Severn Sound

Environmental Association

Sediment Quality, Benthos Community Structure and Water Quality of Sturgeon Bay, Severn Sound, in Relation to the Proposed Upgrade of the Victoria Harbour Wastewater Treatment Plant

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For:

The Corporation of the Township of Tay
and XCG Consultants Ltd.

Foreword

This document reports on technical investigations conducted in Sturgeon Bay and surrounding waters during 2008 by the Severn Sound Environmental Association in partnership with the University of Windsor, Environment Canada and the Ministry of the Environment. The project was conducted for XCG Consultants and the Corporation of the Township of Tay as part of the requirements of the Environmental Assessment for the upgrade of the Victoria Harbour Water Pollution Control Plant.

The report received technical review prior to its publication. This does not necessarily mean that the contents reflect the views and policies of the Township of Tay or the partner agencies. The mention of trade names or commercial products do not necessarily constitute endorsement or recommendation for use.

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Executive Summary

The Severn Sound Environmental Association (SSEA) conducted surveys of the sediment and water quality, and benthic macroinvertebrate (benthos) community of the Sturgeon Bay area in support of the Township's Environmental Assessment for the upgrade and expansion of the Victoria Harbour Waste Water Treatment Plant (WWTP). The survey was conducted in conjunction with the Class EA lead by XCG Consultants Ltd. for the Township. A partnership to conduct the survey was also arranged with the University of Windsor and Environment Canada.

The receiving water body for the existing outfall from the WWTP, Sturgeon Bay, is a shallow, partially sheltered bay in Severn Sound, Georgian Bay with dense coverage of submergent rooted aquatic plants. The approach taken was to survey the water and sediment quality, and the benthic community at locations similar to past surveys in the area, as well as at other sites in the vicinity of Sturgeon Bay for comparison. The aim of the survey was to address whether the environmental quality of Sturgeon Bay is being adversely affected by the current discharge of treated sewage effluent and whether this location would be appropriate for continued discharge following plant expansion.

The sediment quality of the Bay has not changed since before the WWTP was built (i.e. 1980 compared to 1988, 1994, and 2008). There was no relationship between the surficial sediment quality and proximity to the outfall. There was no difference in the concentration of pore water ammonia, an indicator of sewage effluent impact, in the sediment at sites with varying proximity to the outfall. Pore water ammonia within the top 2 cm of sediment cores was lower than deeper sections. There were no differences in pore water ammonia concentration between stations within and outside Sturgeon Bay. Some metals (e.g. copper and iron) in sediment at stations within Sturgeon Bay were elevated, however these are within range of concentrations for the rest of Severn Sound, and were generally below the provincial Severe Effects Level for sediment quality.

The benthos community has been sampled in the past, both prior to and after construction of the WWTP (1980, 1988, 1994, as well as during 2008). The benthos community is typical of a shallow bay with dense stands of aquatic plants, and appears to be unaffected by the existing treated effluent discharge based on densities of pollution tolerant (Oligochaeta) and intolerant taxa (*Hexagenia*).

Comparison of findings from the 2008 open water survey to previous surveys show that the quality of the Bay has improved as a result of the initial installation of the treatment plant. The measured impact of the treated effluent discharge on water quality (especially total phosphorus concentration, TP), since becoming operational, has been positive – i.e. lower TP. Despite additional flows in more recent years, the phosphorus loading from the plant appears to have no significant effect on the concentration of open water TP or overall environmental quality of the Bay. Due to improved sewage effluent treatment and non-point source control of phosphorus from watershed sources, the

long-term TP concentration in the Bay and vicinity has decreased. Comparison of stations sampled in Sturgeon Bay before and after construction of the plant indicates that improvement occurred and that neither the infestation of zebra mussels nor low water levels has affected water quality.

Phytoplankton community structure in Sturgeon Bay is influenced by the presence of dense coverage of rooted aquatic plants. Plants sequester TP in their tissues and generally outcompete phytoplankton for nutrients. Filamentous algae and other species normally associated with plants in Sturgeon Bay are often sampled incidentally in the open water composite sampling at Station BS, adding to the seasonal fluctuations in phytoplankton biovolume. The phytoplankton community is considered representative of a mesotrophic or moderately enriched water body.

The zooplankton community has changed since the invasion of zebra mussels. The proportion of calanoid and cyclopoid copepods has increased while non-daphnid cladocerans have decreased. The proportion of daphnids has remained fairly constant. The shift in community composition could be related to the functional feeding group (e.g. algae grazer, predator, omnivore) that each taxonomic group belongs to, and the influence that zebra mussel filtering has on different feeding groups.

Considering the fact that the existing outfall location appears to be having no significant impact on the environmental quality of Sturgeon Bay, and since the total phosphorus loading from the effluent (at design flow) will not be changing from the existing Severn Sound Remedial Action Plan (SSRAP) target TP loading, there appears to be no reason to consider an alternate outfall location outside Sturgeon Bay. From a receiving water quality view point, the proposed plant upgrade and expansion will satisfy the requirements of the effluent phosphorus loading objective established in the SSRAP.

Moving the outfall to a location off Robin’s Point was considered and rejected as an option as it brings the treated effluent closer to the Intake Protection Zone of the Victoria Harbour Water Filtration Plant, and because the TP loading from the effluent will remain within the SSRAP objectives following the proposed WWTP upgrade.

It is recommended that the existing outfall remain in the same location, provided the annual TP loading from the effluent to Sturgeon Bay does not exceed the SSRAP target of 129 kg/year. In the future, if additional capacity is required that will result in effluent that exceeds the loading target, then consideration should be given to other options for effluent discharge.

Introduction

The Township of Tay requested that the Severn Sound Environmental Association (SSEA) conduct a survey of the water quality, sediment quality and benthic macroinvertebrate (benthos) community of the Sturgeon Bay area in support of the Township's Class Environmental Assessment (CEA) for the upgrade and expansion of the Victoria Harbour Waste Water Treatment Plant (WWTP).

Three aspects of the Bay were investigated as part of the project.

1. The surficial sediment quality was investigated at locations throughout Sturgeon Bay and vicinity, especially near the existing sewage plant outfall. Sampling locations were similar to previous surveys and additional locations outside the Bay were also selected for reference. In order to investigate the impact that the outfall was having on the sediment and to measure changes with time in the sediment, core samples were taken at selected sites and sectioned for individual analysis.
2. Benthic macroinvertebrates were sampled at the same sites that surficial sediment samples were collected in the Sturgeon Bay area in order to compare benthic community structure within the Bay and surrounding waters in relation to the existing sewage plant outfall, and relate it to sediment quality. The benthos survey assessed the impact of the existing outfall and the benthic community in the potential alternative outfall location.
3. Trophic conditions in the Bay were assessed in order to determine the impact of the existing outfall on the Bay and the trophic status of the potential alternate outfall location.

The survey was conducted in conjunction with the Class EA lead by XCG Consultants Ltd. for the Township. A cooperative study agreement with Dr. Jan Ciborowski of the University of Windsor was arranged to conduct the benthos sampling. An agreement with Environment Canada was also made in order to conduct the sediment coring.

The purposes of this report are to summarize the work that has been conducted through various partners on the survey during 2008, and to provide the technical basis for the receiving water based rationale supporting the effluent objectives and requirements for the expanded and upgraded Victoria Harbour WWTP.

Study Area

Severn Sound was identified as one of 42 Areas of Concern on the Great Lakes in 1985 by the International Joint Commission (IJC). Under the International Great Lakes Water Quality Agreement, Canada and Ontario supported the development of a Remedial Action Plan (RAP) for Severn Sound. The RAP was developed in three stages and reported to the IJC at each stage as required. The Severn Sound RAP Stage 2 Report included a list of proposed sewage plant effluent targets (p. 82, Table 4.1 of SSRAP Stage 2 report 1989) in which the target for the Victoria Harbour WWTP was listed as 129 kg total phosphorus (TP) per year. These targets were reviewed by the Ontario

Ministry of the Environment (MOE) and accepted as part of the submission to the IJC. The Severn Sound RAP Stage 3 Report (2002) noted that progress toward achieving these targets at sewage plants, including the one in Victoria Harbour, had been made. In 2003, beneficial uses of Severn Sound were considered to have been substantially restored and the Sound was removed from the list of Areas of Concern with the understanding that these targets would be maintained.

The community of Victoria Harbour is located on the peninsula between Hogg Bay and Sturgeon Bay within Severn Sound, in southeastern Georgian Bay (Figure 1). Currently, the treated sewage effluent discharges to the west side of Sturgeon Bay via a submerged, extended outfall designed with diffuser ports to encourage rapid dispersion of the effluent. The outfall is a 560 mm diameter pipe extending approximately 630 m into the Bay to a depth of approximately 1 m below chart datum (Canadian Hydrographic Services Chart #2041). The existing sewage treatment plant provides tertiary treatment, including enhanced phosphorus removal and sand filtration. The effluent is disinfected by chlorination (XCG Consultants Ltd., 2009).

The receiving water body, Sturgeon Bay, is a shallow, partially sheltered bay in Severn Sound, Georgian Bay. It has dense beds of submergent rooted aquatic plants. The Bay is surrounded by a shelf of sand which deepens to a central basin with a maximum depth of 3.9 m. The substrate in the open portion of the Bay consists of a thin layer of mud over silt-clay. The majority of the shoreline consists of gradually sloping sand with boulders, limestone and some Precambrian bedrock outcroppings at the eastern edge toward the community of Waubaushene. The surface of the Bay is triangular in shape with the open end of the Bay to the north and a rocky shoal, the Middle Ground Shoal, rising across the mouth to restrict exchange with the open waters of Severn Sound to the eastern and western sides of the opening. The Severn River flows into Severn Sound almost due north of Sturgeon Bay. The combined flows of the North and Coldwater Rivers exit Matchedash Bay and flow across the mouth of the Bay from the east. The Sturgeon River discharges to the Bay from the south (Figure 1).

The western side of the Bay is formed by Robin’s Point. Water depths off the mouth of the Bay are also shallow with a restricted navigation channel opening up to the Waubaushene Channel off Robin’s Point before entering the open waters of Severn Sound to the west. These restrictions partially shelter Sturgeon Bay from flows of the Severn, North and Coldwater Rivers. Partial water exchange with the open waters of Severn Sound augments the inflowing water entering the Bay from the immediate watershed, including the Sturgeon River.

Methods

Sediment Quality

Sampling of sediment was carried out at 22 stations (Figure 2). The stations for the 2008 survey correspond to stations sampled in previous sediment and benthos surveys

(500 series; sampled in 1980, 1982, 1988, and 1994) as well as additional reference stations in Hogg Bay (PM2), near Port Severn (PS) and off Robin's Point (stations 2001, 2002, 2003, 2004).

During 2008, sediment quality samples were collected through two partners. The University of Windsor benthos samples included duplicate samples of surficial sediment using Petite Ponar grabs for analysis of particle size, organic content (loss on ignition (LOI)), nutrients (total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and total phosphorus (TP)) and metals from 22 stations collected on Aug 18, 2008 (see Figure 2, Table 1). These samples represented the surficial sediment quality to a depth of approximately 3 cm below the sediment-water interface. Sediment particle size analysis (dry sieving analysis of ashed sediment) was conducted by the University of Windsor. LOI, nutrients and metals were analyzed by Caduceon Environmental Laboratories using standard methods.

In addition to surficial samples, core samples were collected by Environment Canada at nine selected stations (see Figure 2), using a modified benthos corer, and sectioned into 2-cm core sections down to 10 cm depth. The individual sections were analyzed for LOI, TP, metals, and interstitial (pore water) ammonia by the Environment Canada laboratory in Burlington, Ontario. For comparison, sites were selected both close to and far from the Victoria Harbour WWTP outfall.

Provincial Sediment Quality Guidelines (PSQGs) were used to assess quality of surficial sediment from the deposition areas of Sturgeon Bay and vicinity (Persaud et al. 1993). Pearson correlation coefficients were used to determine the presence of relationships between distance from the STP outfall or station depth and sediment quality parameters, as well as relationships between sediment quality parameters. These parameters included LOI, total organic carbon, total phosphorus, total Kjeldahl nitrogen (a measure that includes ammonia and organic nitrogen) and various metals. Tukey-Kramer tests were used to detect differences in sediment quality among sampling years for each station.

