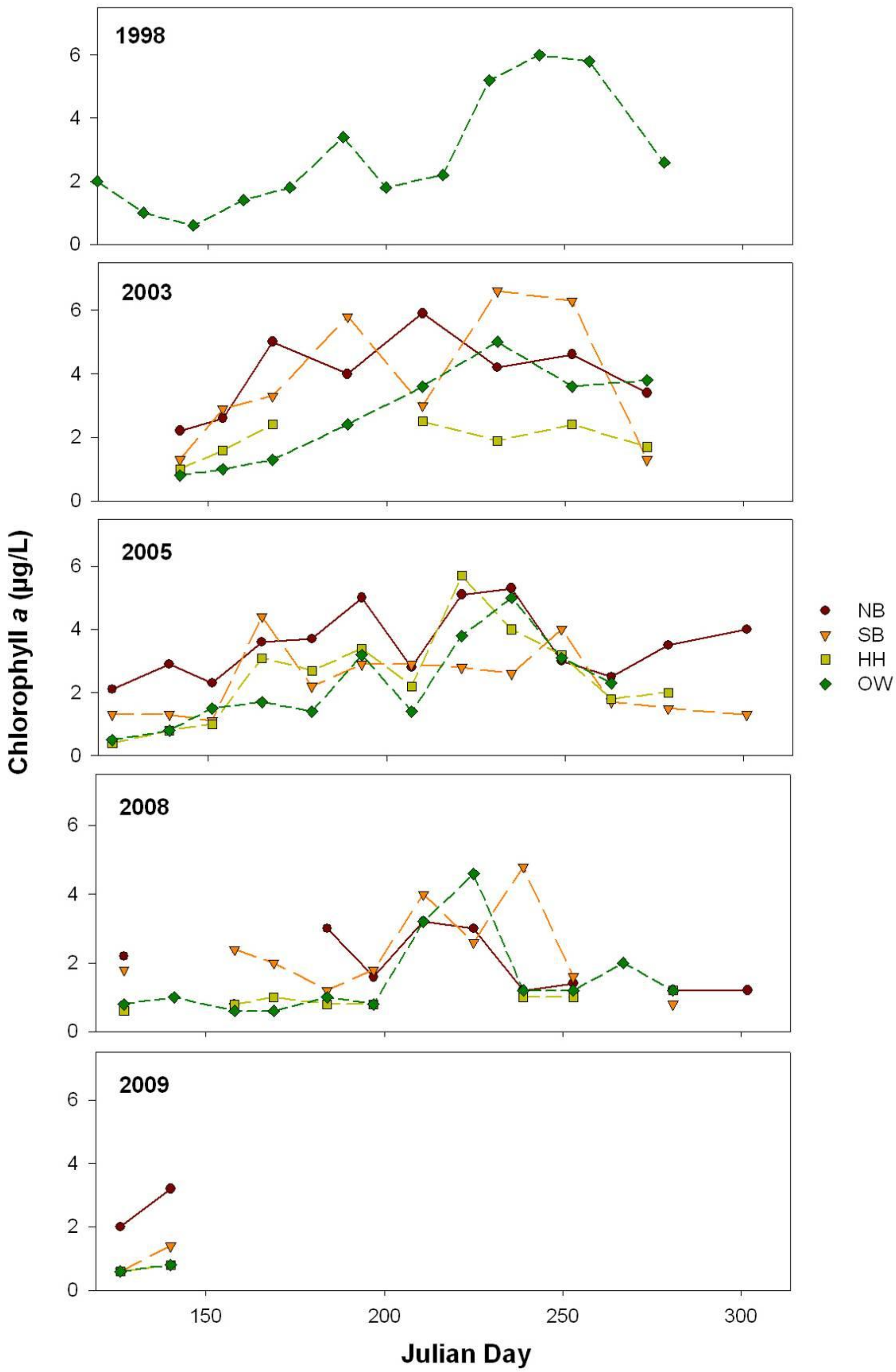

Figure 19. Seasonal trends in chlorophyll *a* over the ice-free period from 1998-2009 for Honey Harbour stations and open water stations (P4 for 1998, and M5 for 2003-2009). Only two samples from each station were analyzed

in 2009 due to reductions in analytical capacity at the lab.

Based on discrete sampling done in 2005, chlorophyll *a* was slightly higher within the metalimnion compared to the rest of the water column at NB, while concentrations changed from 1 to 4 μg/L in the hypolimnion and 1m from the bottom at SB (Figure 20). This is possibly because the euphotic zone extends closer to the lake bottom at SB, which is where the greatest TP concentrations occur, thus supporting greater amount of algal production.

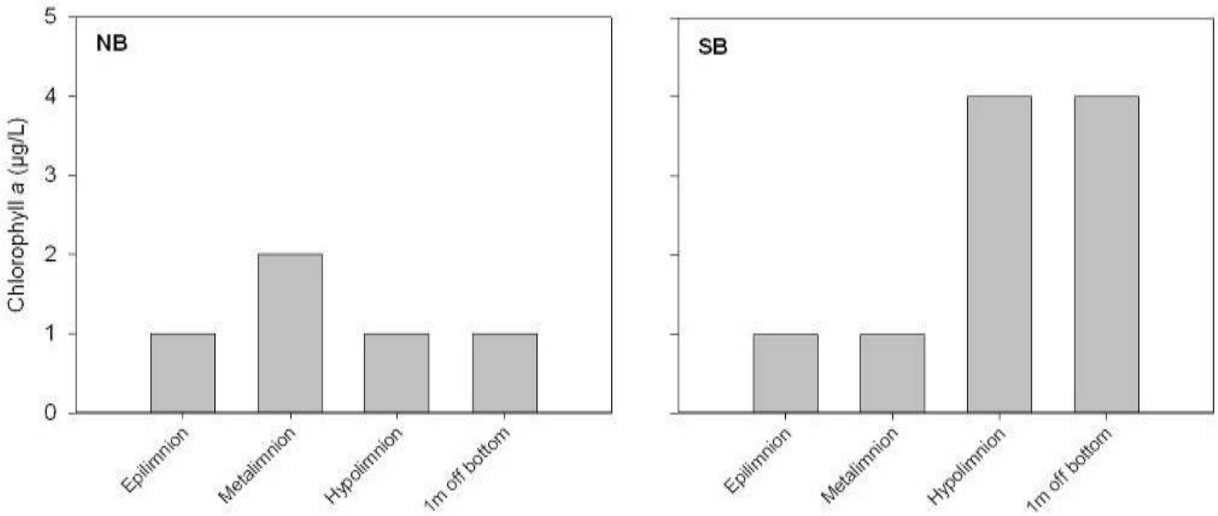

Figure 20. Chlorophyll *a* concentration in euphotic zone, metalimnion, hypolimnion and bottom water samples at NB and SB for July 25 2005.

Nitrogen

Nitrogen can be found in both organic (dissolved and particulate) and inorganic forms (e.g. ammonia, nitrate, and nitrite) and is an important nutrient for algal growth, second only to phosphorus. In Honey Harbour, there is generally 20-40 times the amount of N as P, as determined by the TN:TP ratio. Total nitrogen (TN) did not change significantly at any of the stations over the study period (Figure 21, top left). Total Kjeldahl nitrogen (TKN), a measure of organic nitrogen+ammonia, declined significantly only at P4 (p=0.01), and markedly so after 1994 (Figure 21, top right). Total nitrate (TNO_3, includes nitrate and nitrite) increased significantly at P4 (p=0.006), although it has decreased in recent years (Figure 21, bottom right). TNO_3 decreased at M5 (p=0.01), although it is clear that the trends at this station follow those at P4, so if data were available dating back to when monitoring began at P4, an overall increase would likely have been detected at M5 as well. At the Honey Harbour stations, TNO_3 did not change significantly. Overall, ammonia (TNH_3, includes ammonia and ammonium ion) decreased significantly at P4 (p=0.01), however it has been increasing in recent years (Figure 21, bottom left). TNH_3 significantly increased at NB and SB (p=0.001 and 0.008, respectively). TNH_3 concentrations are generally in low in lakes, and elevated levels are usually a result of human impact.

Comparing open water stations to Honey Harbour stations, TN was lower at NB and HH compared to P4 (p=0.04 and 0.007, respectively). TKN was greater at NB and SB compared to

P4 (p=0.04 and 0.01, respectively) and was greater at SB compared to M5 (p=0.03). All three Honey Harbour stations had lower TNO_3 compared to P4 (p=0.0001, <0.0001, and 0.005, respectively) and NB and SB had concentrations lower than M5 as well (p=0.03 and 0.02, respectively). There were no differences among open water stations and Honey Harbour stations with respect to NH_3.

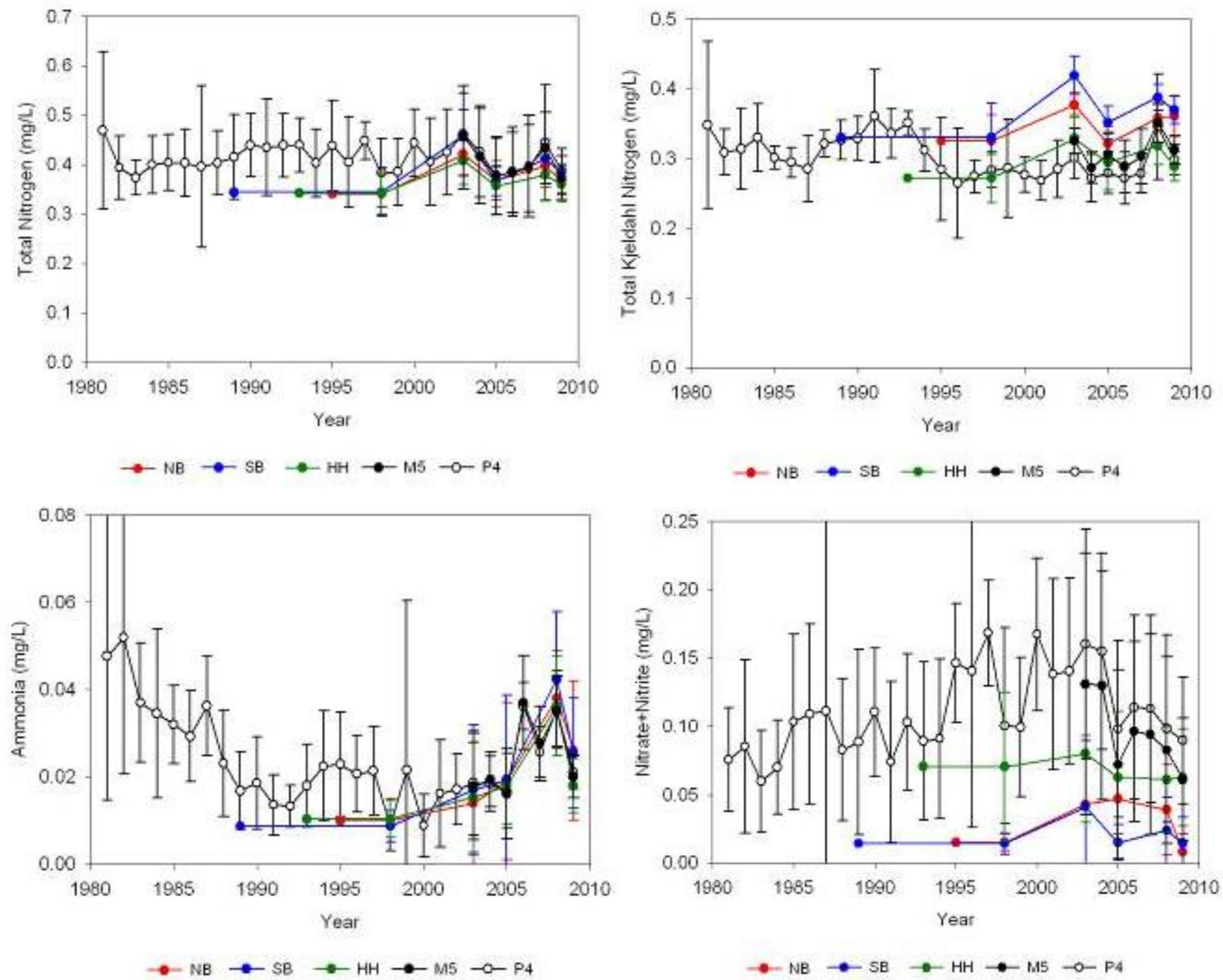

Figure 21. Trends in mean annual TN, TKN, TNO_3 and TNH_3 (clockwise from top left) for Honey Harbour and open water stations. Error bars are $\pm$ 1 standard deviation.

Looking at seasonal patterns, TN decreased from late spring to early fall as the highly available forms, TNO_3 and TNH_3, were used up by plants and algae (Figure 22). Trends for TNO_3 and TNH_3 showed similar patterns (graphs not shown). Concentrations were higher in the spring due to snowmelt runoff. The open water stations are more strongly influenced by agricultural activities in the southern portion of the Severn Sound watershed, hence why spring TN values are higher at the open water stations than at the Honey Harbour stations.