Benthic Invertebrates

Twenty-two sampling stations were sampled from eastern Severn Sound, including Sturgeon Bay and Hogg Bay (Figure 3, Table 1). All 22 sites were sampled in late summer 2008. Sediment samples were collected using a Petite Ponar grab (grab area = 0.023 m^2). Five Petite Ponar grabs were collected at each location for benthos analysis. Samples were emptied into a 0.60-mm mesh sieve bucket and repeatedly rinsed to remove fine sediments. The materials retained in the sieve bucket were rinsed into labeled, polyethylene soil bags and preserved with a formalin-ethanol solution (modified Kahle's fluid 5 parts water: 2½ parts 95% ethanol: 1 part 100% formalin, by volume).

Identification and enumeration of benthos was carried out at University of Windsor using the latest taxonomic reference material. Specimens were identified to the genus level, where practical, using standard taxonomic keys (Oliver and Roussell 1983, Meritt and Cummins 1984, Brinkhurst 1986, Pennak 1989, Coffman and Ferrington 1996, Wiggins 1990). Some exceptions included the Nematoda, Oligochaeta, Hydracarina, Ostracoda, Copepoda, and Chironomidae.

The similarities and differences in zoobenthic community composition among stations were assessed by using nonmetric multidimensional scaling (NMS). This is one of the most commonly used multivariate ordination methods using data that includes biological counts. It is also a component of the approach used in the **Be**nthic **As**sessment of **S**edimen**t** (BEAST) model (Reynoldson et al. 1995). Cluster analysis using Ward's method (city block distances) was also used to group sites based on similar benthic communities.

The geometric mean density of taxa at each station was calculated. To be retained in the NMS analysis, a taxon had to have been collected at a minimum of 20 percent of the 22 stations sampled, and had to be locally abundant enough to constitute at least 0.5% of the abundance at any one station. Rare or narrowly distributed taxa are commonly excluded from multivariate analyses because they can distort the ordination axes, especially when there are relatively few sampling points available for analysis (Gauch 1982). Eleven families of benthic invertebrates met these criteria: Hydridae (*Hydra*), Polychaeta (*Manayunkia*), oligochaete families Tubificidae and Naididae (sludge worms), Valvatidae (snails), Dreissenidae (zebra and quagga mussels), Sphaeriidae (fingernail clams), Gammaridae (amphipod crustaceans), Asellidae (isopod crustaceans), Ephemeridae (*Hexagenia* mayflies), and Chironomidae (midges).

The analysis was performed using PC-ORD® software, Version 4.1, using Sorenson's (also called Bray Curtis) index as the dissimilarity measure. Both two-dimensional and three-dimensional ordinations were performed. An ordination plot was deemed to have successfully summarized the relationships among stations if the stress score (a measure of distortion of the data) was less than 20.

Water Quality

In 1980, a sampling program was established in Sturgeon Bay to monitor sediment and water quality. For water quality, 15 sites were sampled in 1980, between 1-3 times during the summer. Following that, six priority sites were sampled 3-7 times per year until 1986 for two sites and until 1994 for the remaining four sites. In 2008, the initial fifteen sites were again visited three times over the summer. Station BS, located in the centre of Sturgeon Bay, PM2 in Hogg Bay, and P4 in Penetanguishene Harbour, were monitored through the SSEA open water monitoring program from 1969-2008. These long-term stations were sampled on a bi-weekly basis over the period of May to October.

Samples were collected as euphotic zone composites (twice the Secchi disk visibility or from surface to 1 m off bottom, whichever was less). In addition, water quality samples were collected at 16 stations within Sturgeon Bay and off Robin's Point (Table 1) once during July, August and September in order to compare water quality spatially for 2008 and temporally for other years (for selected stations) (Figure 4).

Profiles of temperature, dissolved oxygen, conductivity and pH were collected at 1 m depth intervals at each location using a calibrated YSI Sonde.

Samples from the long-term stations (BS, PM2, P4, M5, PS) were sent to the MOE Dorset laboratory for low-level total phosphorus (TP), total ammonia, nitrate+nitrite, total Kjeldahl nitrogen, conductivity and pH analysis during 2008. Previous years analyses (prior to 2005) were carried out at MOE Rexdale laboratory with the exception of TP which was sent to MOE Dorset. Samples from the 16 additional stations in 2008 were sent to the Trent University Laboratory at Dorset for analysis of TP, total ammonia, nitrate+nitrite, total Kjeldahl nitrogen, alkalinity, conductivity, lab pH and turbidity. Standard methods were used for TP, nitrogen parameters, alkalinity, conductivity, pH and turbidity.

Periods from 1980-1984, 1985-1994, 1995-1999 (BS only), and 2000-2008 were used as categories for temporal comparison of water quality. The first period corresponds to the pre-sewage treatment period in Victoria Harbour while the second corresponds to post-sewage treatment period but pre-zebra mussel invasion. The third and fourth correspond to post-zebra mussel invasion during high and lower water level years, respectively. A Tukey-Kramer HSD test ($\alpha = 0.05$) was used to determine whether there were differences between periods at the six priority sites plus BS. To compare lake-water TP at all 15 500-series sites sampled in 1980 and 2008, a paired *t*-test was used on summer means (Jul-Sept). A Tukey-Kramer test was also used to detect spatial differences among sites in 1980 and 2008. A Mann-Kendall trend test, which detects the presence of monotonic (single direction) trends in non-parametric data (Yue et al. 2002), was used to analyze lake-water TP trends at the six priority sites plus BS. Finally, regression analysis was used to examine the relationship between lake-water TP and daily P load from the Victoria Harbour STP from 2003-2008. The significance level for all tests was 0.05.

Phytoplankton and Zooplankton

Phytoplankton samples were collected as euphotic zone composites at the long-term stations from 1969-2008. These were preserved with Lugol's solution and kept on ice in the dark during shipping to the laboratory. At the MOE Rexdale laboratory, phytoplankton samples were concentrated for counting, and enumerated using an inverted microscope and Utermöhl counting chamber according to Hopkins and Standke (1992). Identification and counting were carried out by Elaine Carney, an MOE approved phytoplankton taxonomist. Identification was to the genus level, and cell biomass was expressed as biovolume (Hopkins and Standke 1992).

Zooplankton samples were collected at long-term stations using, a conical, 80 μm mesh net (various Wisconsin-type nets were used over the sampling period) lowered to approximately 1 m off bottom and hauled to the surface at a constant rate. After sufficient rinsing of the outside of the net with water, each sample was flushed from the collection bucket into a sample jar and preserved with 4% buffered formalin. Counting was performed by various contractors using MOE identification and enumeration protocols (Allen et al. 1994). For 2008 samples, Lynne Whitty of Laurentian University identified, enumerated and estimated biomass of zooplankton. Zooplankton community data were analyzed using NMS ordination as described for benthic invertebrate data. In order to be retained in the analysis, taxa had to be present in at least 3 sampling years.

Results and Discussion

Effluent Characterization

The existing Victoria Harbour WWTP, commissioned in 1983/84, discharges treated sewage effluent to the west side of Sturgeon Bay via a submerged, extended outfall designed with diffuser ports which discharge at a depth of approximately 1 m below the surface. The existing sewage treatment plant provides tertiary treatment, including enhanced phosphorus removal and sand filtration. According to the SSRAP Stage 2 Report (1993), the TP loading objective for the plant is 129 kg/y in order to maintain and enhance the quality of Sturgeon Bay at an average design flow of 2364 m^3/d.

The proposed upgrade will include measures to improve treatment while increasing flow to 3550 m^3/d in order to maintain the loading objective of 129 kg TP/yr. This means that the TP concentration objective would be 0.10 mg/L on average (XCG Consultants Ltd., 2009). The monitoring data for the last five years shows that the plant regularly achieved TP concentrations of less than 0.10 mg/L. Recognizing that the TP loading objective is estimated on an annual basis and taking into account variability in effluent quality from sample to sample, the proposed compliance limit is 0.15 mg TP/L or an annual TP loading of 194 kg/y. This loading is slightly less than the current loading compliance limit of 197 kg/y (effluent concentration requirement of 0.3 mg/L TP).

Sediment Quality

Sturgeon Bay is shallow with sand substrate from shore to depths of approximately 1 m over 75% of the nearshore area. The eastern shoreline, especially toward the community of Waubaushene, has a mixture of exposed bedrock, rock-boulder and glacio-lacustrine clay along the nearshore to depths of 1.5 m. In this shallow zone, wind and wave action generally keep fine-grained organic sediments from accumulating. The Middle Ground Shoal area across the northern mouth of the Bay is also composed of bedrock outcrops, boulders, and rock with little fine-grained organic sediment. The deeper areas (greater than 1-1.5 m depth) have some accumulated fine-grained organic sediment. However, Pb^{210} dating of a sediment core collected near station BS in 1997, through a Geological Survey of Canada geophysical study of Severn Sound (Geological Survey of Canada 1997, unpublished), suggested that there was no long-term (year after year) sediment accumulation taking place in Sturgeon Bay. For the present study, surficial sediment was sampled in these areas and in adjacent deeper areas outside Sturgeon Bay to investigate the sediment quality in relation to the treated effluent discharge. If the existing discharge was having a negative influence on the sediment quality, then sediment samples taken closer to the discharge would be expected to show poorer quality compared to samples taken farther from the discharge.

The quality of lake bed sediments is an important indicator of lake health. Sediment dwelling organisms, many of which are a food source for fish, can be negatively impacted by polluted sediment. Due to their close contact with sediments, they can take up persistent pollutants, such as heavy metals, through feeding and burrowing activities. These pollutants become biomagnified in their tissues, and can subsequently bioaccumulate up the food chain. Birds, predatory fish, and ultimately humans, can be affected by this accumulative process if concentrations of toxins reach high enough levels. Excessive nutrients in sediments can be re-suspended through mixing and become available for aquatic plants and algae. High levels of organic material require oxygen for decomposition, which depletes the oxygen content of the sediment. If the sediment oxygen is completely depleted, phosphorus, ammonia and hydrogen sulfide can build up in the pore-water spaces between the sediment particles and may then be released into the water column. This can alter the chemistry and toxicity of various pollutants, as well as negatively impacting the community of sediment-dwelling organisms.

The concentration of TP in surficial sediments within Sturgeon Bay ranged between 450 - 1200 μg/g, and was not significantly different between sites within the Bay and sites outside the Bay (off Robins Point, in Hogg Bay, or near Port Severn) (*t*-test, $p = 0.62$; see Table 2). Total Kjeldahl nitrogen and total organic carbon (TOC) concentrations ranged between 204 - 5870 μg/g and 0.3 - 6.0%, respectively and were not significantly different among sites within the Bay and sites outside the Bay ($p = 0.31$ and 0.63). The sediment nutrient quality was not significantly correlated with proximity of the sample site to the treated effluent discharge.

Nutrient analyses of the core samples from selected sites within Sturgeon Bay and outside the Bay showed some variation in concentration with increasing core depth (Milne 2009, Appendix A). Pore water ammonia was significantly lower at 0-2 cm depth compared to the middle sections of cores at most of the stations ($p = 0.005$, Figure 5). Sediment pore water concentration of ammonia ranged from 0.1 to 1.6 mg/L and was considered low compared to sediment known to be affected by historical sewage discharges (SSRAP Stage 3 Report 2002). There was no relationship between distance to the outfall and pore water ammonia. Core TP ranged from 0.8-1.28 mg/L, and was significantly lower in the bottom sections of the cores at all stations except BS ($p = 0.04$, Figure 6). Values were similar among all stations. LOI ranged from 6-19%, and was similar among sites within Sturgeon Bay (Figure 7). Outside the Bay, station PS had the highest values. Surface layers within Sturgeon Bay tended to have higher LOI than lower layers, though not significantly so. Pore water ammonia, TP and LOI within the Bay were similar among core sites, suggesting that there was little influence from the sewage effluent discharge on sediment nutrient chemistry.

Metals analyses of the 2008 samples were conducted on both surficial sediment samples (Table 2) and core sections (Appendix B). For those stations where both types of samples were collected, surficial samples (grab samples) were used for comparison with sediment quality criteria for surficial sediment samples (Table 2). The provincially set Severe Effect Level (SEL) is the concentration at which sediment is considered highly polluted and likely to affect the health of sediment-dwelling organisms (Persaud et al. 1993). The Lowest Effect Level (LEL) is the concentration at which sediment is considered to be clean to marginally polluted, and have no effect on the majority of sediment-dwelling organisms (Persaud et al. 1993). Concentrations of metals and nutrients met SELs at all sites within Sturgeon Bay, with the exception of Stn 541 which exceeded the SEL for TKN.

There were several exceedances of the LEL for different variables. Of the nutrient parameters, bulk surficial TP exceeded the LEL at 81% of the sites, TKN exceeded at 87% of the sites, and TOC exceeded at 75% of the sites. Sediment TP at each cored station also exceeded the LEL in each core section but was less than the SEL. With respect to metals, the LEL for cadmium was exceeded at one site, while the chromium LEL was exceeded at 12% of the sites. The LEL for copper was exceeded at 81% of the sites. The copper concentrations found here are typical in the Severn Sound area sediments and the average concentration in Sturgeon Bay (19.5 μg/g) is slightly lower than the average copper concentration (20 μg/g, Table 2) found by Painter from his review of Geological Survey of Canada data for Severn Sound (Painter unpublished). The LELs for iron, manganese, and nickel were exceeded at 25% of the sites, and the LEL for zinc was exceeded at 12% of the sites.

Outside Sturgeon Bay, station 2001 off Robin's Point exceeded the LEL for arsenic, and the SEL for iron and manganese. LELs for TP, TKN, TOC, copper, iron and manganese were frequently exceeded outside Sturgeon Bay. There were no significant differences in surficial chemistry at stations inside Sturgeon Bay compared to those outside the Bay, with the exception of selenium, which was 0.6 μg/g inside the Bay compared to 0.4 μg/g outside the Bay (p=0.04).

In terms of the core samples taken at 534, 538, BS and PM2, concentrations of cadmium, zinc, mercury, and lead tended to decrease with increasing core depth, while concentrations of iron, nickel, arsenic and chromium tended to increase (Figure 8). LELs were exceeded at some point in the core sample for cadmium (Stn 538 only), chromium, zinc (Stns 538 and PM2 only), nickel and iron.

While some level of sediment impairment was found, there were few significant relationships between metal concentrations and station distance from the effluent discharge (correlation analysis, p>0.09, Appendix C). Those that occurred were all in 1994. Concentrations of all metals except cadmium were strongly correlated with the organic content of the sediment (represented as LOI and TOC; p<0.001, Appendix D).

A historical comparison of mean surficial sediment quality among four sampling years (Table 3) using Tukey-Kramer tests showed that there were no significant differences in TOC, cadmium or lead. Concentrations for TP (Figures 9 and 10), and iron were highest in 1980 and 1988. Mercury was highest in 1988, while chromium was highest in 1988 and 1994. Zinc was highest in 1994. Nickel was lowest in 2008 while copper was lowest in 1980.

Benthos

As indicators of the health of aquatic environments, the benthic macroinvertebrate community, or benthos, has a long history of use in studies of the effect of pollution sources in lakes and rivers (Schloesser et al. 2001). Benthos are useful because:

- there is a wide diversity of species, habits and sensitivities
- the benthos are in intimate contact with sediments through most or all of their life cycle, and the community of organisms living in a location reflects the degree of sediment contamination and integrity of the benthic ecosystem
- the benthos are relatively immobile and reflect local conditions
- they are relatively short-lived and can reflect recent conditions
- they are an integral part of aquatic and terrestrial food webs - in many cases they are important food items for fish
- they are easy to sample in sufficient numbers

The community of organisms living in the mud at the bottom of a bay can reflect both the natural physical or chemical conditions as well as the presence of toxic factors such as those from discharges or the presence of contaminants laid down in the sediments in the past. The interactions between benthos and their surroundings can be complicated and pose difficulties in summarizing and interpreting what the community structure should be in terms of species richness and densities. With each benthos survey of Sturgeon Bay, observations were made of the species richness of the benthic community and of the abundance of selected benthic organisms known to be sensitive or insensitive to pollution sources.

Typically, benthic environments rich in organic materials (from sewage or nutrient runoff) support algae and bacteria growth in the sediment, which in turn supports a disproportionately large abundance of oligochaetes, or aquatic worms (Hynes 1960). A healthy aquatic ecosystem supports a balanced benthic community that is made up of a mix of benthic species and is not dominated by oligochaetes, especially of the family Tubificidae (tubificids). When an area becomes disturbed, species diversity declines and pollution-tolerant organisms such as oligochaetes, chironomids (midge larvae) and the amphipod crustaceans *Gammarus* and *Hyalella* replace pollutant-sensitive species. The desired objective for Severn Sound as set by the RAP is <3000 Tubificidae/m^2 (SSRAP Stage 3 Report 2002).

The presence of the burrowing mayfly *Hexagenia* is a general indicator of ecosystem health in the nearshore areas of the Great Lakes (Reynoldson et al. 1989, SSRAP Stage 3 Report 2002). However, it is generally sparse in shallow sediments dominated by heavy growths of submerged rooted aquatic plants such as Sturgeon Bay (J. Ciborowski, pers. comm.).

Past surveys in Sturgeon Bay

The benthic (in the mud) and epiphytic (on plants) invertebrate communities were surveyed in Sturgeon Bay during 1980, 1982 and 1988 in order to assess the benthos community before and after the construction of the Victoria Harbour WWTP (Barton 1981, 1983, and Speller and Pope 1989). A survey during 1994 was carried out to assess a new statistical tool used to compare impacted areas within the Great Lakes with a reference or "unimpacted" data set of benthos and related sediment quality (Reynoldson et al. 1995, Reynoldson and Day 1998). These surveys had several stations in common that were also sampled in 2008. However, methods of sampling and processing of invertebrate samples differed over the years, as did the time of year that sampling took place. The 1980 pre-construction surveys were carried out in mid-summer while the 1988 and 1994 surveys were carried out in late summer/early fall. These differences in methods added to the expected variability of the benthic community among survey years.

Tubificids were found at all stations, with the exception of stations 536, 543 and 546, in abundances that were not appreciably different in 1988 or 1994 than were found before the WWTP went into operation.

From all of the previous surveys, species richness tended to be greater in the eastern side of the Bay, probably due to the greater exposure to wind and wave action that limited plant growth. The sheltered western side of the Bay tended to have denser coverage of aquatic plants and lower benthic species richness. The same observations were made before and after the WWTP went into operation. Species richness of benthic invertebrates was significantly lower in 1988 than in the 1980 and 1982 survey (Speller and Pope 1989, p=0.05). This may have been due to differences in sampling method or due to the later sampling dates.

Overall abundance of benthic invertebrates appeared lower in 1988 than in the 1980 and 1982 survey (Speller and Pope 1989). This may also have been due to differences in sampling method or due to the later sampling dates.

The findings of the 1994 survey (Reynoldson and Day 1998) indicated that the benthic community was potentially stressed at stations 537 and 543. Station 538 was considered potentially toxic, based on acute sediment toxicity tests. The station closest to the outfall, 534, was considered unimpaired and the sediment was non-toxic based on acute and chronic toxicity tests. Neither the benthic community effects nor the potential toxicity could be explained by sediment quality and were considered to be associated with nutrient enrichment of the sediment (Reynoldson and Day 1998).

2008 benthos survey

The survey of benthos during 2008 included all stations sampled in previous surveys plus additional reference locations (Figure 3, Ciborowski and Barker 2009). The range of taxa found during 2008 and their densities are shown in Table 4. Based on density, the benthos community was dominated by nematode worms, oligochaetes and chironomids.

Cluster analysis of the benthos community (Figure 11) showed four main site clusters. The stations did not show spatial grouping based on proximity to the discharge, as would be expected if the effluent was having a large impact on the community, but rather appeared to group based on station depth, exposure and presence of submergent aquatic plants.

Average species richness within Sturgeon Bay ranged from a minimum of 7.3 at station 540 to a maximum of 13.7 at station 534 (adjacent to the outfall). The lowest species richness outside the Bay was found at station PM2, which had a value of 6 (Figure 12, Table 4).

During 2008, oligochaetes were found at all 22 of the sites (Figure 13), and represented 25-50% of the benthic invertebrates collected in a given sample. Maximum average oligochaete densities were 12 428, 9722, 9631 and 9529 worms/m^2, at sites 541, 546, 544, and 543 respectively, towards the eastern side of the Bay (Figure 14). Thirteen of the stations had abundances of over 3000 worms/m^2, indicating moderate enrichment (SSRAP Stage 2 and 3 Reports, 1993 and 2002). All of the sites located within the Bay had abundances >1000 worms/m^2. Sites outside the Bay that had high abundances (> 3000 worms/m^2) were 2001 and 2003. The sites with the lowest average abundances were PM2 and PS, with 17 and 429 worms/m^2, respectively.

Substantial proportions of the worm communities were made up of members of the family Naididae, some of which are indicators of organic enrichment. Some naidid species are associated with aquatic vegetation (e.g., *Stylaria lacustris, Ophidonais serpentina*, and *Dero digitata*; Nijboer et al. 2004). Although some naidids are relatively intolerant of organic enrichment (e.g., *Nais alpina, N. bretscheri*, and *N. pardalis*), enrichment of stony substrates can stimulate a 10 to 20-fold increase in abundance of other naidid species (e.g. *Nais elinguis, N. barbata, N. communis, N. variabilis,* and *Chaetogaster diaphanous*; Learner et al. 1978). Naidids were codominant with the more pollution tolerant tubificids at some sites, especially those on the west side of the bay (Figure 15). However, naidids were only about 1/15th as abundant as tubificids at sites along the eastern side of Sturgeon Bay. Densities of naidids ranged from around 100 worms/m^2 at sites 533 and 2002 to over 7000 worms /m^2 at station 541 (Figure 16). Densities exceeded 3000 tubificid worms /m^2 at 9 of the stations sampled (Figure 17).

The distribution of Oligochaeta in Sturgeon Bay suggests that the relatively high but variable densities reflect the rich sediment that characterizes all of the heavily vegetated portions of the Bay (see SSRAP Stage 1 Report 1989), rather than the accumulation of materials as a consequence of the sewage outfall. Biomass of organic detritus collected in Ponar grabs was unrelated to distance from the outfall (Figure 18). There was no evidence that the relative abundance of oligochaetes was greater at locations near the outfall than farther away (Figure 19). The density of oligochaetes at the site nearest the outfall (station 534) was approximately 6,000 worms/m^2 of which about 4,500 /m^2 were tubificids, implying moderate enrichment at that location. However, this density was near the median for the 22 stations. Many other sites, remote from the outfall, had much higher densities of worms (Figure 19). Thus, there was no evidence that oligochaete distribution or density were influenced by the treated sewage effluent discharge into Sturgeon Bay.

Chironomid abundance showed the same pattern as oligochaete abundance, which makes sense since detritus was variably distributed throughout the Bay (Figure 20).

Dreissenid (zebra and quagga mussel) densities and distribution were variable in Sturgeon Bay. They were nearly absent from only two locations (2002 and 532), but reached densities of almost 8 000/m^2 in some locations. Dreissenids typically are most abundant on hard substrates. Shifting sand and organic sediments with heavy growths of submerged aquatic plants would be expected to be especially unsuitable. The low densities found in Sturgeon Bay compared with other areas of Severn Sound may be explained by the sheltering of the Bay and the resulting unsuitable substrate. There did not appear to be a relationship between dreissenid abundance and the amount of detritus in sediments at a site (Figure 21). Instead, dreissenid density seemed to vary across Sturgeon Bay based on exposure – densities were uniformly low on the sheltered west side, and were variable on the exposed east side of the Bay possibly reflecting variable substrate conditions. Variability in dreissenid density also tended to increase with increasing distance from the location of the sewage outfall (Figure 22). Where substrate and currents are suitable, zebra mussels are abundant. For example, underwater inspections of the area around the outfall show that the outfall structure itself is encrusted with zebra mussels (2006 underwater inspection video).

Both two-dimensional and three-dimensional NMS ordinations produced acceptable summaries of the benthos data, with stress scores of 9.74 and 5.6, respectively. The simpler, 2-dimensional ordination was used for interpretation (Figure 23). Most of the stations were relatively tightly clustered, and 21 of the 22 stations fell within the 90% confidence ellipse derived from Great Lakes reference community data (BEAST model). This indicates that the benthic community in Sturgeon Bay is very similar to typical communities in the Great Lakes.