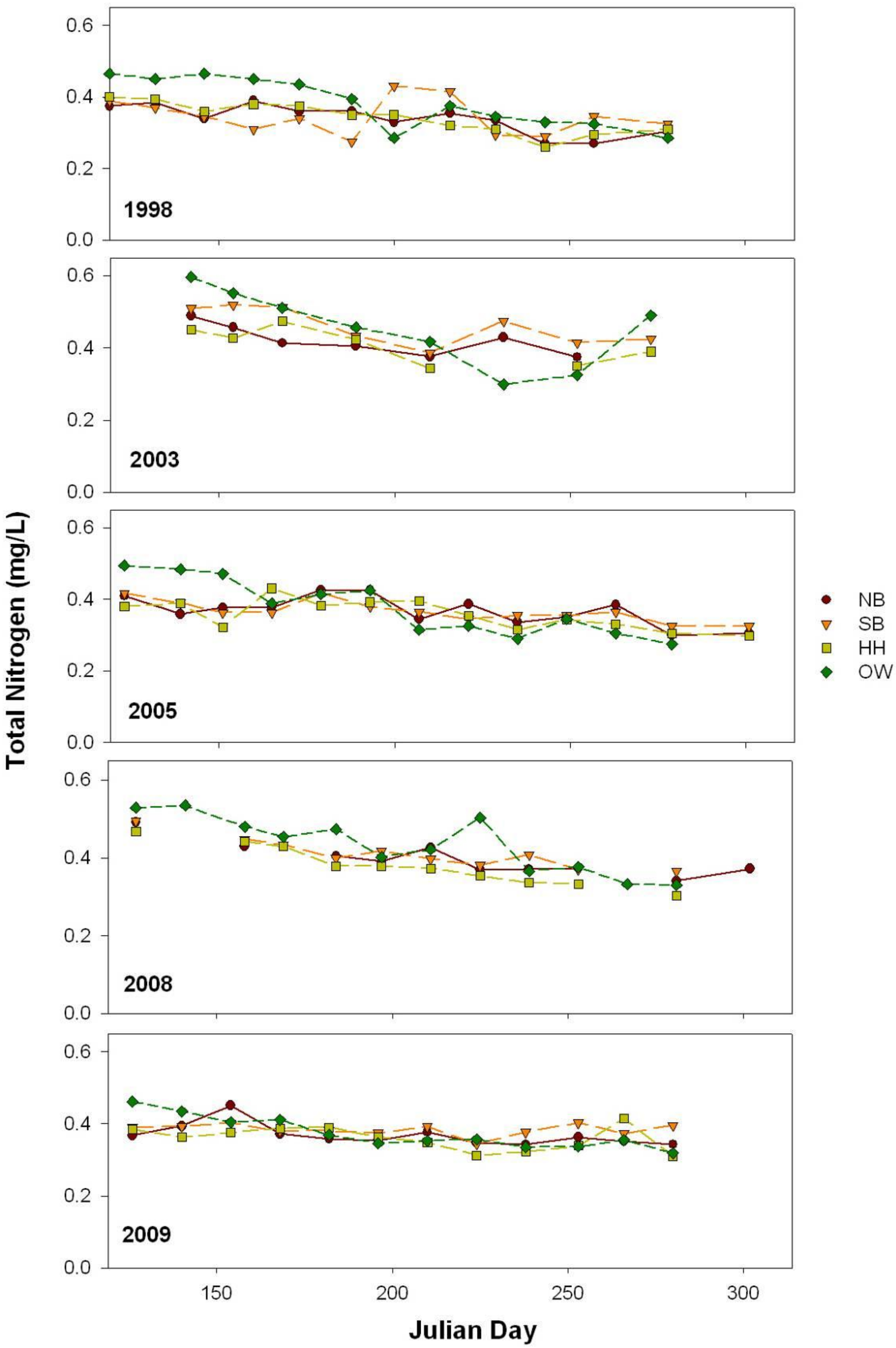

Figure 22. Seasonal trends in TN over the ice-free period from 1998-2009 for Honey Harbour stations and open water stations (P4 for 1998, and M5 for 2003-2009).

Nitrogen parameters sampled at three thermal layers in 2005 showed similar concentration gradients as TP. TNH_3 decreased from the epilimnetic to hypolimnetic waters of NB, then increased to 0.58 mg/L at 1 m off bottom (Figure 23, top). At SB, the increase in the bottom waters was much less dramatic, to 0.04 from 0.02 mg/L. Similar results were found in the bottom waters of NB in 2009, with mean TNH_3 values during the hypoxic period (DO < 1 mg/L) of 0.12 mg/L (Figure 23, bottom). These high bottom water TNH_3 concentrations are the results of bacterial decomposition of organic matter in the sediments. As bottom waters become more anoxic, ammonium, the toxic ionic form of ammonia, is released from the sediment as well, and this process likely contributed to the high concentrations of TNH_3 in the bottom of the hypolimnion.

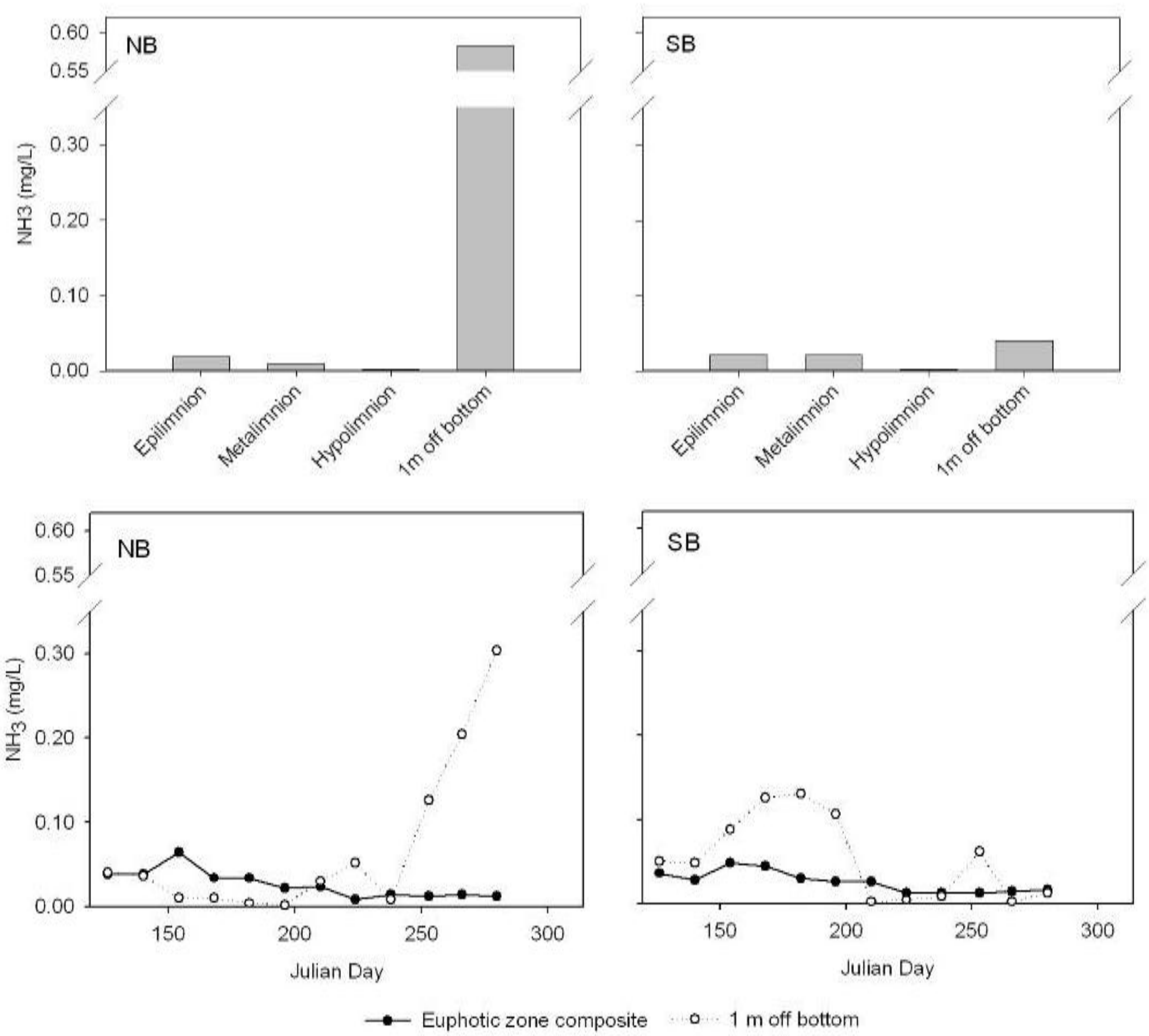

Figure 23. TNH_3 concentration in euphotic zone, metalimnion, hypolimnion and bottom water samples at NB and SB for July 25 2005 (top), and in euphotic zone and bottom water samples for the ice-free season of 2009 (bottom). Note the scale break for TNH_3.

With respect to TNO_3, a different concentration gradient was observed at NB in 2005, where concentrations increased to the hypolimnion depth, then decreased closer to the lake bottom (Figure 24). Furthermore, in 2009, bottom water concentrations were elevated much earlier in the year compared to TNH_3. Waters are most anoxic close to the lake bottom, and this anoxia triggers the reduction of NO_3 to ammonium. Thus, concentrations of NO_3 are lower than in the more oxygenated upper hypolimnion. This can be further illustrated using SB, where TNO_3 increased with depth and was highest in the bottom waters, which are more highly oxygenated that those at NB.

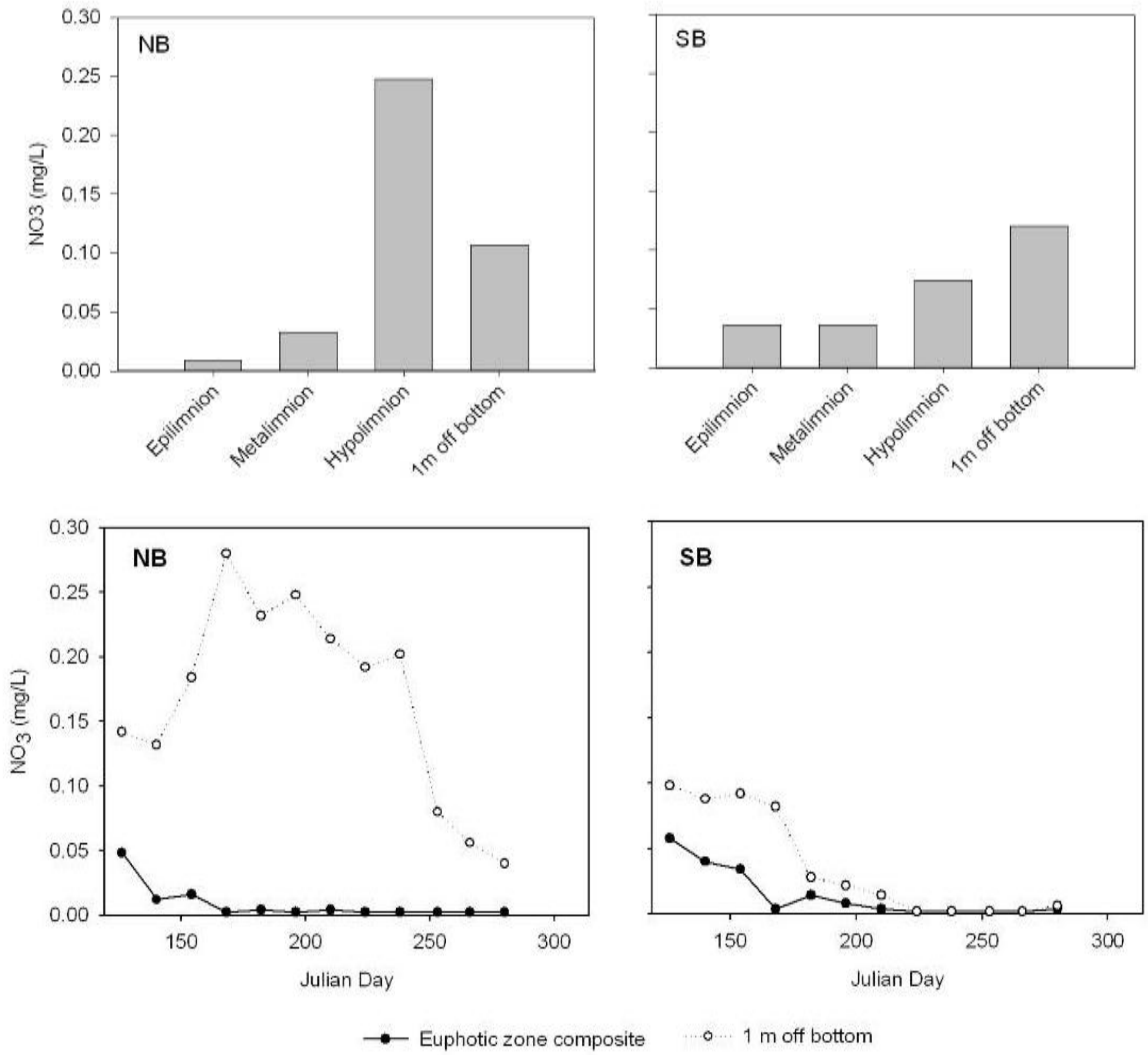

Figure 24. TNO_3 concentration in euphotic zone, metalimnion, hypolimnion and bottom water samples at NB and SB for July 25 2005 (top), and in euphotic zone and bottom water samples for the ice-free season of 2009 (bottom).

Patterns in the concentration gradient of TKN was similar to TNH_3 for both NB and SB for 2005 and 2009 sampling, although the difference between euphotic zone and bottom water TKN was not as large (Figure 25).

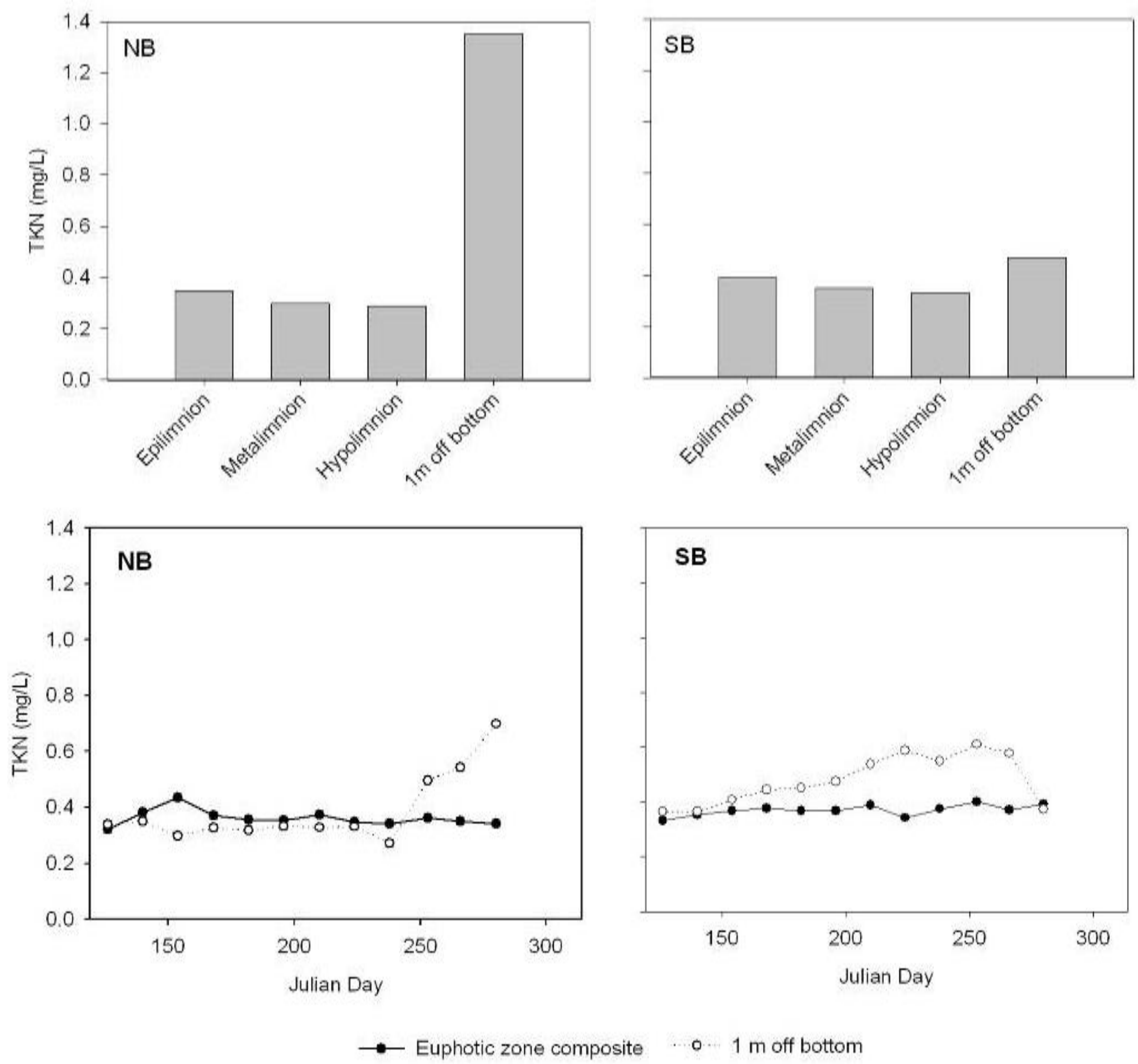

Figure 25. TKN concentration in euphotic zone, metalimnion, hypolimnion and bottom water samples at NB and SB for July 25 2005 (top), and in euphotic zone and bottom water samples for the ice-free season of 2009 (bottom).

SEDIMENT QUALITY

The surficial sediment was generally fine-grained mud. The presence of hydrogen sulfide (H_2S), a sign of anaerobic conditions, was noted in the sediment from upper South Bay (station 118). Results were compared to Ontario Ministry of Environment Sediment Quality Guidelines (Lowest and Severe Effects Levels; Persaud et al. 1993).

Table 2 shows the nutrient and metals concentrations in the sediment samples from Honey Harbour. The phosphorus concentrations at most sites exceeded the Lowest Effect Level and the phosphorus at station 117 (Upper North Bay) exceeded the Severe Effect Level, reflecting the highly organic nature of the sediments. The interstitial pore water ammonia concentration was high in Upper South Bay (Station 118) which is consistent with anoxic conditions in bottom waters of this area.

Compared to the sediment guidelines, concentrations of metals are typical for mud sediments in Severn Sound. Most metals with guidelines were above the Lowest Effect Level of the MOE Sediment Quality Guidelines (SQGs). Total phosphorus (TP) was highest in Upper North Bay (Station 117) which was the only station above the Severe Effect Level, all others being above the Lowest Effect Level for TP. Iron (Fe) was also above the Severe Effect Level at most stations with the exception of Station 120 in the western part of Honey Harbour. Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Managanese (Mn), Nickel (Ni) and Zinc (Zn) were all found above the Lowest Effect Level. These elevated concentrations are not unusual for fine-grained, enriched mud sediments such as those from this area. The elevated iron may relate to the Precambrian geology of the area. Mercury was the only heavy metal of concern in the area that was consistently found below the Lowest Effect Level.

Table 2. Surficial sediment quality of sites in Honey Harbour, March 4-7, 2002: basic chemistry, nutrients and metals (all results in ug/g dry weight unless otherwise indicated). Data Source: J. Milne, Environment Canada.

STN #	DEPTH (m)	LOI (%)	NH_3 (mg/L)	TP	Al	Sb	As	Ba	Be	Bi	Cd
121	8		0.01	1130	29750	0.4	7.5	200	1.2	0.4	2.1
117	20	28.2	2.25	2230	28650	0.6	12.5	298	1.2	0.5	1.5
118	11	24.4	28.93	1365	38550	0.3	6.5	270	1.4	0.4	1.3
119	10		0.08	1510	34100	0.2	8.0	270	1.3	0.3	1.2
116	8		0.81	1135	34100	0.3	6.0	230	1.2	0.3	1.3
115	19	22.3	1.29	1675	33750	0.5	7.5	263	1.4	0.5	1.8
120	8		0.13	870	18500	0.2	4.5	98	0.8	0.2	1.0
LEL				**600**			**6**				**0.6**
SEL				**2000**			**33**				**10**

STN #	DEPTH (m)	Cr	Co	Cu	Ga	Fe	Pb	La	Li	Mn	Hg
121	8	55	14.55	35	9.2	41550	200	57.9	24.8	1080	0.161
117	20	53	16.8	41	8.4	58150	146	58.0	20.7	923	0.185
118	11	70	18.75	36	11.0	52900	80	65.6	31.1	912	0.153
119	10	69	20.3	34	11.3	57550	90	63.9	31.7	1980	0.150
116	8	59	16.35	28	9.5	46950	106	66.9	25.0	1353.5	0.131
115	19	61	18.35	45	10.3	58200	136	77.5	29.1	747	0.174
120	8	30	8.7	18	5.8	25100	71	34.5	16.5	855	0.068
LEL		**26**		**16**		**20000**	**31**			**460**	**0.2**
SEL		**110**		**110**		**40000**	**250**			**1100**	**2**

STN #	DEPTH (m)	Mo	Ni	Rb	Sr	Tl	U	V	Zn
121	8	0.6	36	40.1	47	0.3	3.7	68	325
117	20	1.7	34	38.5	49	0.3	4.0	80	261
118	11	0.7	35	52.4	59	0.4	3.1	85	242
119	10	0.5	36	53.4	60	0.4	3.0	83	256
116	8	0.6	31	45.2	51	0.4	3.2	76	245
115	19	0.7	40	44.1	52	0.4	4.6	84	287
120	8	0.6	18	20.5	28	0.2	2.2	44	174
LEL			**16**						**120**
SEL			**75**						**820**

LEL = Lowest Effect Level OMOE Sediment Quality Guidelines 1993
SEL = Severe Effect Level OMOE Sediment Quality Guidelines 1993

PHYTOPLANKTON

Phytoplankton are unattached algae that are found in the water column of lakes. Densities can vary throughout the season depending on light, temperature, and nutrient availability. High densities can appear as surface algal blooms and the presence of some species may affect the taste and odour of drinking water. Phytoplankton have value as indicator organisms since certain species have specific requirements that can be used to describe the ambient water quality.

In general, the phytoplankton communities at the Honey Harbour stations were most often dominated in terms of biovolume by two phyla, the chrysophytes and the bacillariophytes (diatoms), whereas the open water stations were generally dominated by diatoms (Figure 26). Due to their tendency to sink, diatoms flourish in open, well mixed waters, hence their strong dominance at the open water stations. On an annual average basis, at NB, diatoms and cryptophytes dominated in 1998, and then dominance shifted to chrysophytes and dinophytes in 2003. In 2005, 2008 and 2009, chrysophytes and diatoms were dominant. At SB, cyanophytes (blue-green algae or cyanobacteria) were dominant in 1998, then dominance shifted to chrysophytes in 2003, and to diatoms and chrysophytes in 2005, 2008 and 2009. HH was dominated by diatoms in 1998, and by chrysophytes in 2003 to 2009. Diatoms dominated the total biovolume at the open water station during all five sampling years.

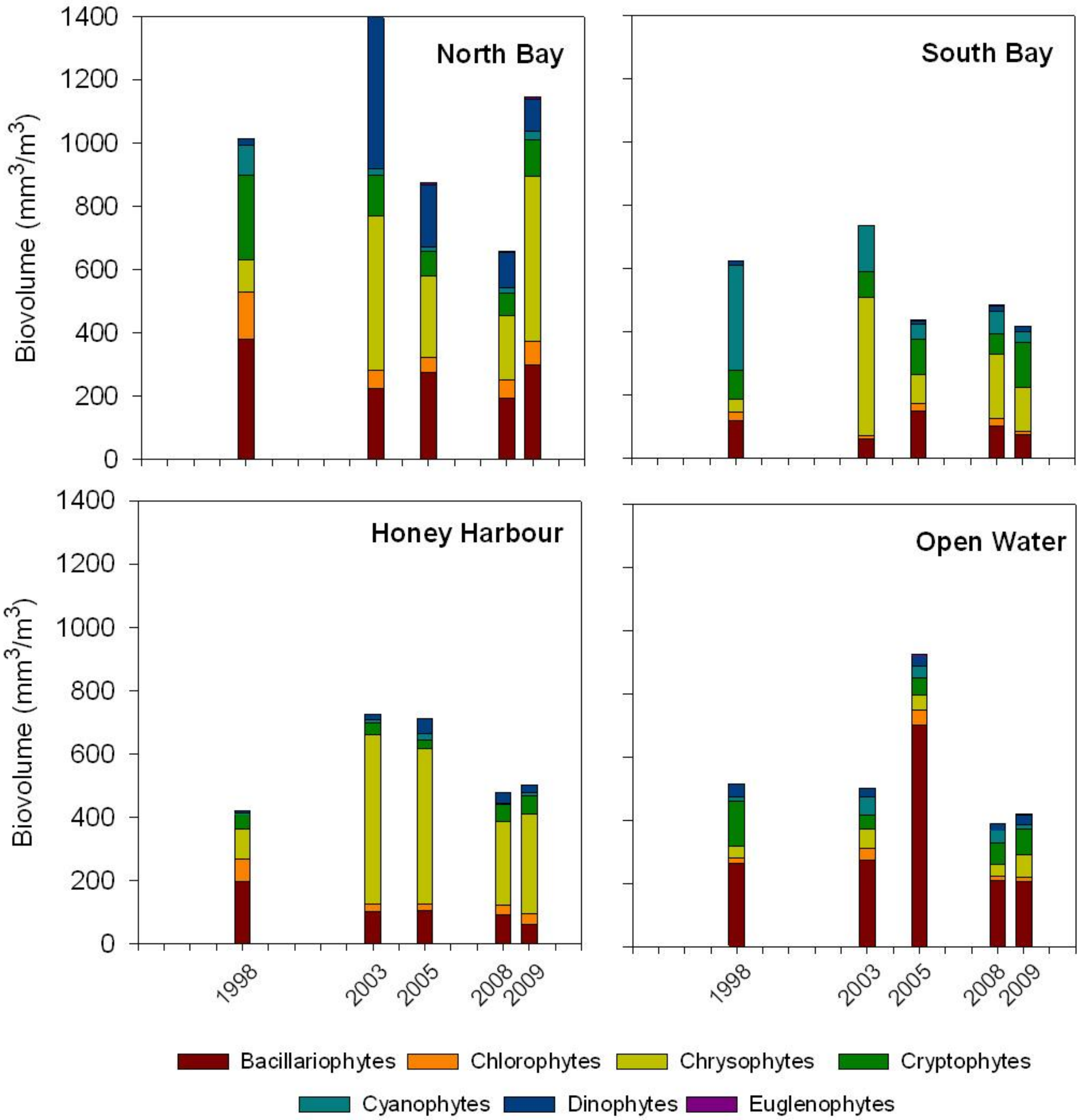

Figure 26. Annual biovolume for seven algal phyla at three Honey Harbour stations and an open water reference station (P4 in 1998 and M5 from 2003-2009).