Station PM2 differed from the other stations along ordination axis 2. This station was deeper and lacked the dense vegetation that characterized most of the stations in Sturgeon Bay. It had low densities of organisms overall, but had especially few oligochaetes and dreissenids. Crustaceans were also absent from this station. Station MD1 (at the mouth of Matchedash Bay) was also very different from the Sturgeon Bay samples along ordination axis 1 and fell close to the 90% confidence ellipse. This rocky site lacked most of the taxa that are normally associated with organic sediments or aquatic vegetation. Instead, this station was dominated by *Hydra*. Station 534 (closest to the outfall) fell near the centre of the ordination plot. Its position on the graph relative to the other Sturgeon Bay stations indicated that its benthic community composition was typical for the Bay and well within the normal range of variation. There was no basis on which to distinguish this station from any other sampled within Sturgeon Bay.

Open Water Quality

Samples for water quality were collected at long-term open water sites in Severn Sound from 1969-2008 and at 16 sites within Sturgeon Bay during 1980 and 2008 (Figure 4).

Water clarity and temperature

Water clarity in Severn Sound is measured as Secchi disk visibility. In Sturgeon Bay, the Secchi disk is often either visible sitting on the bottom or is partially obscured by the rooted aquatic plants. During 2008, turbidity was also measured to supplement clarity measurements. Mean turbidity values ranged from 0.63 to 1.64 NTU, which were considered low for open water (Table 5). Turbidity at the stations sampled was not correlated with proximity to the treated effluent discharge.

Data from drinking water intakes in Hogg and Sturgeon Bay were used to assess recent fluctuations in water temperature (Appendix E). Since 2006, mean summer and winter temperature have remained constant in Sturgeon Bay (Figure 24). Mean summer temperature has decreased and mean winter temperature has increased in Hogg Bay.

Total phosphorus

Long-term trends in TP concentration, using data from 1969-2008 (Appendix F), were examined using a Mann-Kendall test for station BS in Sturgeon Bay, PM2 in Hogg Bay and P4 in the Outer Harbour of Penetanguishene Harbour (Figure 25). These three stations were selected because they provide a long-term reference for fluctuations in the quality of open waters of Severn Sound in comparison with Sturgeon Bay. There were significant decreasing trends for TP at all three stations over the period 1969 to 2008 ($p < 0.005$). These trends indicated that the phosphorus control strategies implemented by the Severn Sound RAP, including both point and non-point source control, had a beneficial effect on the open water quality of Severn Sound.

In order to examine major events affecting the Sturgeon Bay ecosystem , the TP at the three long term stations was also grouped into four time periods:

- pre-WWTP commissioning (1969-1979; 1980-1984);
- post-WWTP commissioning and pre-zebra mussels (1985-1994);
- post-zebra mussels and high water levels (1995-1999);
- and low water levels (2000-2008).

TP during the earlier two periods was significantly greater than the other three for all three sites (Tukey-Kramer test, $\alpha<0.05$, Figure 26). The three time periods after commissioning of the sewage plant were not significantly different from each other, suggesting that neither the infestation of zebra mussels nor the decrease in water levels had a significant influence on TP concentrations in Sturgeon Bay.

Five sites within Sturgeon Bay (532, 534, 543, 545 and BS) were compared using summer (Jul-Sept) data for three time periods based on available data – pre-WWTP commissioning (1980 – 1984); post-WWTP commissioning and pre-zebra mussels (1985-1994) and post zebra mussels (2008). Reductions in TP were found between the pre-WWTP commissioning period and the other two periods, which were significant at 545 and BS. No difference was noted between the post-commissioning/pre-zebra mussel period and the 2008 survey (Tukey-Kramer test, $\alpha<0.05$, Figure 27).

These comparisons suggest that since the commissioning of the WWTP, water quality of Sturgeon Bay has improved. A similar analysis of changes in water quality at Station BS between 1988 and 2003 was done by Croft and Chow-Fraser (2007), who reached a similar conclusion. The similarity of TP concentration between 1985-1993 and 1994-1999 suggested that the infestation of zebra mussels in Severn Sound did not have a significant effect on nutrient levels in Sturgeon Bay. This is logical since the substrate in the Bay is generally not suitable for zebra mussel colonization.

Mean TP values at each station sampled during the summer of 2008 ranged from 9.4 to 21.9 μg/L with a mean value within the Bay of 14.2 μg/L (Table 5). Spatial analysis of the 2008 TP data showed no significant difference between stations with the exception of station 540, which was significantly higher than stations 535 and 536 (Tukey-Kramer test, $\alpha<0.05$, Figure 28). Station 540 has the highest mean summer concentration and stations 535 and 536 have the lowest mean summer concentration. The range of concentrations in 1980 was similar but more spatially variable than 2008 (Figure 29). A paired *t*-test showed no significant difference between 1980 and 2008 data.

In order to assess the direct impact of the discharge on the open water quality, correlation analysis was performed using the TP concentration at Station BS and the TP load (kg/d) from the treated sewage effluent (the closest date from WWTP monitoring records to the date of open water sampling was used) from 2003-2008 (Figure 30, data in Appendix G). The effluent TP load, on occasion, approached the Severn Sound RAP loading target of 0.35 kg/d, however, the open water TP at station BS showed no correlation with daily TP load, even at these higher effluent loads. In fact, high open water concentrations occurred at low as well as high effluent loads. Internal sources of phosphorus such as from re-suspended sediment, may be contributing to the concentrations found in the open water, resulting in a lack of a direct relationship with effluent TP loading.

Nitrogen

Based on Mann-Kendall trend analysis, total ammonia concentration has not changed significantly over the long-term in Sturgeon Bay, Penetanguishene Harbour or Hogg Bay (Figure 31A, data in Appendix F). Concentrations were highest between 1980-1984, just before the WWTP was built. At the Sturgeon Bay stations, ammonia was lowest from 1985-1994, after the WWTP was commissioned, and increased in the 2008 survey (Figure 31B). In 2008, there were no significant spatial differences within Sturgeon Bay (based on a Tukey-Kramer test; Figure 32). Total ammonia concentrations were generally low in all years and met the Ontario Provincial Water Quality Objective (PWQO) for un-ionized ammonia (20 μg/L; concentrations of un-ionized ammonia did not exceed 9 μg/L at an average pH of 8.5 and temperature of 21°C) throughout the Bay.

Nitrate concentrations in the bays of Severn Sound tend to have a seasonal cycle of rapid decrease from moderate concentrations in spring (~0.1 mg/L) to low values (<0.02 mg/L), by late spring/early summer. This is likely due to the influence of the tributaries, which carry high nitrate loads in the spring from surrounding agricultural lands. Tukey-Kramer tests using data from long term stations showed no significant differences between the periods before and after commissioning of the WWTP, although P4 shows an increasing trend (Figure 33A). The summer values found in Sturgeon Bay during 2008 were lower than the period from 1985-1994, although not significantly so (Figure 33B). The treated sewage effluent has relatively high concentrations of nitrate-nitrogen (typically on the order of 10 mg/L). However, based on spatial analysis of the 2008 survey results, there appears to be no relationship between nitrate concentration in the Bay and the treated sewage effluent discharge location (Figure 34).

Phytoplankton Community

The phytoplankton community structure in Sturgeon Bay is influenced by the presence of dense growths of submergent rooted aquatic plants, as the rooted plants sequester TP in the plant tissues and generally outcompete phytoplankton for nutrients. The presence of filamentous algae and algal species normally associated with rooted plants in Sturgeon Bay are often incidentally sampled in the open water composite sampling at station BS, adding to the seasonal fluctuations in phytoplankton biovolume.

At five long-term monitoring sites, total phytoplankton biovolume in Severn Sound has decreased significantly based on Mann-Kendall trend tests, from peak values of 6000 mm^3/m^3 in the late 1980s to early 1990s to less that 1000 mm^3/m^3 (p<< 0.001; Figure 35, data in Appendix H). Total biovolume in Sturgeon Bay was consistently the lowest of all the long term stations, and ranged between 157-2424 mm^3/m^3.

The proportion of *Melosira* and *Stephanodiscus*, large-bodied diatoms associated with nutrient enrichment, has decreased since the early 1990s (SSRAP Stage 3 Report, 2002). The community structure may also be influenced by selective filtration of dreissenid mussels. Dreissenids filter particles 5-45 μm, excluding filamentous algae and some types of blue-green algae (MacIsaac et al. 1991). Increases in blue-green algae (Cyanophyta) such as *Microcystis* spp. and increased complaints of shoreline filamentous green algae (Chlorophyta) such as *Oodegonium*, *Mougeotia* and *Spirogyra* have been noted in Severn Sound. The response of phytoplankton to changes in nutrient loadings may be masked, in part, by the infestation of Severn Sound with zebra mussels, which began in 1994.

In Sturgeon Bay (Stn BS) and at three other open water stations (PM2, M5 and PS), the dominant algal classes in 2008 were diatoms (Bacillariophyta) and Cryptophyta, with green algae (Chlorophyta) also dominant in mid-summer in Sturgeon Bay (Figure 36, data in Appendix I). The difference in community composition and biovolume between Sturgeon Bay and the other deeper open water stations likely relates to the association between several green algae and submergent rooted aquatic plants. The most common genera of algae within these classes are *Fragillaria* (bacillariophyte) and *Rhodomonas* (cryptophyte) (Figure 37, data in Appendix J). *Microcystis* (cyanophyte) was also present in late summer (as it was at the other stations) but did not represent a large proportion of total biovolume. The dinophyte *Peridiniopsis* was also well represented for a brief period in Sturgeon Bay in 2008.

The blue-green filamentous alga *Gleotrichia*, has been found in several bays in Severn Sound, including Sturgeon Bay. This benthic alga rises in the water column during the growing season and forms suspended colonies that accumulate and drape over rooted aquatic plant beds, occasionally causing temporary shading of plants. In Sturgeon Bay, occasional blooms of this alga occurred in the western side of the Bay near the outfall. However, growth of this alga is not dependent on nutrient levels in the water column (Barbiero and Welch 1992). Although the alga adds little to the overall phytoplankton biovolume, its presence as a nuisance species has been noted throughout the period of sampling record.

In summary, the slightly higher biovolume of certain types of phytoplankton in Sturgeon Bay as compared to the other three stations may relate to the association of the phytoplankton community in the Bay with the submergent rooted aquatic plants. The phytoplankton community is considered representative of a mesotrophic or moderately enriched water body. There are no major concerns with toxic or nuisance algae.

Zooplankton Community

Just as benthos are good indicators of sediment quality, zooplankton communities are good indicators of open-water quality. They are an important part of the food web, keeping phytoplankton populations in check through grazing, and providing an important food source for fish.

Due to the shallow and macrophyte-dominated nature of Sturgeon Bay, zooplankton communities would be expected to be distinctive from the rest of Severn Sound, and comparisons with other long term stations would not especially useful. Data were instead examined for temporal changes on a community level using NMS ordination analysis. Zooplankton data are available for Stn BS from 1988-2005 and 2008. Ordination analysis summarized the zooplankton community well, with a final stress of 5.35. Based on cluster and ordination analysis (Figure 38), sampling years were classified into two groups, 1988-1994 and 1995-2005. 2008 was included in the first group, while 1991 was included in the latter group due to anomalous community composition for those years.

The shift in community structure that led to the aforementioned grouping coincided with the establishment of dreissenids. The influence of dreissenids on lower trophic levels has be documented in the Great Lakes and other inland lakes (e.g. MacIsaac et al. 1995, Brines-Miller and Watzin 2007). Dreissenids are efficient and selective filter feeders, feeding on particles from 5-45 μm, and tend to not only select phytoplankton that are also suitable for zooplankton grazers, but also filter small microzooplankton (MacIsaac et al. 1991). Thus dreissenids can affect zooplankton populations directly by predation and indirectly by food limitation. A plot of relative biomass over time (Figure 39, data in Appendix K) showed that non-daphnid cladocerans (which are strictly herbivores) have been decreasing and are being replaced by calanoid copepods (which range from herbivores to carnivores). It may be that non-daphnid cladocerans are being out-competed by dreissenids, while the diverse feeding habits of calanoid copepods have allowed members of that order to increase in density. The relative biomass of daphnids (herbivores) and cyclopoid copepods (herbivores to carnivores) have been consistent over recent years.