Annual biovolume of diatoms varied between 1998 and 2009 at the Honey Harbour stations and the open water stations. Within this group, dominant genera over the five sampling years (which in this context is defined as one that appears in the top 30 in terms of biomass for at least 2 stations over at least 2 sampling years) included: *Asterionella, Cyclotella, Diatoma, Fragilaria, Melosira, Rhizosolenia, Stephanodiscus, Synedra,* and *Tabellaria*,. *Fragilaria* was frequently the most dominant group in terms of biovolume.

Chlorophyte (green algae) biovolume decreased at NB and HH over the five sampling years, and remained fairly constant at SB and the open water stations. Dominant genera included:

Chlamydomonas, Coccomyxa, Coelastrum, Cosmarium, Crucigenia, Eudorina, Gloeocystis, Gyromitus, Oocystis, Scenedesmus, Sphaerocystis, and Tetraëdron.

Chrysophyte biovolume was low in 1998 at all stations, and subsequently increased substantially to become the dominant taxonomic group. Over the sampling period, dominant genera included: *Chromulina, Chrysochromulina, Chrysosphaerella, Dinobryon, Mallomonas, Spiniferomonas, Synura*, and *Uroglena*.

Cryptophyte biovolume decreased from 1998 to 2009 for all the sampling stations, except SB in which cryptophyte biovolume was the highest in 2005. Dominant genera included: *Chroomonas, Cryptomonas, Katablepharis,* and *Rhodomonas*.

Cyanophyte (blue green algae) biovolume decreased from 1998 to 2009 at NB, SB and HH, although values were higher in 2005 at HH. Biovolume was low in 1998 at P4, and higher at M5, remaining constant from 2003-2009. Although the overall contribution from cyanophytes was fairly low throughout the years, there has been an increase in the number of taxa detected at all stations. Dominant genera included: *Anabaena, Chroococcus, Coelosphaerium, Lyngbya, Microcystis,* and *Oscillatoria*. At NB and SB, biovolumes of the toxin-producing *Microcystis* have remained below 2 mm^3/m^3 since 1998. At HH, it was not detected in 1998, but was found at concentrations of 4 mm^3/m^3 in 2003, 17 mm^3/m^3 in 2005, 1 mm^3/m^3 in 2008 and 9 mm^3/m^3 in 2009. At P4, *Microcystis* was not found in 1998. At M5, biovolumes fluctuated between 7-33 mm^3/m^3 between 2003-2009. Peaks occur at the end of July at all stations, and by fall, biovolumes drop to zero (Figure 27). Some species of *Microcystis* produce a hepatotoxin called microcystin, which at elevated levels can cause health problems if it enters drinking water supplies untreated.

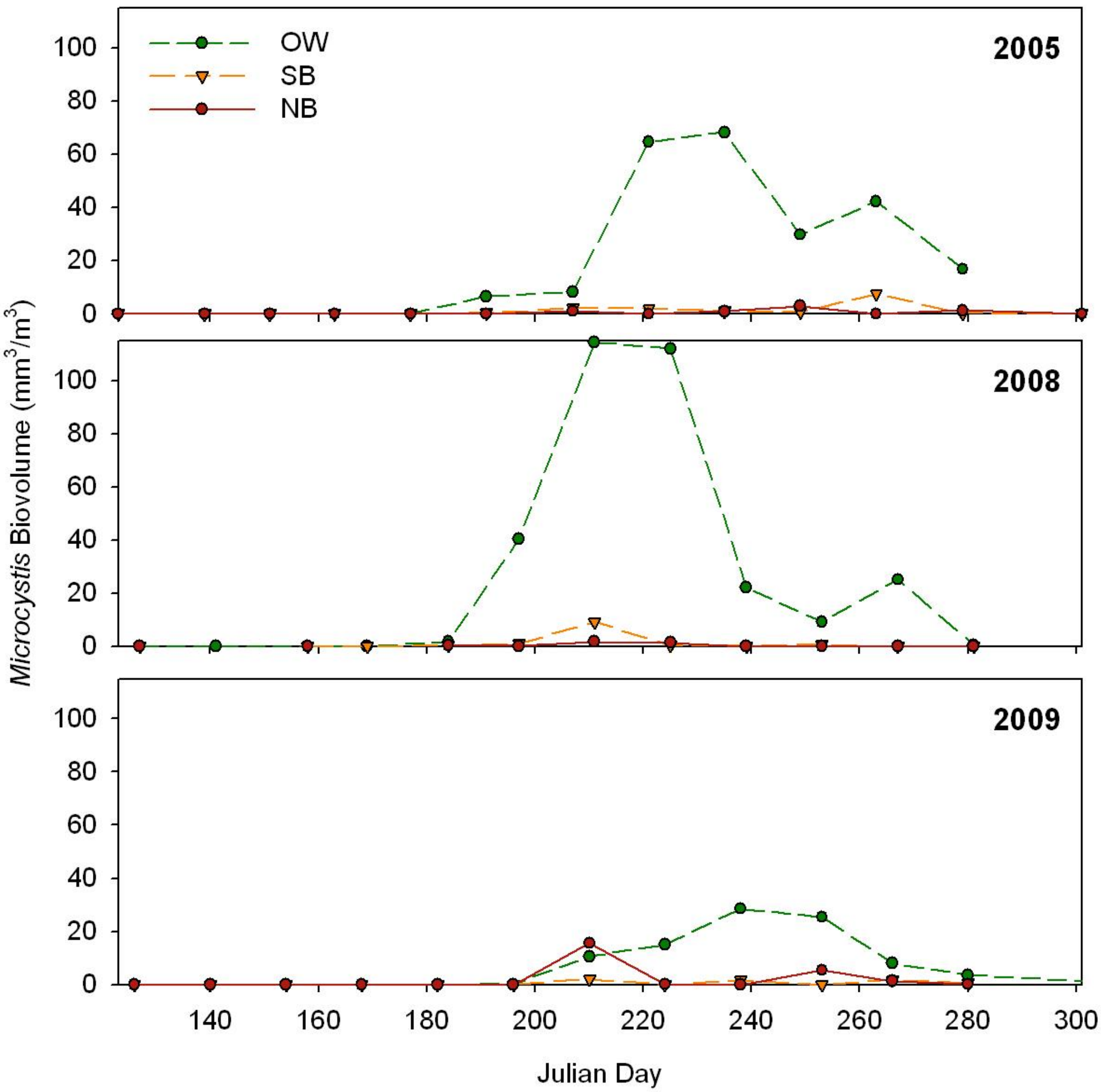

Figure 27. Seasonal biovolume of *Microcystis* for NB, SB and the open water station for 2005, 2008 and 2009.

Dinophyte biovolume has increased modestly at HH and substantially at NB over the sampling period. Dominant genera included: *Ceratium, Gymnodinium, Peridiniopsis,* and *Peridinium*.

Euglenophytes were not found at the Honey Harbour or open water stations in 1998, and have been detected in biovolumes <7 mm^3/m^3 since that year. Overall they make up a very small portion of the overall biovolume at all the stations. *Euglena* was the only genus representing this class.

Diversity (measured as the number of genera) increased significantly between 1998 and 2008 at the Honey Harbour stations (Figure 28; p=0.01 for all sites). Diversity was similar at NB and

SB, and slightly lower at HH and the open water stations. The majority of genera observed at the Honey Harbour stations as well as the open water stations belonged to either Chlorophyta, Bacillariophyta, or Chrysophyta.

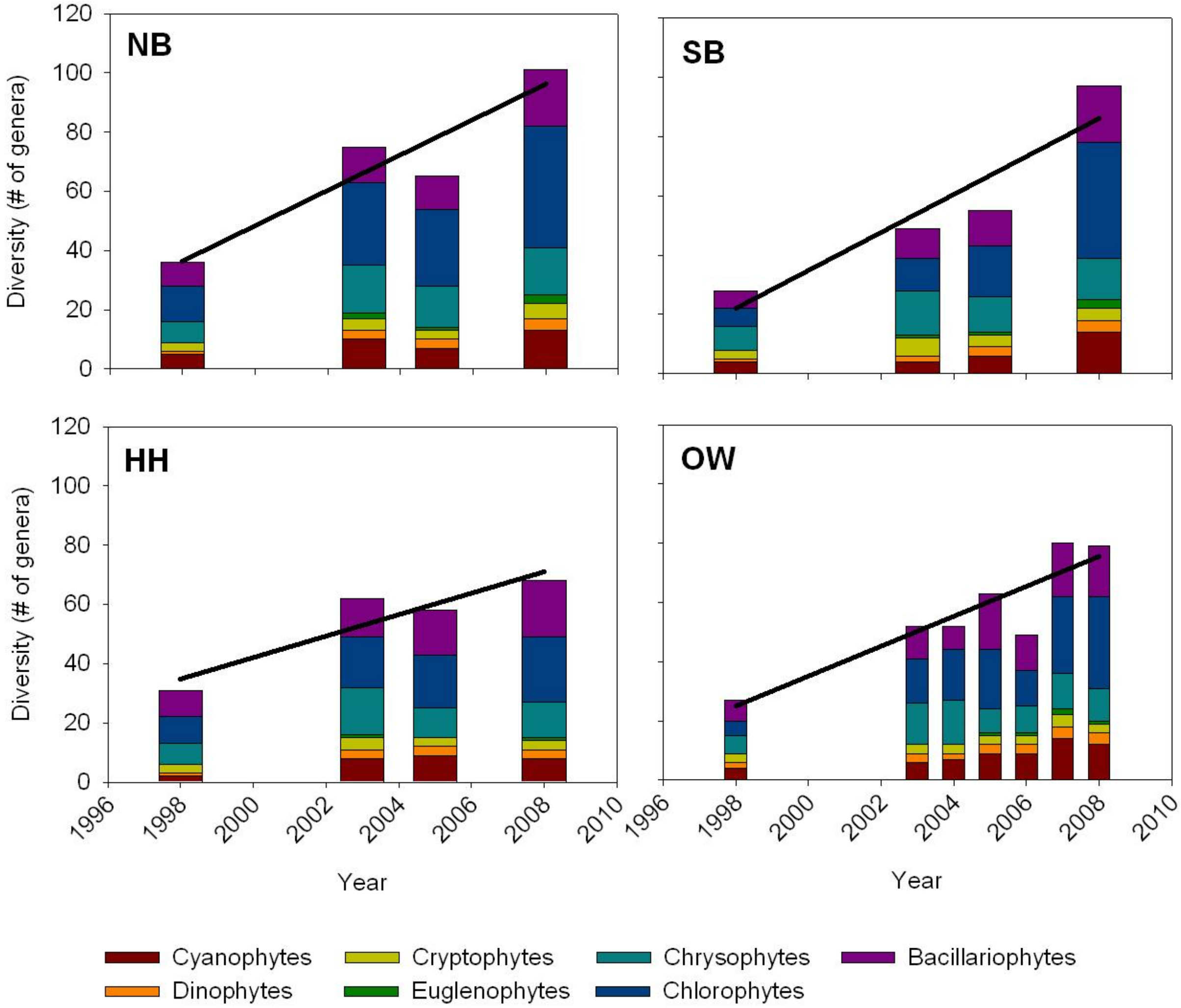

Figure 28. Diversity (number of genera) at three Honey Harbour stations and an open water reference station (P4 in 1998 and M5 from 2003-2008).

Seasonal Dynamics

In 2005, 2008 and 2009, phytoplankton samples from each biweekly sampling run were counted separately, as opposed to being combined and counted as an single annual sample, as was the case for the 1998 and 2003. Counting of biweekly samples allows for seasonal analysis of biovolume fluctuations. At the beginning of the 2005 sampling season, the phytoplankton community at NB was dominated by the chrysophyte *Synura*, which made up approximately 65% of the biovolume (Figure 29). By mid-May the phytoplankton community was dominated by diatoms, in particular *Melosira* (early spring), *Fragilaria* (which made up approximately 50% of the biovolume into June), and *Cyclotella*. In the summer, the dinophyte *Peridinium* made up approximately 50% of the total biovolume. By the middle of August, the chrysophyte *Chrysosphaerella* dominated the total biovolume, making up close to 70% of the total. In the fall, biovolumes of both chrysophytes (represented mainly by *Chrysosphaerella*) and diatoms (represented by *Melosira*, *Fragilaria,* and *Cyclotella*) increased again; both taxa combined made up 70% of the total biovolume.