Rooted Aquatic Plants

Rooted aquatic plants have been known to dominate Sturgeon Bay due to the shallow depths and relatively soft organic sediments (SSRAP Stage 1 Report 1989). Studies of rooted aquatic plant communities were conducted by the MOE before the Victoria Harbour WWTC was constructed (1980, reported in SSRAP Stage 1 Report 1989; OMOE unpublished; see also Miller 1977) and after construction (1988 field season in Speller and Pope 1989). Denser beds of rooted aquatic plants were found in the western, more sheltered side of the Bay (SSRAP Stage 1 Report 1989). Dense emergent plant growth has historically been associated with the southern end of the Bay where the Sturgeon River and other smaller streams discharge into the Bay.

More recently, as part of a research project conducted by McMaster University, eight stations sampled in 1988 (Speller and Pope 1989) were revisited in 2004 for comparison of percent cover of submersed aquatic plants and submergent plant community composition (Croft and Chow-Fraser 2007). Croft and Chow-Frazer (2007) concluded that a quality index based on the aquatic plant community improved with time (1988 compared to 2004) in Sturgeon Bay, suggesting that the presence of the sewage plant discharge did not have a negative impact on the plant community. Moreover, the aquatic plant community may be benefiting from the improved water quality of the Bay resulting from the enhanced sewage treatment provided by the tertiary plant. Their analysis of the sites within Sturgeon Bay concluded that variability in plant community structure could not be attributed to either distance from the effluent discharge pipe or to shoreline impacts.

In a more general survey of aquatic plants in wetlands of the Great Lakes, McNair and Chow-Fraser (2006) compared the plant community of Matchedash Bay with Sturgeon Bay during 2003 and 2004, and noted that Sturgeon Bay was more similar to other

Georgian Bay sites and some Lake Superior sites. This was likely due to similarities in depth, substrate, connectivity with the open waters and watershed inputs.

Submerged plant beds were captured in air photos taken during 2006 by SSEA and in photos from the surface taken on a particularly calm day during 2008. These photos suggest continued widespread coverage of aquatic plants in the Bay.

From previous studies (Speller and Pope 1989, SSRAP Stage 2 Report 1993) it has been noted that a significant decline or removal of the rooted submerged aquatic plants could result in deterioration of the water quality of the Bay. The rooted plants sequester phosphorus that would otherwise be used by suspended algae and help to hold sediment in place during wind events. Aquatic plant beds are important in maintaining the quality of Sturgeon Bay, and the existing treated sewage discharge does not appear to be adversely affecting the plants in the Bay.

Trophic Status of Sturgeon Bay

Based on the trophic indicators discussed above, Sturgeon Bay is considered mesotrophic or moderately enriched. The overall trophic status of the Bay appears to have improved since the construction and operation of the Victoria Harbour WWTP.

The TP sources to Sturgeon Bay have been discussed in the SSRAP Stage 2 Report (1993). The majority of the TP load originates from the Sturgeon River watershed, with smaller contributions from the Severn River to the north and the Coldwater and North Rivers via the discharge at the mouth of Matchedash Bay (SSRAP Stage 2 Report 1993). The phosphorus loading to the Bay has not changed since the evaluative model presented in the Stage 2 Report was developed. Refinement of the model flushing term could be accomplished through hydrodynamic modeling of the exchange between Sturgeon Bay and the open waters of Severn Sound.

Conclusions

The evidence presented shows that the existing outfall location is having no significant impact on the environmental quality of Sturgeon Bay in terms of sediment quality, water quality, and benthos, phytoplankton, zooplankton and macrophyte communities. Since the effluent TP load at design flow will not be changing from the existing target TP load, there appears to be no reason to consider an alternate outfall location outside Sturgeon Bay. From a receiving water quality view point, the proposed upgrade and expansion will satisfy the requirements of the effluent phosphorus loading objective established in the Severn Sound RAP.

Moving the outfall to a location off Robin’s Point was considered and rejected as an option as it brings the treated effluent closer to the intake protection zone of the Victoria

Harbour Water Filtration Plant, and because the effluent TP load objective will remain the same following the proposed WWTP upgrade.

Recommendations

It is recommended that the existing outfall remain in the same location provided the effluent annual TP loading to Sturgeon Bay does not exceed the Severn Sound RAP target of 129 kg/year. In the future, if additional capacity is required beyond the loading target, then consideration should be given to other options for effluent discharge.

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Table 1. Station locations for the 2008 survey of Sturgeon Bay and area.

		Media sampled			Location (UTM NAD83, Zone 17)	
Station	Description	Sediment	Benthos	Water	Easting	Northing
532	Sturgeon Bay	√	√	√	598768	4957067
533	Sturgeon Bay	√	√	√	598853	4956677
534	Sturgeon Bay	√	√	√	598865	4956427
535	Sturgeon Bay	√	√	√	598790	4956187
536	Sturgeon Bay	√	√	√	599002	4955747
537	Sturgeon Bay	√	√	√	599249	4956677
538	Sturgeon Bay	√	√	√	599317	4956387
539	Sturgeon Bay	√	√	√	599256	4956197
540	Sturgeon Bay	√	√	√	599924	4957047
541	Sturgeon Bay	√	√	√	599696	4956417
542	Sturgeon Bay	√	√	√	599980	4956027
543	Sturgeon Bay	√	√	√	599745	4955297
544	Sturgeon Bay	√	√	√	601032	4957067
545	Sturgeon Bay	√	√	√	600978	4956447
546	Sturgeon Bay	√	√	√	600618	4955687
BS	Sturgeon Bay	√		√	599788	4955846
2001	Robin's Point	√	√		598284	4958260
2002	Robin's Point	√	√		598635	4958300
2003	Robin's Point	√	√	√	598602	4958070
2004	Robin's Point	√	√		599115	4958330
MD1	Waubaushene		√		602778	4956870
PM2	Hogg Bay	√	√	√	595742	4957370
PS	off Port Severn	√	√	√	600836	4959770
	WWTP outfall		n.a.		598810	4956400

Table 2. Data for bulk surficial sediment chemistry from Sturgeon Bay area collected August 18 2008. Results are in µg/g dry weight unless otherwise indicated.

Station	Depth (m)	TP	TKN	TOC (% by wt)	LOI (% by wt)	Al	Sb	As	Ba	Be	Bi	Cd	Cr	Co
method det.lim. →				0.1	0.05	10	0.1	1	1	0.2	5	0.5	1	1
532	1.6	1010	2850	2.3	6.94	6300	0.1	<1	83	0.2	<5	<0.5	13	7
533	1.9	830	3670	3.1	9.11	7630	<0.1	<1	99	0.3	<5	<0.5	15	8
*534	2	550	1020	0.9	3.02	6190	<0.1	<1	55	<0.2	<5	<0.5	13	6
535	1.8	690	3040	3.5	9.70	8210	<0.1	1	107	0.3	<5	<0.5	16	8
536	1.9	920	2600	3.3	9.81	9880	0.1	2	122	0.3	<5	<0.5	19	9
537	2.1	1200	4440	3.5	9.94	8490	<0.1	<1	123	0.3	<5	<0.5	17	8
*538	2.4	910	3910	4.1	12.60	10100	0.1	2	139	0.4	<5	<0.5	20	9
539	2.1	790	3330	3.8	10.80	9140	<0.1	2	121	0.3	<5	<0.5	19	9
540	3.3	770	3890	5.7	15.10	17600	0.2	2	247	0.6	<5	<0.5	34	14
541	2.9	940	5870	6.0	15.20	13000	<0.1	2	195	0.5	<5	<0.5	25	11
542	2.9	760	4260	5.5	14.90	12200	0.1	<1	175	0.4	<5	<0.5	24	10
543	2	950	3580	3.8	10.20	8440	<0.1	1	118	0.3	<5	<0.5	18	8
544	2.5	450	204	0.3	1.02	2310	<0.1	<1	26	<0.2	<5	<0.5	6	3
545	2	530	556	0.6	2.37	5290	<0.1	<1	58	<0.2	<5	<0.5	13	5
546	2	610	924	1.2	4.07	4320	<0.1	1	46	<0.2	<5	<0.5	11	4
*BS[1]	2	1049			12.50	14800	0.2	4	210	0.6	0.1	0.6	46	11
2001	4	590	1410	1.4	6.66	13600	0.1	20	284	0.6	<5	<0.5	23	17
2002	8	710	965	0.9	4.62	7910	<0.1	2	97	0.3	<5	<0.5	18	8
2003	4.3	550	1230	0.8	4.20	5780	<0.1	<1	59	<0.2	<5	<0.5	12	5
2004	3.5	560	611	0.8	3.62	9030	<0.1	1	102	0.3	<5	<0.5	21	9
*PM2	8.5	930	3350	3.2	10.20	16700	0.2	2	188	0.6	<5	<0.5	33	13
PS	5	1170	4900	8.1	19.30	8590	<0.1	2	102	0.3	<5	0.7	18	9
CCME ISQG								5.9				0.6	37.3	
CCME PEL								17				3.5	90	
LEL		600	550	1				6				0.6	26	
SEL		2000	4800	10				33				10	110	
GSC								1				0.66	60.4	
Sturgeon Bay mean		810	2943	3.2	9.20	8994	0.1	1.5	120	0.3	4.7	0.5	19	8

Station	Cu	Fe	Pb	Li	Mn	Hg	Mo	Ni	Se	Sr	Tl	U	V	Zn
method det.lim. →	1	10	5	0.1	1	0.005	1	1	0.1	1	0.2	0.1	1	1
532	16	12200	12	6.2	232	0.044	<1	9	0.5	28	0.2	1.0	18	70
533	20	14300	15	7.1	319	0.050	<1	12	0.6	31	0.2	1.2	20	79
534	16	11700	6	6.9	205	0.024	<1	9	0.2	23	<0.2	0.8	17	48
535	19	14900	13	7.5	259	0.050	<1	11	0.5	43	<0.2	1.0	21	67
536	18	17500	14	9.0	286	0.049	<1	13	0.5	37	0.2	1.3	25	75
537	20	15500	20	8.4	340	0.056	<1	13	0.7	41	0.3	1.5	25	89
538	25	17900	22	9.9	386	0.065	<1	15	0.8	38	0.3	1.3	28	97
539	21	16800	18	8.8	354	0.053	<1	13	0.7	33	0.2	1.3	27	86
540	34	27700	36	17.4	623	0.081	<1	25	0.9	52	0.4	2.0	47	162
541	29	21900	29	13.1	591	0.080	<1	18	1	84	0.4	1.7	35	123
542	27	20100	27	11.8	561	0.077	<1	16	0.9	91	0.3	1.5	33	105
543	17	15300	13	7.9	305	0.049	<1	11	0.6	70	<0.2	1.3	23	67
544	8	7210	<5	2.5	124	0.014	<1	3	0.1	9	<0.2	0.5	13	27
545	13	13200	6	5.3	167	0.018	<1	7	0.2	16	<0.2	1.1	26	32
546	12	10200	5	4.2	154	0.024	<1	5	0.3	18	<0.2	1.0	19	37
BS[1]	17	27400	21	15.2	826	0.067	0.5	19	1	81	0.2	1.0	50	109
2001	20	67300	21	12.4	2930	0.034	<1	15	0.4	61	0.3	1.0	43	111
2002	12	20800	13	7.3	425	0.028	<1	11	0.3	18	<0.2	0.9	26	70
2003	11	11700	6	7.1	211	0.021	<1	7	0.2	14	<0.2	0.6	19	48
2004	13	20700	13	11.5	624	0.030	<1	12	0.3	24	<0.2	2.0	32	85
PM2	26	28500	28	16.9	1070	0.064	<1	24	0.6	36	0.3	1.7	45	120
PS	23	15300	33	8.6	509	0.086	<1	14	0.5	24	<0.2	1.4	23	121
CCME ISQG	35.7		35			0.17								123
CCME PEL	197		91.3			0.486								315
LEL	16	20000	31		460	0.2		16						120
SEL	110	40000	250		1100	2		75						820
GSC	20		9			0.129		14						103
Sturgeon Bay Mean	19.5	16488	16	8.8	358	0.050	1.0	12	0.6	43	0.2	1.2	27	80

All surficial samples were collected with a Ponar by UW staff and analyzed by Caduceon Environmental Laboratories, with the exception of Station BS

[1] average of results from top 4 cm of NWRI core sample analyzed at Environment Canada Laboratory, Burlington, ON

< indicates values below analytical detection limits (limits differ for NWRI sample)

CCME ISQG - Canadian Sediment Quality Guidelines for the Protection of Aquatic Life for freshwater sediments - Interim Freshwater Sediment Quality Guidelines(1999, updated 2002)

CCME PEL - Canadian Sediment Quality Guidelines for the Protection of Aquatic Life for freshwater sediments (1999, updated 2002) - Probable Effects Limits
LEL - Lowest Effect Level OMOE Sediment Quality Guidelines 1993
SEL - Severe Effect Level OMOE Sediment Quality Guidelines 1993
GSC - Geological Survey of Canada lake sediment survey metals concentration for Severn Sound area (Painter, unpublished)

Table 3. Historical comparison of mean surficial bulk sediment quality for Sturgeon Bay (averaged by station). Results are in μg/g dry weight unless otherwise indicated.