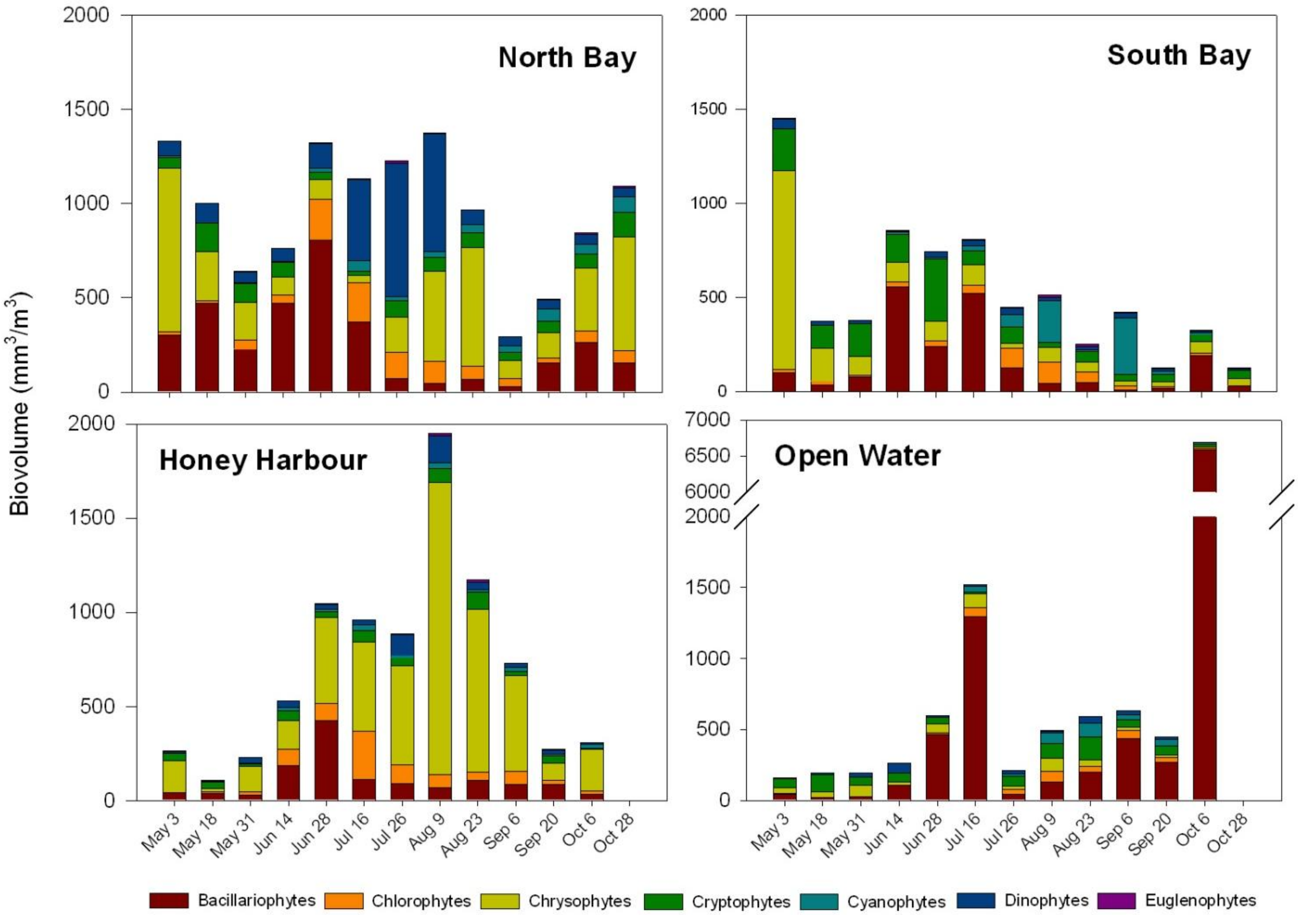

Figure 29. Seasonal biovolume for seven algal phyla at three Honey Harbour stations and an open water reference station (M5) in 2005. Note the scale break for the open water graph.

The phytoplankton community at SB was similar to NB at the start of May, with the dominance of the chrysophyte *Synura*. Throughout the spring, biovolume of the cryptophyte *Cryptomonas* contributed an average of 30% to the total biovolume. Into the late spring, diatoms, particularly *Fragilaria* and *Asterionella*, made up approximately 50% of the total biovolume. Late July saw a rise in biovolume of the cyanophyte *Planktothrix*, which continued into September. By late fall, diatoms once again dominated the total biovolume (close to 60%), this time by the genera *Melosira*.

The phytoplankton community at HH greatly differed from those of NB and SB. Throughout the season, the chrysophyte *Chrysosphaerella* dominated the total biovolume, contributing approximately 62% to the total. Only three times in the season did the total biovolume of chrysophytes go below 35%, twice in the spring, in which diatoms (primarily *Fragilaria* and *Asterionella*) and cryptophytes (*Cryptomonas*) dominated, and once in the fall in which diatoms dominated (again mainly *Fragilaria* and *Asterionella*).

The dominant phytoplankton community in the open water differed from all three Honey Harbour stations. In early spring, the cryptophyte *Cryptomonas* was the main contributor to the total biovolume, and then the chrysophyte *Dinobryon* by late May. In late spring/early summer and late summer/early fall, diatoms made up an average of 80% of the total biovolume (primarily *Fragilaria* and *Asterionella*, and *Melosira* and *Fragilaria*, respectively). Mid-summer saw a dominance of *Cryptomonas*, the chrysophytes *Chromulina* and *Chrysosphaerella*, and the chlorophytes *Coelastrum*, *Oocystis*, and *Scenedesmus*.

In 2008, seasonal phytoplankton composition at class level was similar to 2005 (Figure 30). At NB, diatom biovolume increased in the spring, then dropped as the summer progressed. *Fragilaria* and *Cyclotella* were primary contributors. By mid-summer, chrysophyte biovolume increased, mainly dominated by *Chrysosphaerella*. Chrysophyte biovolume decreased by late summer/early fall, and was replaced once more by diatoms, this time dominated by *Rhizosolenia*.

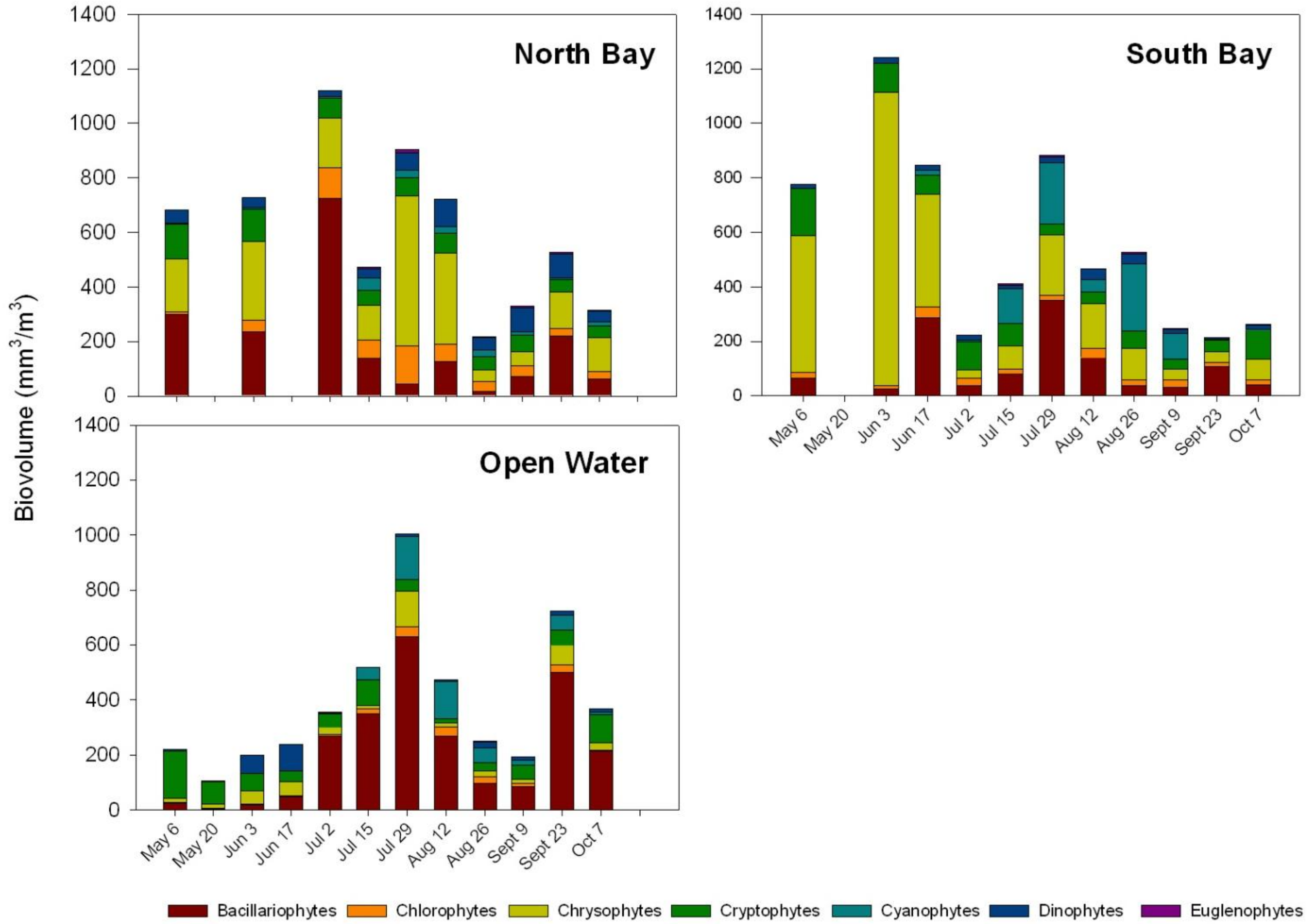

Figure 30. Seasonal biovolume for seven algal phyla at three Honey Harbour stations and an open water reference station (M5) in 2008.

At SB, chrysophyte biovolume was high early in the season, dominated by *Dinobryon* and *Uroglena*. Diatom and cyanophyte biovolume increased as the season progressed (mainly represented by *Fragilaria* and *Rhizosolenia*, and *Planktothrix*, respectively).

Similar to 2005, the open water station was dominated overall by diatoms in 2008, particularly *Asterionella*, *Fragilaria*, and *Aulacoseira*.

2009 was similar to the previous years in terms of seasonal progression of dominance of various phytoplankton classes. At NB, diatoms dominated in the spring, mainly represented by *Cyclotella*, *Asterionella*, *Fragilaria* and *Aulacoseira* (Figure 31). Mid-summer saw a large bloom of the chrysophyte *Chrysosphaerella* which dropped off by fall.

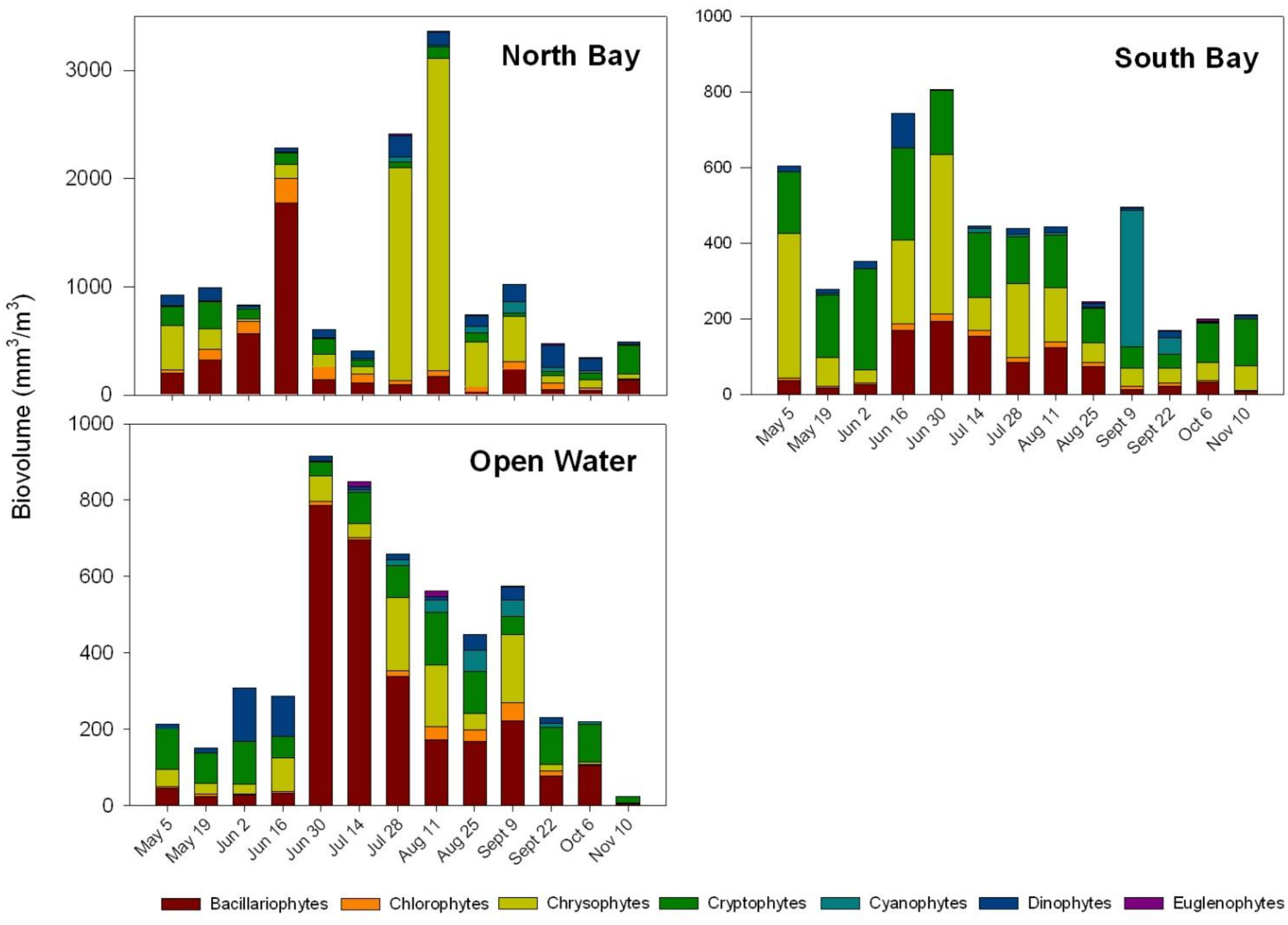

Figure 31. Seasonal biovolume for seven algal phyla at three Honey Harbour stations and an open water reference station (M5) in 2009.

At SB, chrysophytes and cryptophytes dominated from early spring to late summer, mainly represented by *Chromulina*, *Mallamonas*, and *Cryptomonas*, respectively. In late summer, biovolume of the cyanophyte *Planktothrix* increased sharply, then quickly dropped off to be replaced by the cryptophytes *Cryptomonas* and *Rhodomonas*.

At the open water station, elevated biovolumes of diatoms appeared in early summer, and persisted into late summer. This group was almost entirely dominated by *Fragilaria* and *Asterionella*. In mid-summer, the chrysophyte *Chrysosphaerella* also appeared in elevated amounts. By fall, cryptophytes and diatoms were the main contributors to total biovolume.

While these seasonal patterns show some variation, there are distinct patterns of dominance of certain taxa that indicate the prevailing conditions at each station. For example, diatoms thrive in well mixed waters, particularly in the spring and fall when winds are high and rains bring in a fresh nutrient supply from the surrounding watershed. It is not surprising that they are found in the greatest quantities at the open water station.

Vertical Distribution of Phytoplankton

On July 25 of 2005, phytoplankton samples were taken in the epilimnion, metalimnion and hypolimnion at NB and SB to examine the vertical distribution of phytoplankton. Not surprisingly, the epilimnion had the greatest biovolume at NB (Figure 32). At the time of sampling, approximately 70% of the biovolume in this layer was dominated by the dinophyte *Peridinium*. The chrysophytes *Chrysosphaerella* and *Chrysochromulina* and the chlorophytes *Oocystis* largely made up the remainder of the total biovolume. The biovolume in the metalimnion was almost 50% lower than in the epilimnion. The diatoms *Rhizosolenia* and the chlorophytes *Botryococcus*, *Coelastrum*, *Oocystis* and *Tetraëdron* represented approximately 50% of the total biovolume in the metalimnion. The upper hypolimnion biovolume was 50% lower than the metalimnion, with approximately 50% of the biovolume coming from the diatom *Rhizosolenia*.

Interestingly, at SB the hypolimnion biovolume was approximately 50% higher than both the epilimnion and the metalimnion. This is a much shallower station compared to NB, and low levels of light are able to penetrate further into the water column. The chlorophyte *Sphaerocystis* and the diatom *Rhizosolenia* were large components of the community in the epilimnion. *Rhizosolenia* made up approximately 45% of the total biovolume in the metalimnion. The upper hypolimnion total biovolume was dominated by the cyanophyte *Planktothrix agardhii*.

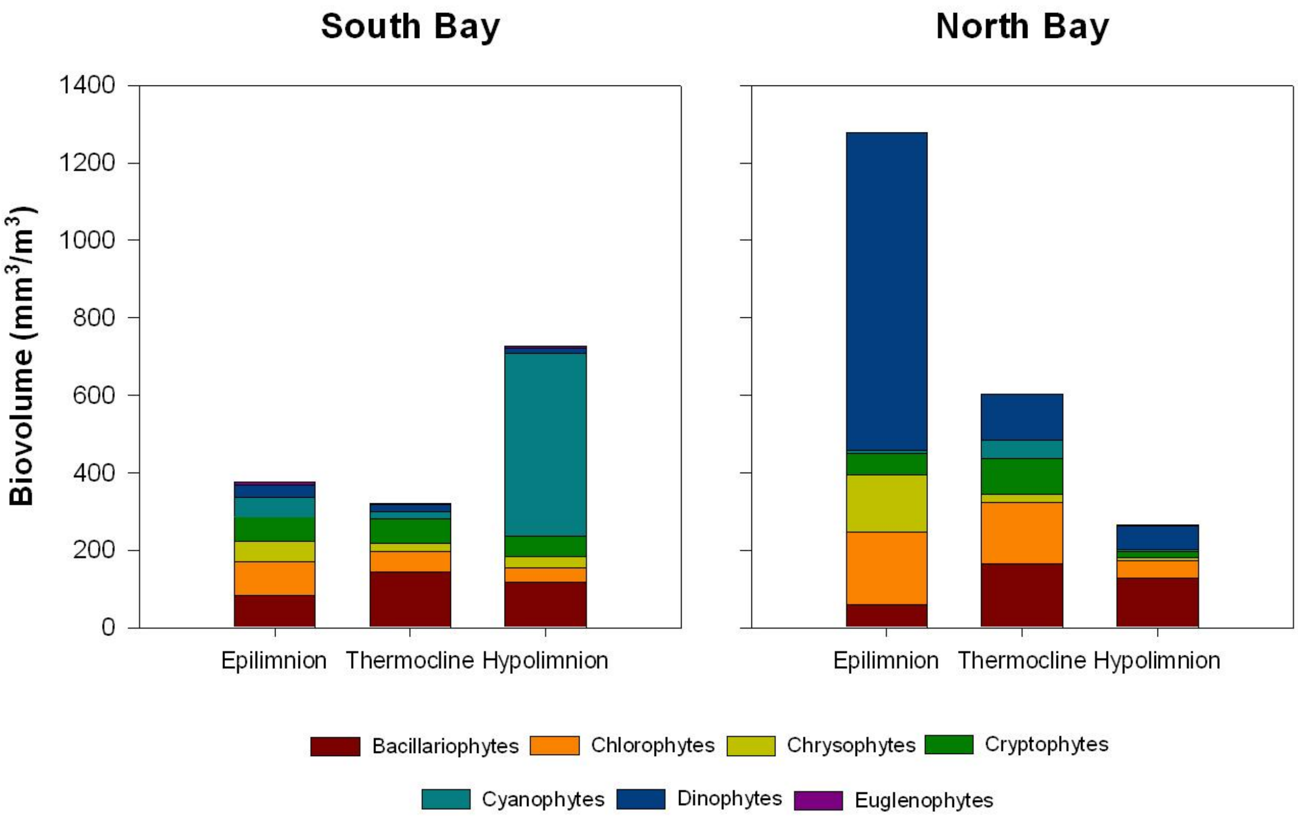

Figure 32. Composition of the phytoplankton community by class in the epilimnion, thermocline and hypolimnion at SB and NB on July 25, 2005.

ZOOPLANKTON

During 1998, 2003 and 2005, 28 to 33 species were identified for all 4 stations. Seasonal trends for both NB and SB showed species richness increasing in the spring, peaking in June and July, then declining in the fall (Figure 33, Figure 34, and Figure 35). Richness at HH and the open water station rose in May to mid-July and slowly dropped in late July. The HH station shows a rise again in the fall (September) and the OW station shows a rise in early August until October.

Of the four major groups examined for all 4 stations over the three sampling years, cyclopoid copepods had the highest biomass and density (with the exception of HH which had non-daphnid cladocerans with the highest biomass), followed by non-daphnid cladocerans, daphnid cladocerans, and calanoid copepods (OW had higher calanoid copepods than daphnid cladocerans).

Cyclops bicuspidatus thomasi (particularly in NB), *Cyclopoid copepodid*, and *Cyclopoid nauplius* were the dominant cyclopoid copepods. These three copepods were common throughout the season, with some higher peaks particularly in the spring. There has been a decrease in total biomass of cyclopoid copepods at the Honey Harbour stations, however OW station has a total biomass that doubled in 2005. *Calanoid copepodid*, *Leptodiaptomus* *minutus*, and *Skistodiaptomus oregonensis* were the dominant cyclopoid copepods, especially at HH and OW stations. Primarily these three were more abundant in the summer and into the fall, *Skistodiaptomus* showed an early peak of abundance in early summer for SB. Similarly to cyclopoid copepods, the total biomass has decreased over the three sampling years.

The most abundant daphnid cladocerans were *Daphnia retrocurva*, *D. longiremis*, and *Ceriodaphnia lacustris*, particularly at NB and SB stations. There are seasonal fluctuations particularly in the early summer and fall. NB and SB stations have both shown a decrease in yearly biomass totals, in particular NB biomass has been cut in half (125 mg/m^3 to 47 mg/m^3). The opposite has been occurring at the HH and OW stations, and both stations have seen an increase in biomass. *Diaphanosoma birgei*, *Holopedium gibberum*, and *Bosmina longirostris* are the most abundant non-daphnid cladocerans. *Bosmina* was a top contributor at all the stations with high abundances particularly in the spring and fall. SB and OW stations have shown a large decrease in total biomass (211 mg/m^3 to 60 mg/m^3 and 117 mg/m^3 to 67 mg/m^3, respectively). HH station has also shown a decrease, but NB appears to have no major changes. Both *Holopedium* and *Diaphanosoma* were more abundant in the early summer. Similarly to the other groups the total biomass has decreased over the three sampling periods.

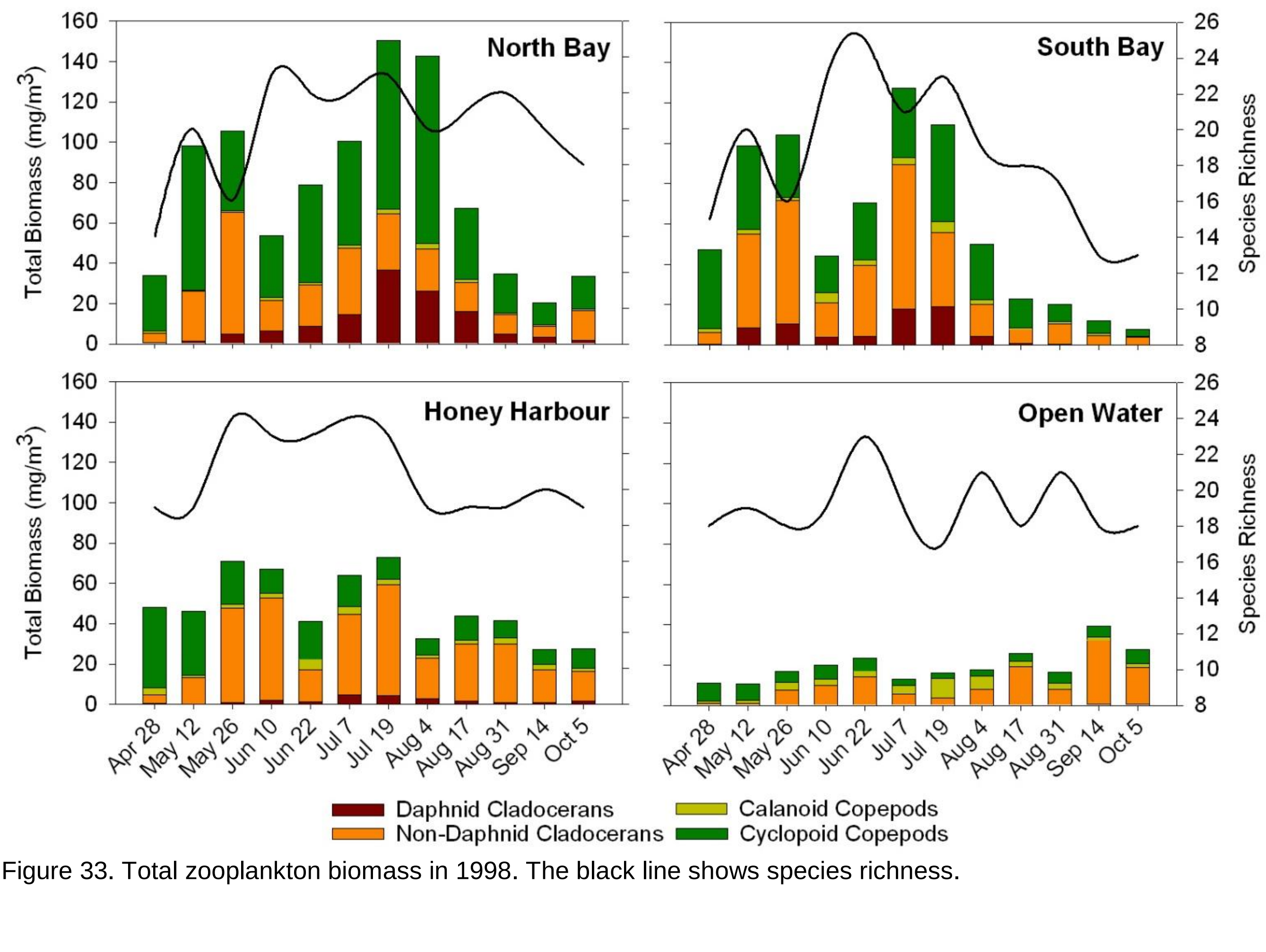

Figure 33. Total zooplankton biomass in 1998. The black line shows species richness.