	1980[1]		1988[2]		1994[3]		2008[4]				Statistical
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	LEL	SEL	notes
TP	1100*	180	1080*	120	890	100	790	200			highest in '80 & '88
TOC (%)	3.5	0.7	4.2	0.7	4.0	1.0	3.2	0.2	1	10	no sig. diff.
Hg	0.04	0.02	0.08*	0.03			0.05	0.02			highest in 1988
Cd	0.45	0.12	0.29	0.16	0.45	0.29	0.5	0	0.60	10.00	no sig. diff.
Cr	27	7	39*	9	78*	7	18	7	26	110	highest in '88 & '94
Cu	12*	4	15	4	19	5	20	7	16	110	lowest in 1980
Fe	20583*	4188	25236*	4674			15761	5005	20000	40000	highest in '80 & '88
Pb	14	7	21	6	24	10	16	9	31	250	no sig. diff.
Mn			576	120			327	157	460	1100	insuff. data
Ni			20	5	22	7	12*	5	16	75	lowest in 2008
Zn	73	26	89	23	115*	36	78	36	120	820	highest in 1994
Al			17153	3948			8607	3766			insuff. data

[1] from Severn Sound RAP Stage 3 Report
[2] from Krantzberg and Sherman 1995
[3] from Reynoldson and Day 1998
[4] from this study
* indicates a statistical difference compared to other years using a Tukey-Kramer test
LEL - Provincial Sediment Quality Guidelines Lowest Effect Level
SEL - Provincial Sediment Quality Guidelines Severe Effect Level

Table 4. Benthos species richness and density (arithmetic mean ± Standard Error in #/m^2, *n*=3) of major benthos taxa represented in Sturgeon Bay and vicinity during August 2008 (Ciborowski and Baker 2009).

Station	# Taxa			Density (per m^2)			Oligochaeta (per m^2)			Chironomidae (per m^2)			*Gammarus* (per m^2)			*Hyalella* (per m^2)		
532	10.0	±	1.5	30033.5	±	15774.0	5108.6	±	1868.2	10283.9	±	5745.1	0.0	±	0.0	545.4	±	231.7
533	9.7	±	1.3	18544.4	±	5089.4	1770.6	±	1103.8	4631.8	±	886.2	0.0	±	0.0	1275.6	±	1093.3
534	13.7	±	3.4	41833.4	±	20257.7	7080.8	±	2163.5	10447.7	±	3719.9	0.0	±	0.0	156.3	±	156.3
535	9.0	±	0.6	16971.0	±	6447.9	2213.1	±	1623.6	9224.7	±	2929.2	0.0	±	0.0	131.5	±	65.7
536	9.7	±	1.2	52319.0	±	7708.1	11492.8	±	2925.7	25143.9	±	5144.1	123.1	±	123.1	123.1	±	123.1
537	8.0	±	0.0	36220.7	±	15752.2	4907.3	±	801.0	15102.7	±	8808.3	0.0	±	0.0	985.8	±	927.9
538	10.0	±	1.5	32604.9	±	16876.6	12200.0	±	10118.8	7626.8	±	2192.4	0.0	±	0.0	391.8	±	178.1
539	11.7	±	2.2	20063.7	±	9294.4	3462.1	±	1565.4	4243.8	±	1653.7	0.0	±	0.0	0.0	±	0.0
540	7.3	±	0.9	10307.4	±	2728.6	1804.7	±	174.4	2280.2	±	641.6	0.0	±	0.0	366.3	±	37.8
541	9.3	±	1.5	62190.0	±	17852.7	12629.7	±	2462.3	9707.3	±	3735.6	0.0	±	0.0	2605.1	±	2187.0
542	9.7	±	1.5	36099.9	±	26392.7	7752.5	±	3822.5	1881.2	±	505.1	0.0	±	0.0	1674.4	±	946.3
543	9.7	±	1.5	31825.1	±	9397.4	9147.1	±	1824.0	13981.7	±	5408.2	0.0	±	0.0	45.4	±	45.4
544	12.0	±	1.2	67771.2	±	27871.7	13478.0	±	4537.6	12621.6	±	4643.1	0.0	±	0.0	195.3	±	173.5
545	10.0	±	1.2	25266.3	±	12211.3	4235.9	±	1795.2	9112.5	±	4081.5	0.0	±	0.0	167.6	±	108.0
546	10.0	±	1.5	68549.4	±	24680.4	14858.0	±	4922.1	22801.8	±	7085.7	0.0	±	0.0	26.5	±	26.5
2001	8.3	±	0.7	9881.5	±	1063.1	3629.6	±	163.0	3614.8	±	372.1	0.0	±	0.0	0.0	±	0.0
2002	7.7	±	0.3	8179.9	±	2421.9	1172.5	±	753.9	3824.3	±	988.3	0.0	±	0.0	0.0	±	0.0
2003	10.0	±	1.2	29302.2	±	7609.6	3822.5	±	1176.5	3736.3	±	1241.1	0.0	±	0.0	14.8	±	14.8
2004	9.3	±	0.3	40875.7	±	9725.4	4095.6	±	2230.2	11032.1	±	4267.5	0.0	±	0.0	14.8	±	14.8
MD1	11.7	±	2.4	17125.9	±	4530.0	7081.5	±	1778.2	1125.9	±	141.3	103.7	±	103.7	207.4	±	207.4
PM2	6.0	±	1.2	3885.9	±	1683.0	346.7	±	211.2	577.8	±	219.2	0.0	±	0.0	0.0	±	0.0
PS	9.0	±	1.0	8359.3	±	1379.4	372.3	±	147.4	2269.9	±	171.1	0.0	±	0.0	0.0	±	0.0

Table 5. Mean summer water quality of Sturgeon Bay and area stations during 2008.

Station	Surface Temp. (°C)	D.O. (mg/L)	Field Cond. (μmhos/cm)	Alkalinity (mg/L)	Conductivity (μmhos/cm)	Total Ammonia (μg/L)	Total Nitrate (μg/L)	lab pH	Tot. Kjeldahl N (μg/L)	Total P (μg/L)	Turbidity (NTU's)	N:P ratio
532	20.7	9.2	256	89.3	252	49.5	19.8	8.77	415.0	14.1	1.14	32.1
533	20.8	9.3	262	85.4	258	52.9	75.8	8.69	393.9	15.2	1.05	34.1
534	20.8	9.2	260	93.3	260	48.6	24.3	8.61	388.1	12.9	0.77	33.5
535	20.8	8.8	268	97.0	268	39.5	13.3	8.51	358.0	9.4	0.75	39.7
536	20.7	8.8	272	103.6	272	41.9	13.1	8.53	355.2	9.9	0.67	37.9
537	20.8	8.8	264	79.9	266	56.6	16.1	8.35	479.4	20.8*	1.64	26.1
538	20.8	8.5	266	83.8	266	71.9	16.2	8.42	429.4	20.9*	1.40	22.5
539	20.8	8.8	267	81.9	268	42.2	13.5	8.54	402.5	12.8	0.87	32.6
540	21.4	8.7	279	81.6	281	58.9	13.3	8.08	432.4	21.9*	1.20	21.5
541	21.1	8.8	276	82.1	278	49.5	14.6	8.47	406.8	17.5	0.93	24.7
542	21.2	8.4	281	86.0	281	56.9	15.7	8.45	409.0	14.5	0.92	29.8
543	20.4	9.2	286	114.6	287	70.1	24.1	8.46	370.1	10.7	0.85	37.6
544	20.8	8.7	288	87.3	289	50.3	14.4	8.17	421.0	11.8	0.72	37.1
545	21.0	9.3	278	81.4	279	40.1	13.3	8.34	403.1	11.1	0.63	39.1
546	21.2	9.1	273	86.8	271	46.3	13.9	8.56	413.5	11.9	0.84	36.1
BS	20.6	9.2	273		267	47.0	11.0		459.0	18.0		27.2
2003	20.7	8.7	266	80.7	267	39.8	13.3	8.42	442.6	11.0	0.75	42.6
PM2	21.5	9.3	242		239	32.0	14.0		359.0	13.6		27.5
PS	21.6	9.2	267		267	36.6	6.6		411.6	11.6		35.9
Mean	20.9	8.9	270	88.4	269	49.0	18.2	8.46	407.9	14.2	0.95	32.5
Max	21.6	9.3	288	114.6	289	71.9	75.8	8.77	479.4	21.9	1.64	42.6
Min	20.4	8.4	242	79.9	239	32.0	6.6	8.08	355.2	9.4	0.63	21.5
PWQO		5[1]				166[2]				20[3]		

PWQO – OMOE Provincial Water Quality Objectives (1994). Results that exceeded the guidelines are marked with *.
[1] For cold water biota.
[2] The PWQO is set for un-ionized ammonia at 20 mg/L, which at 21°C and pH=8.5 is 12% of the total ammonia. The PWQO was converted to total ammonia for ease of interpretation.
[3] Interim guideline for preventing nuisance plant and algae growth.

Figure 1. Severn Sound area, showing bathymetry, long term sampling locations and waterfront communities. Enlarged area shows features of Sturgeon Bay.

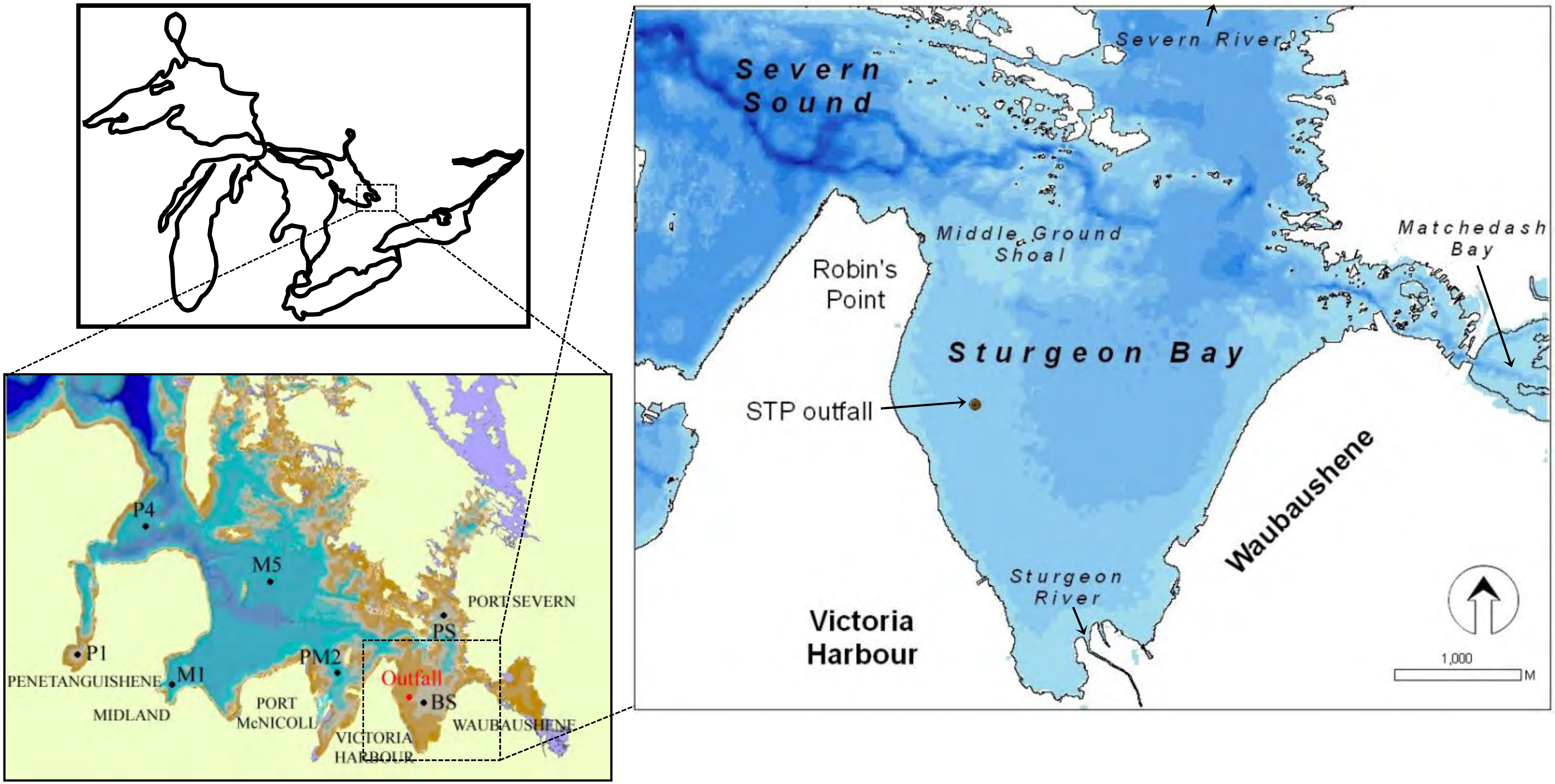


Figure 2. Sediment and core sampling locations, 2008. Long term monitoring stations are also shown.