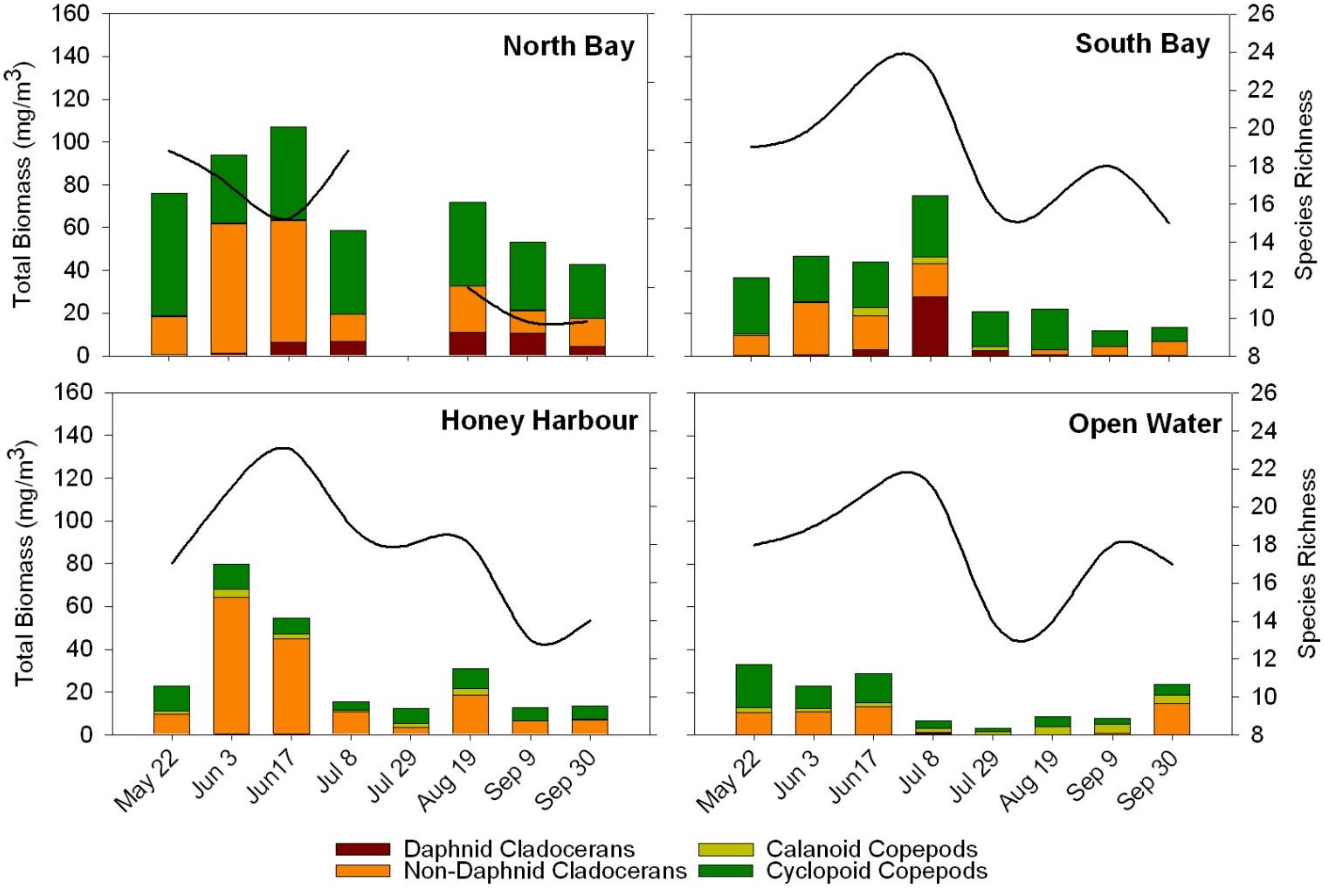

Figure 34. Total zooplankton biomass in 2003. The black line shows species richness.

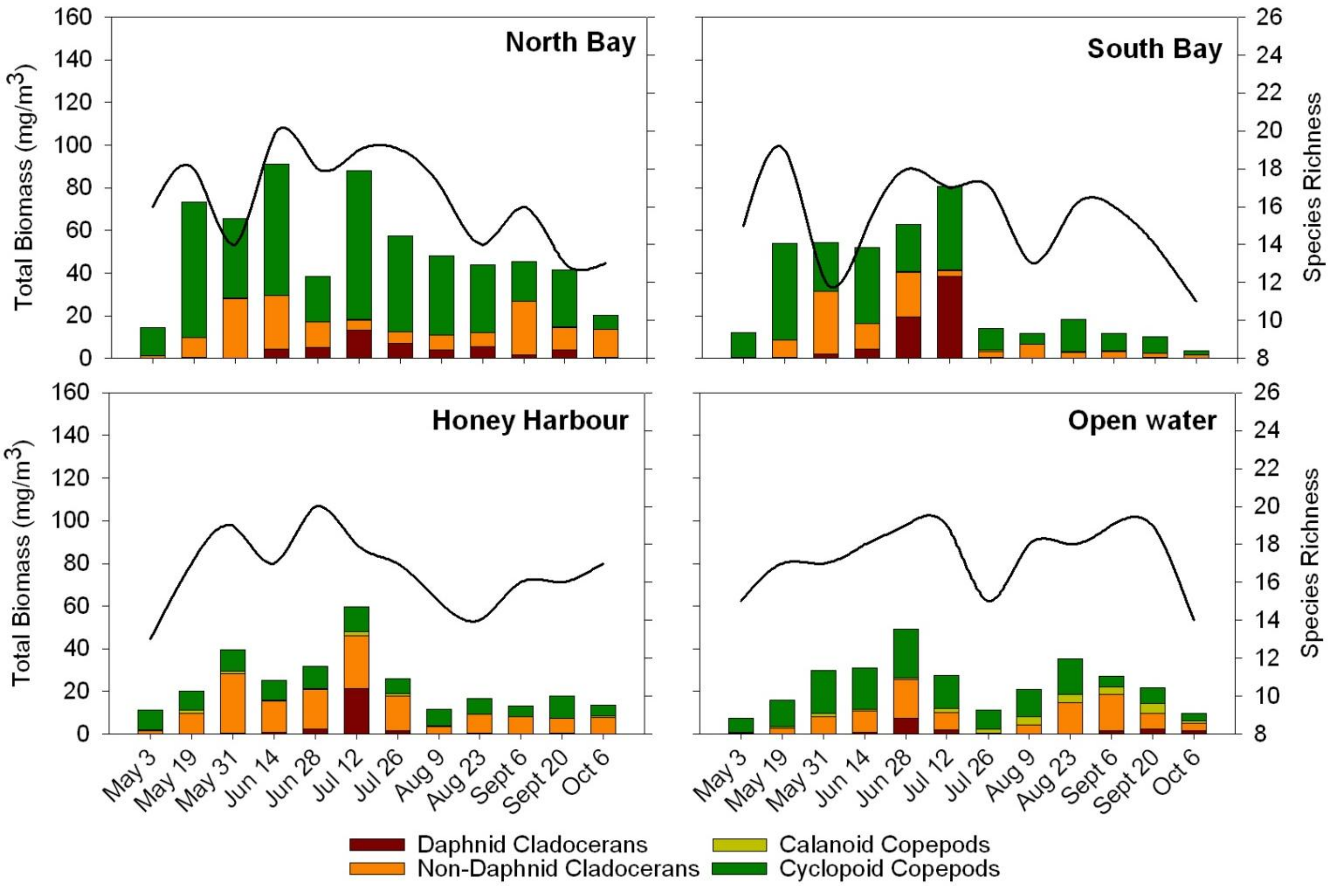

Figure 35. Total zooplankton biomass in 2005. The black line shows species richness.

Seasonal Dynamics

Over the three sampling years at NB, non-daphnid cladoceran biomass increased over the spring and fall, daphnid cladocerans increased during the late spring and into the summer. Cyclopoid copepods biomass was greatest during the spring and summer and slowly declined in the fall and calanoid copepods remained low throughout the season.

Both daphnid cladocerans and non-daphnid cladocerans biomass peaked during the spring to early July at SB. Cyclopoid copepods biomass was greatest during the spring and started to decrease mid-July. Calanoid copepods remained low throughout the season; a slight increase of biomass occurred in June and July (clearly shown in 1998 and 2003, Figure 35).

At HH, non-daphnid cladocerans biomass was consistently high throughout the season with a small decline in the fall. Cyclopoid copepods remained relatively steady throughout the season. Calanoid copepods biomass remained low throughout the season, with the largest peaks in biomass in the spring and early summer. Daphnid cladocerans start increasing in June and peak in the middle of July. Daphnid cladocerans in the 2003 sampling period had a very low total biomass.

At the OW station, non-daphnid cladoceran biomass increased in the late spring and then again in the end of summer into the fall. Cyclopoid copepod biomass remained fairly consistent throughout the season with a slight decrease in the fall. Calanoid copepod biomass was the largest in late July into the fall. Daphnid cladoceran biomass was low throughout the season, however in 2005, an increase in biomass occurred in June through July, and then again in the fall.

Zebra Mussel Veligers

Video analysis of drinking water intakes and the presence of veligers (free-swimming juvenile form) in zooplankton samples suggest that zebra mussels (*Dreissena polymorpha*) were first established in Severn Sound in 1994. Veliger data for Honey Harbour are available for 1998, 2003 and 2005. Over these three sampling years, the OW station had the highest density and biomass of veligers (Figure 36 and Figure 37). Veliger density peaked at all of the sites during late July/early August in all three years, with the highest densities observed in 1998 at the OW station (61 615 individuals/m^3). Peak densities at the open water station were generally an order of magnitude greater than at the Honey Harbour sites. It is likely then, that the influence of zebra mussel filtering on the trophic status indicators discussed above as well as phytoplankton communities is much less, or perhaps negligible compared to the open water station in the southern portion of Severn Sound.

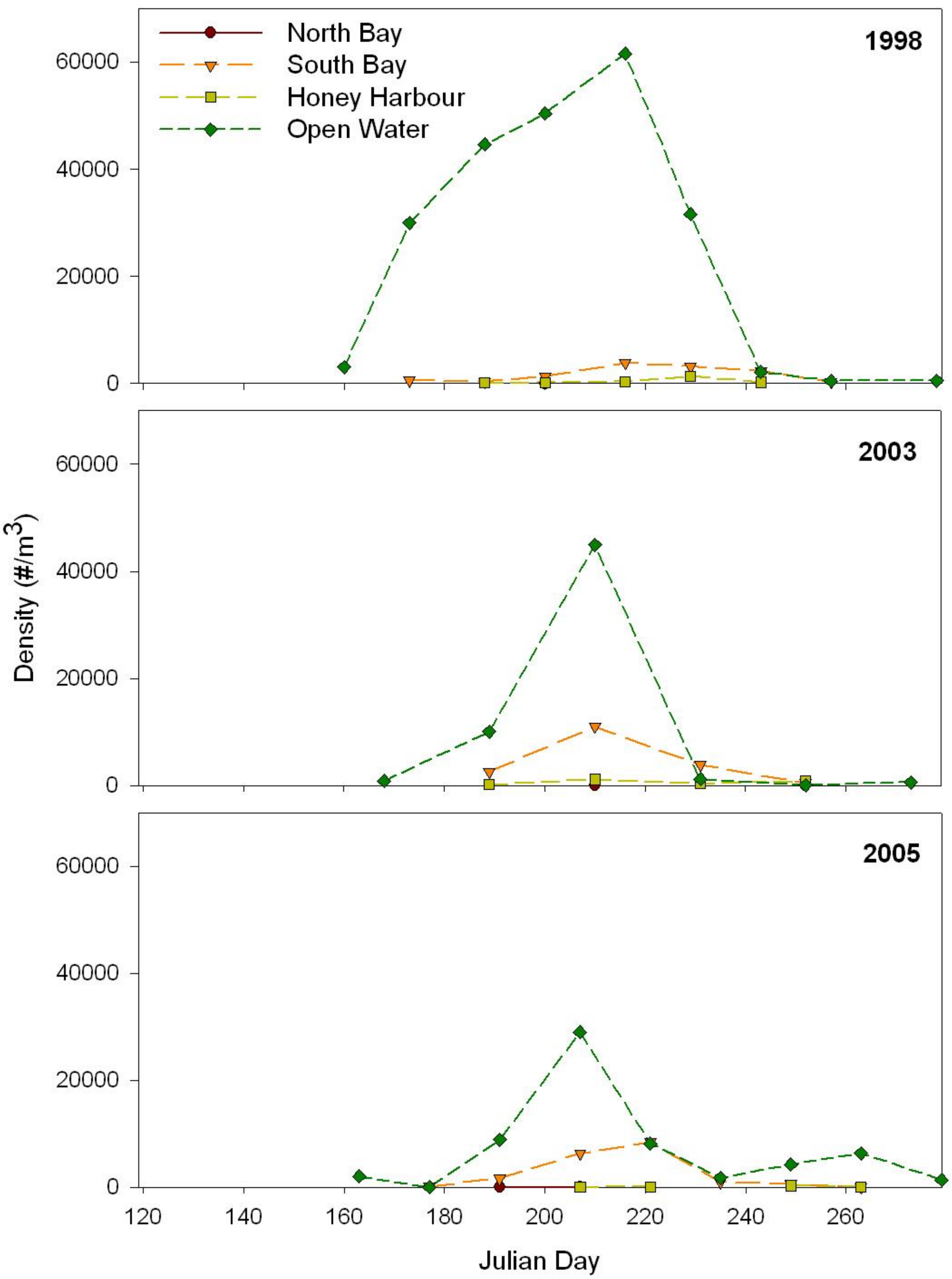

Figure 36. Zebra mussel veliger density at the Honey Harbour stations and open water station from 1998-2005.

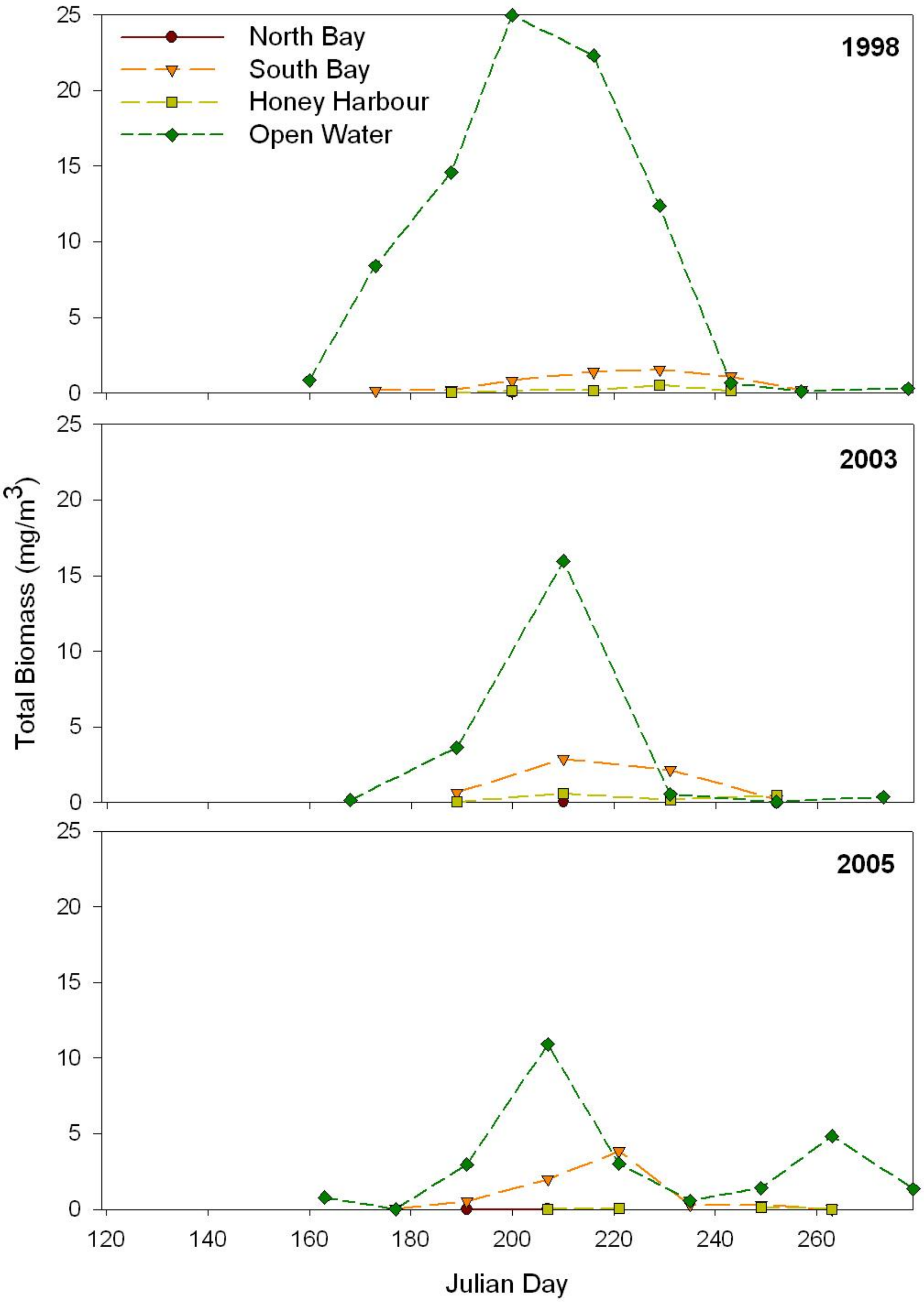

Figure 37. Zebra mussel veliger biomass at the Honey Harbour stations and open water station from 1998-2005.

CONCLUSIONS

Based on the trophic indicators monitored, the Honey Harbour area is considered mesotrophic, or moderately enriched. From a comparison over two decades of monitoring, the trophic state of North Bay, South Bay and Honey Harbour does not appear to have changed appreciably.

The oxygen regimes, through the water column in North Bay and South Bay have not changed appreciably over the monitoring period. North Bay continues to experience a dissolved oxygen minimum within the thermocline (or metalimnion, approximately 6-9 m) that declines to less than 1.0 mg/L by late July-early August. Oxygen concentration below this depth is greater (minimum of 3 mg/L) and then declines to less than 1.0 mg/L near the deepest point in the bay. The bottom waters here approach complete oxygen depletion as evidenced by the presence of hydrogen sulphide in bottom water samples. The volume-weighted hypolimnetic oxygen concentration in late summer was estimated for available years with profile and bathymetric data and has not changed significantly over the years. This means that the oxygen depletion each year in North Bay is not worsening and may relate to the basin shape rather than any change in trophic status. Similar bottom water depletion is occurring in the deep portion of South Bay, however, due to the shallower nature of the basin, no minimum is noted in the thermocline.

Total phosphorus concentration increases at 1 m off bottom in both North and South Bay during summer oxygen depletion each year. The peak concentration at 1 m off bottom in the deep points of North Bay and South Bay rise to high concentrations. However, the increases appear to be limited to the deep portion of the hypolimnion. The oxygen depletion near the bottom coincides with elevated total phosphorus concentrations but this build up does not appear to affect the total phosphorus concentrations in water higher in the water column. The euphotic zone composite total phosphorus concentration does not increase over the ice-free period of the year.

Total phytoplankton biovolume fluctuates over the growing season as well as from year to year at all location in Honey Harbour. The community composition is also changing. In 2009, at station NB, diatoms dominated in the spring, mainly represented by *Cyclotella, Asterionella, Fragilaria* and *Aulacoseira*. Mid-summer at NB saw a bloom of the chrysophyte *Chrysosphaerella* which disappeared by fall. At SB, chrysophyte biovolume was high early in the season, dominated by *Dinobryon* and *Uroglena*. Diatom and cyanophyte biovolume increased as the season progressed (mainly represented by *Fragilaria* and *Rhizosolenia*, and *Planktothrix*, respectively). These fluctuations in phytoplankton community composition may represent subtle changes that will need continued monitoring.

Zebra mussel veliger densities are much lower in Honey Harbour than in the southern portion of Severn Sound, and thus the influence they have due to their filter feeding behavior is likely lower.

RECOMMENDATIONS

1. It is recommended that the monitoring program be continued each year until 2013 in order to track trends in nutrients and related indicators of trophic status, as well as other environmental stressors that could impact this busy recreational area.

2. The conditions in North Bay should be further assessed with additional sampling of bottom water conditions and vertical distribution of phytoplankton. This will assist in interpretation of the nutrient status of North Bay, and also further investigate any subtle changes in the phytoplankton community and their relation to environmental stressors.

3. The results of more detailed phytoplankton studies should be evaluated following the 2013 season in order to revamp the monitoring program for future years.

REFERENCES

Allen, G., N.D.Yan, and W.T.Geiling. 1994. ZEBRA2 - Zooplankton Enumeration and Biomass Routines for APIOS: A Semi-automated Sample Processing System for Zooplankton Ecologists. Ontario Ministry of Environment. ISBN 0-7778-1388-2.

Gemza, A.F. 1995b. Zooplankton seasonal dynamics and community structure in Severn Sound, Lake Huron. Water Quality Research Journal of Canada 30(4): 673-691.

Hopkins, G.J, and Standke, S.J. 1992. Phytoplankton methods manual, with special emphasis on waterworks operation. Internal Methods Manual, Ontario Ministry of the Environment (ENV 1854), ISBN 0-7729-8923-0. 88 pp.

Locke, B.A., and L.D. Scott. 1986. Studies of lakes and watersheds in Muskoka-Haliburton, Ontario: Methodology. Ontario Ministry of Environment. Data report #86/4.

McCune, B. and M.J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data. Version 4.41 MjM Software, Gleneden Beach, Oregon, U.S.A.

MOE. 1974. Outline of analytical methods: a guide to the occurrence, significance, sampling and analysis of chemical parameters in water. Laboratory Services Branch OMOE, Toronto, Ontario. Queen's Printer for Ontario.

MOE. 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. OMOE, Toronto, Ontario. Queen's Printer for Ontario. PIBS 1962. 32 p.

Nicholls, K.H., E.C. Carney and G.W. Robinson. 1977. Phytoplankton of an inshore area of Georgian Bay, Lake Huron, prior to reductions in phosphorus loading. Journal of Great Lakes Research 3: 79-92.

Palmer, C.M. 1962. Algae in water supplies. U.S. Department of Helath, Education, and Welfare, Public Health Service Publication No. 657. Washington, D.C.

Severn Sound Remedial Action Plan (SSRAP). 1988. Stage 1, Part 1: Environmental conditions and problem definitions. ISBN 0-7729-4702-3.

Severn Sound Remedial Action Plan (SSRAP). 2002. Stage 3 Report: The Status of Restoration and Delisting of Severn Sound as an area of Concern.

Appendix 1. Water quality results (annual means) from 1981-2009.

	Station	Year	SDV (m)	Chl *a* (μg/L)	TP (μg/L)	NH_3 (mg/L)	TKN (mg/L)	NO_3 (mg/L)	TN (mg/L)
Honey Harbour Sites	NB	1981	3.57	3.60					
		1984	3.67	2.73	10.33				
		1989	3.94	3.38	16.50				
		1993	3.44	3.26	14.00				
		1995	2.69	4.78	16.00				
		1998	3.70		13.83	0.010	0.33	0.015	0.34
		2003	3.35	3.99	13.90	0.014	0.38	0.043	0.42
		2005	2.89	3.52	12.32	0.019	0.32	0.047	0.37
		2008	3.65	1.88	11.47	0.038	0.36	0.039	0.40
		2009	2.88	2.60	12.43	0.026	0.36	0.008	0.37
	SB	1981	3.43	4.30					
		1984	3.50	2.90					
		1989	3.30	6.00					
		1998	4.33		17.00	0.009	0.33	0.014	0.34
		2003	3.65	3.81	14.98	0.017	0.42	0.041	0.46
		2005	3.31	2.31	13.34	0.019	0.35	0.015	0.37
		2008	3.77	2.30	12.90	0.042	0.39	0.024	0.41
		2009	3.09	1.00	12.64	0.025	0.37	0.015	0.38
	HH	1993		3.00	10.00				
		1998	3.78		10.33	0.010	0.27	0.070	0.34
		2003	2.93	1.93	10.15	0.015	0.33	0.080	0.41
		2005	2.72	2.53	9.72	0.018	0.29	0.063	0.36
		2008	3.27	0.90	9.56	0.036	0.32	0.061	0.38
		2009	2.76	0.70	8.88	0.018	0.29	0.063	0.36
Open Water Sites	P4	1981	3.60	3.56	16.33	0.048	0.35	0.076	0.47
		1982	3.89	5.58	16.86	0.052	0.31	0.085	0.39
		1983	3.88	3.06	13.86	0.037	0.31	0.060	0.37
		1984	3.23	7.51	15.38	0.035	0.33	0.070	0.40
		1985	3.48	4.59	10.67	0.032	0.30	0.103	0.40
		1986	3.17	4.37	11.00	0.029	0.29	0.109	0.40
		1987	2.91	4.05	10.50	0.036	0.29	0.111	0.40
		1988	2.96	6.35	12.33	0.023	0.32	0.083	0.40
		1989	3.37	4.96	11.90	0.017	0.33	0.089	0.42
		1990	3.06	4.79	11.90	0.019	0.33	0.110	0.44
		1991	2.96	4.21	13.80	0.014	0.36	0.074	0.44
		1992	3.22	2.42	12.09	0.013	0.34	0.103	0.44
		1993	2.97	3.56	11.82	0.018	0.35	0.089	0.44

	1994	3.14	3.24	11.60	0.022	0.31	0.091	0.40
	1995	4.34	2.68	9.33	0.023	0.28	0.146	0.44
	1996	5.08	2.04	7.78	0.021	0.26	0.141	0.41
	1997	4.83	1.88	7.80	0.021	0.27	0.168	0.45
	1998	4.78	2.82	10.00	0.009	0.28	0.100	0.38
	1999	4.75	2.67	11.54	0.022	0.29	0.099	0.39
	2000	5.06	2.30	7.28	0.009	0.28	0.167	0.44
	2001	4.33	2.25	7.68	0.016	0.27	0.138	0.41
	2002	3.75	2.58	9.03	0.017	0.29	0.140	0.43
	2003	4.01	2.44	8.57	0.019	0.30	0.160	0.46
	2004	3.84	2.14	10.65	0.018	0.27	0.155	0.43
	2005	3.69	2.86	9.39	0.017	0.28	0.098	0.38
	2006	4.14	1.17	8.89	0.036	0.27	0.114	0.39
	2007	4.13	1.06	8.59	0.026	0.28	0.113	0.39
	2008	4.18	1.71	9.68	0.035	0.35	0.098	0.44
	2009	3.95	0.50	8.23	0.021	0.30	0.090	0.39
M5	2003	4.10	2.69	10.90	0.018	0.33	0.131	0.46
	2004	3.63	2.53	11.18	0.019	0.29	0.130	0.42
	2005	2.99	2.25	11.28	0.016	0.31	0.072	0.38
	2006	3.55	1.30	9.90	0.037	0.29	0.096	0.38
	2007	3.69	0.97	9.80	0.028	0.30	0.094	0.40
	2008	3.84	1.52	10.80	0.035	0.35	0.083	0.43
	2009	3.62	0.70	9.96	0.020	0.31	0.061	0.37