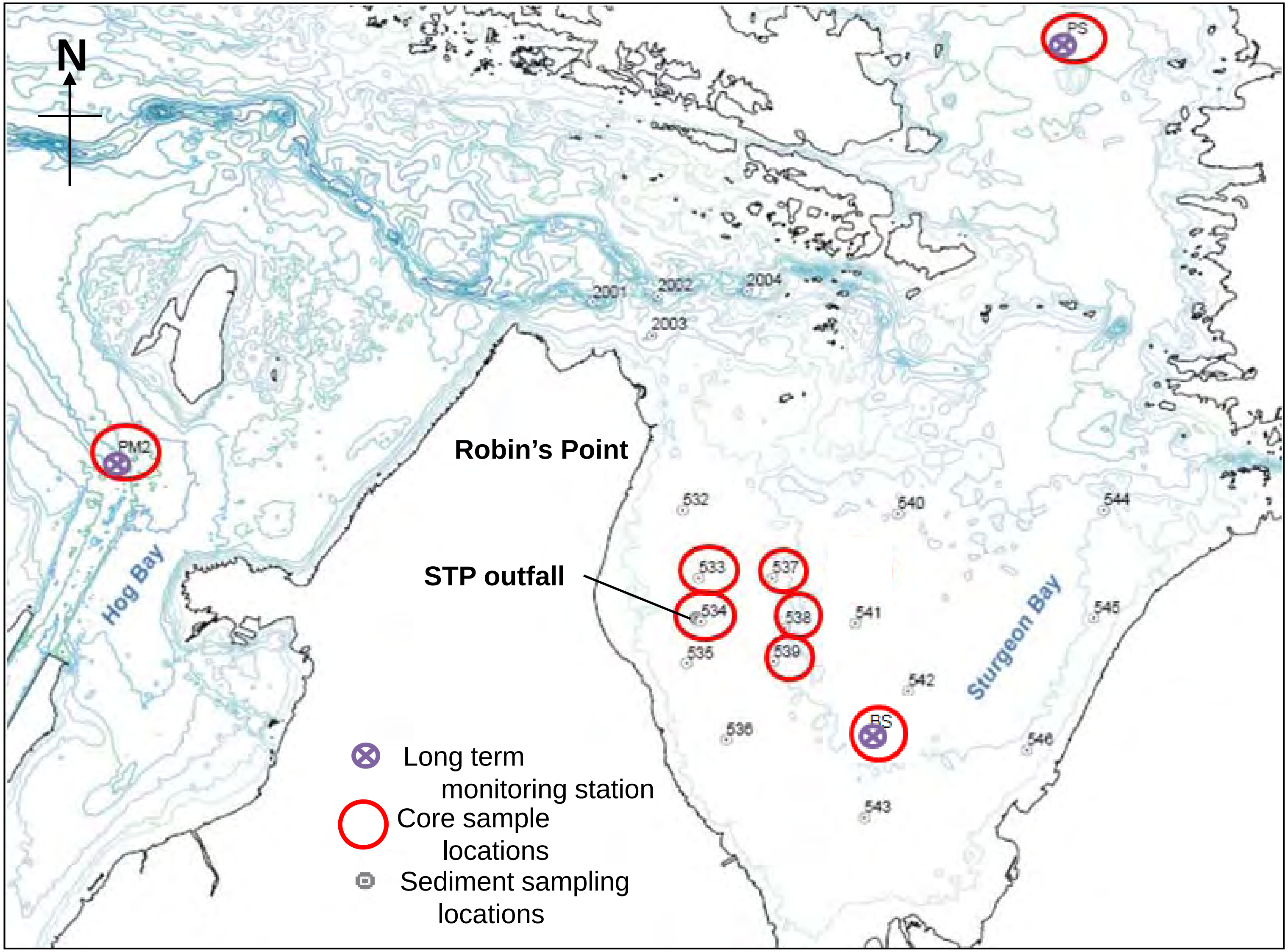


Figure 3. Benthos sampling locations 2008.

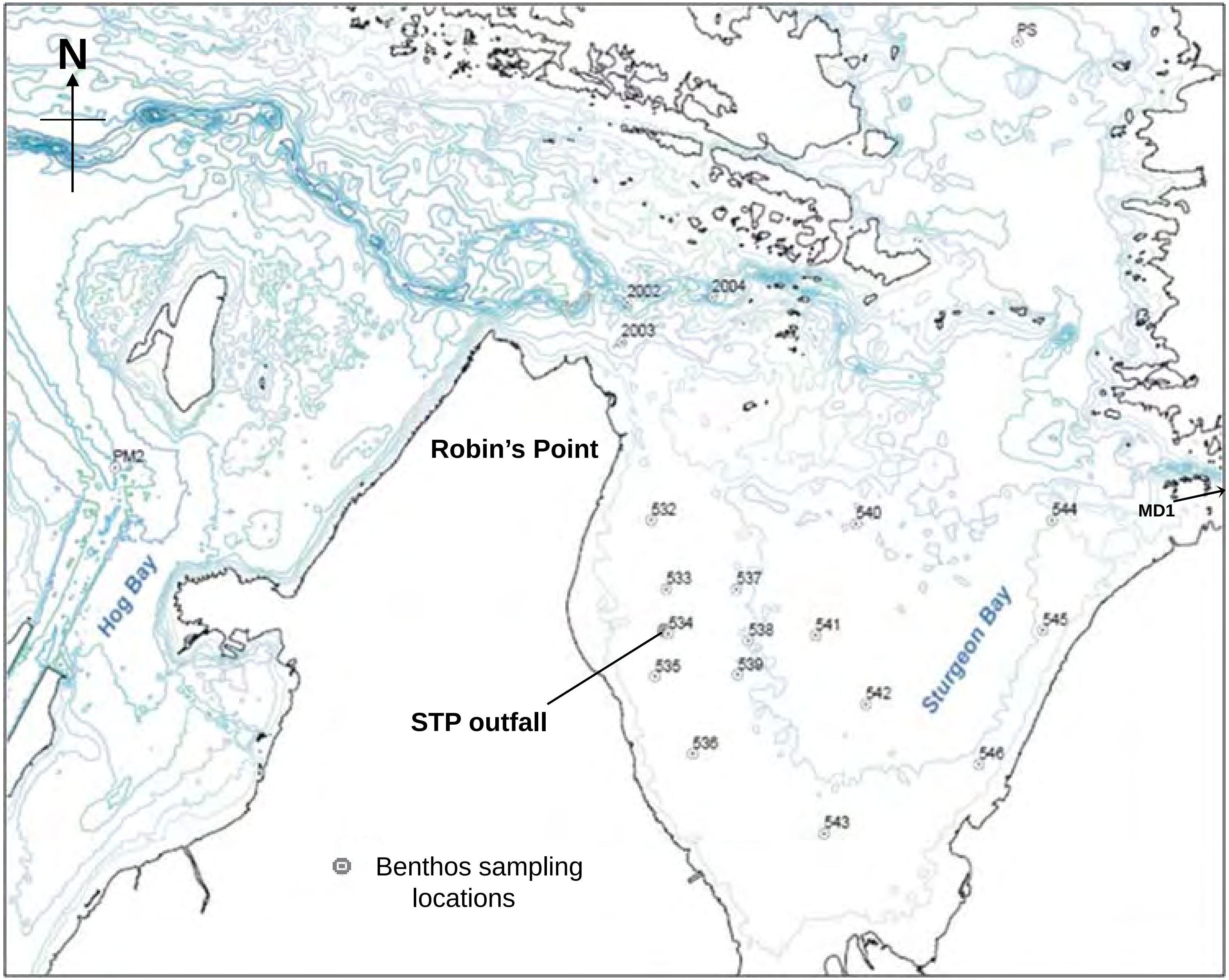


Figure 4. Water quality sampling locations, 2008. Also shown are long-term monitoring stations and locations with >10 years of continuous data.

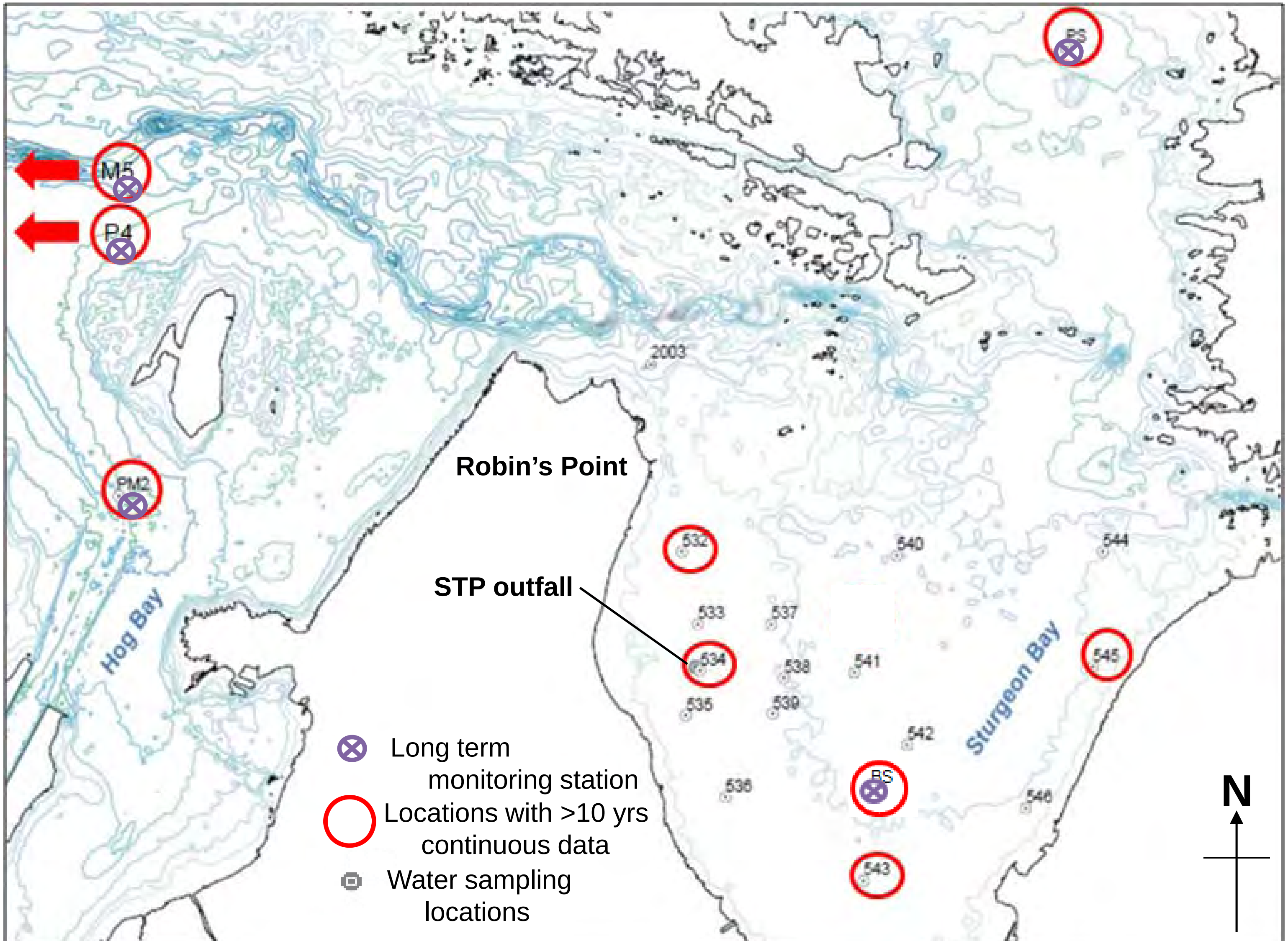
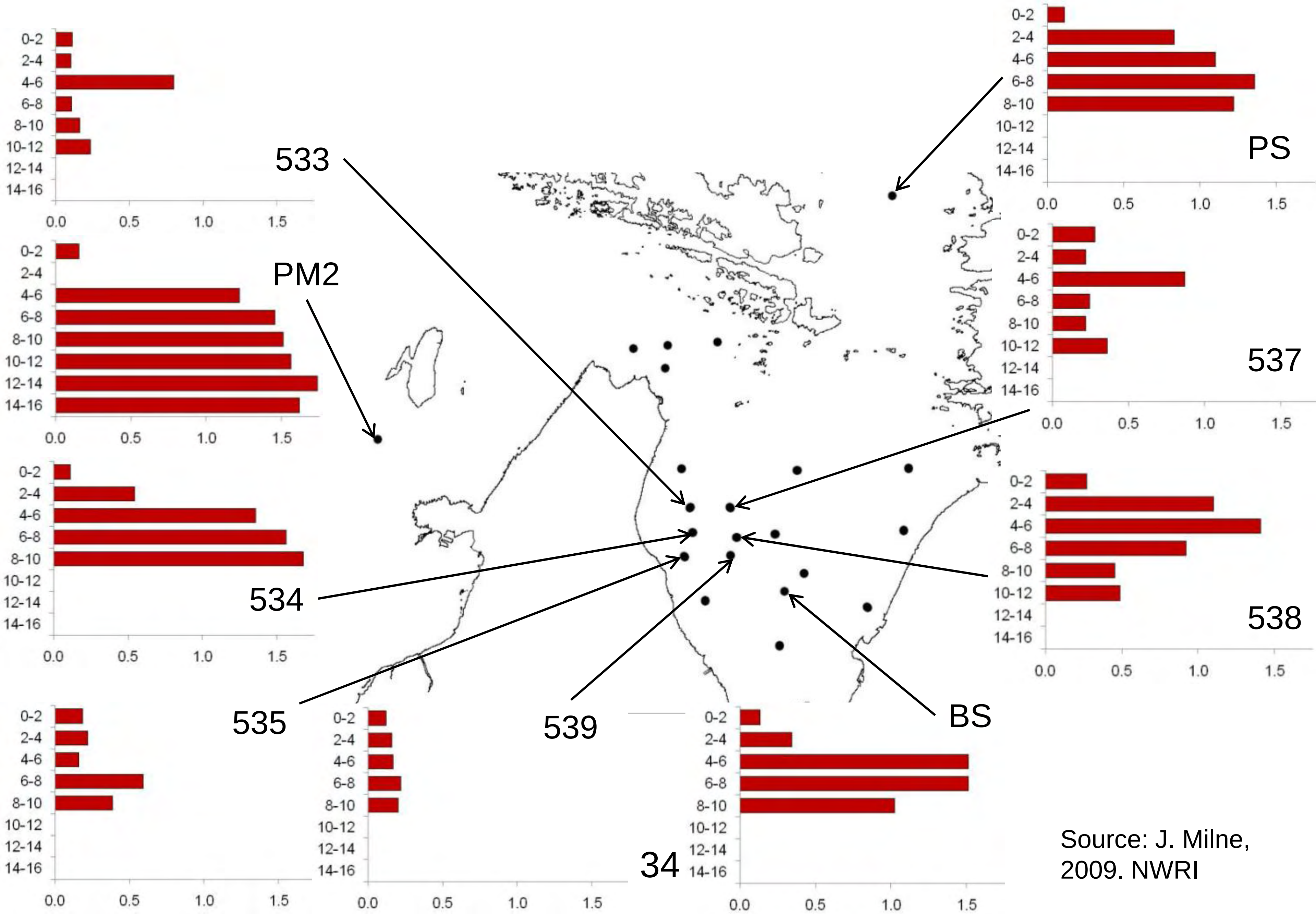
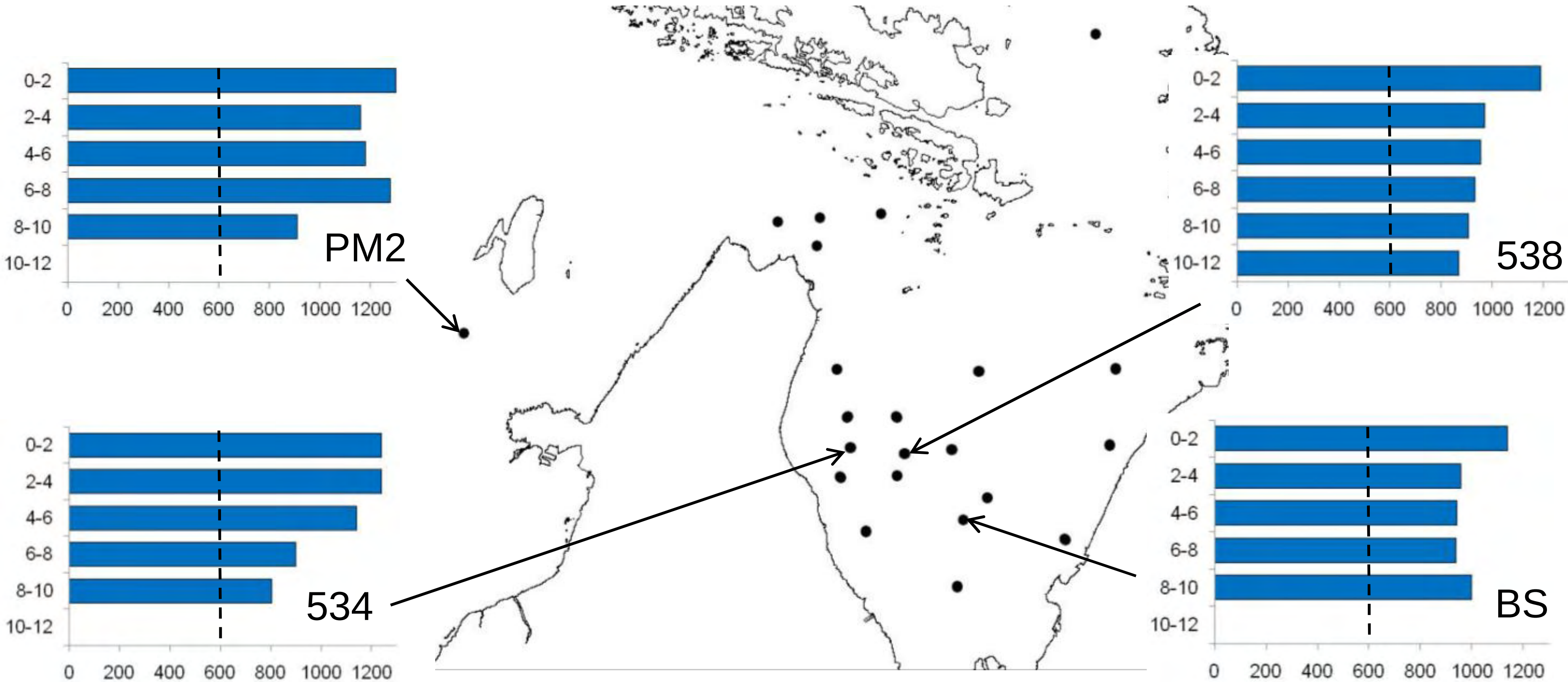


Figure 5. Pore water ammonia (mg/L) in 2 cm sections of sediment cores, 2008.



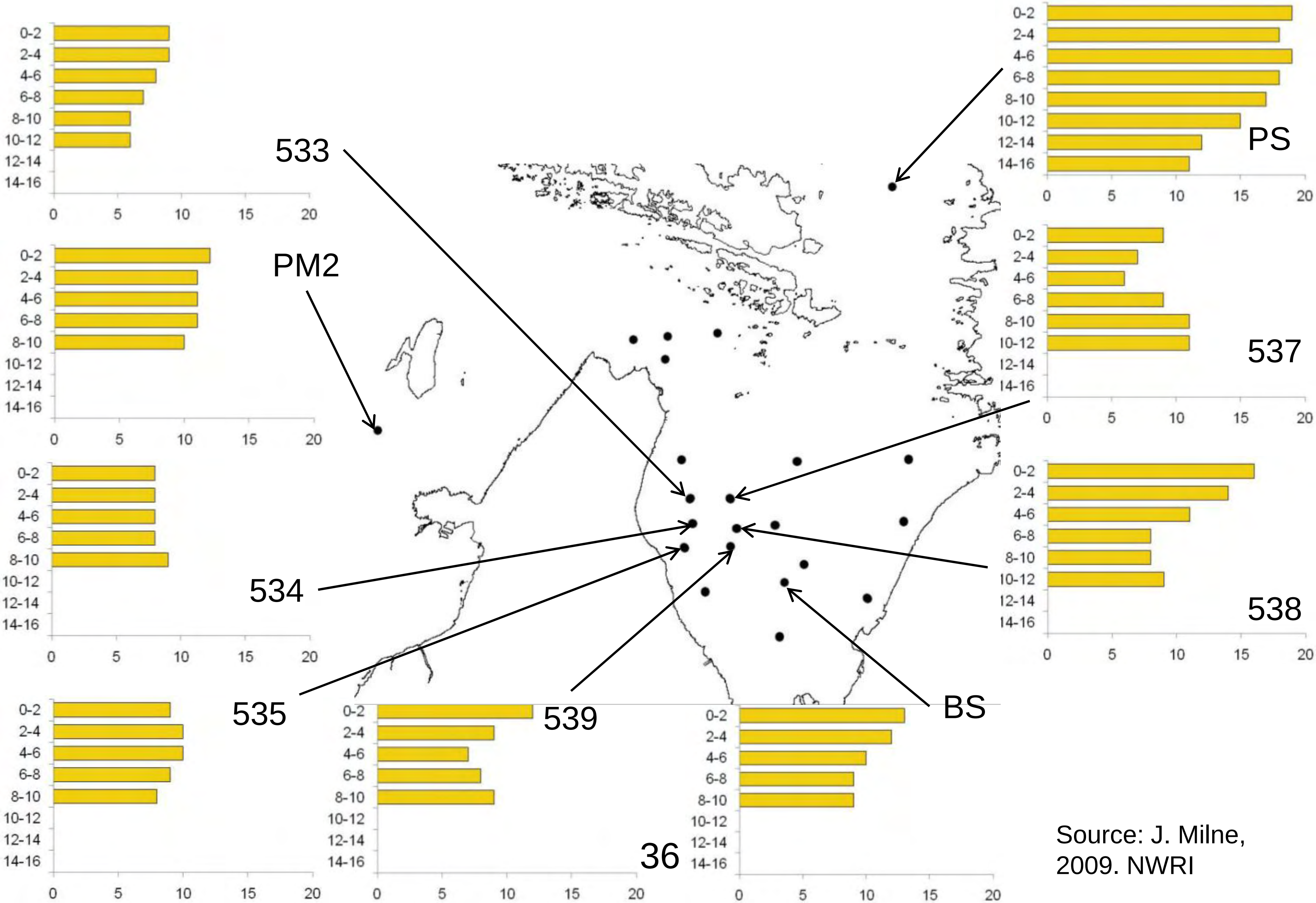
Source: J. Milne, 2009. NWRI

Figure 6. Total phosphorus (μg/g) in 2 cm sections of sediment cores, 2008. The lowest effects levels according to Provincial Sediment Quality Guidelines are represented by the dashed lines.



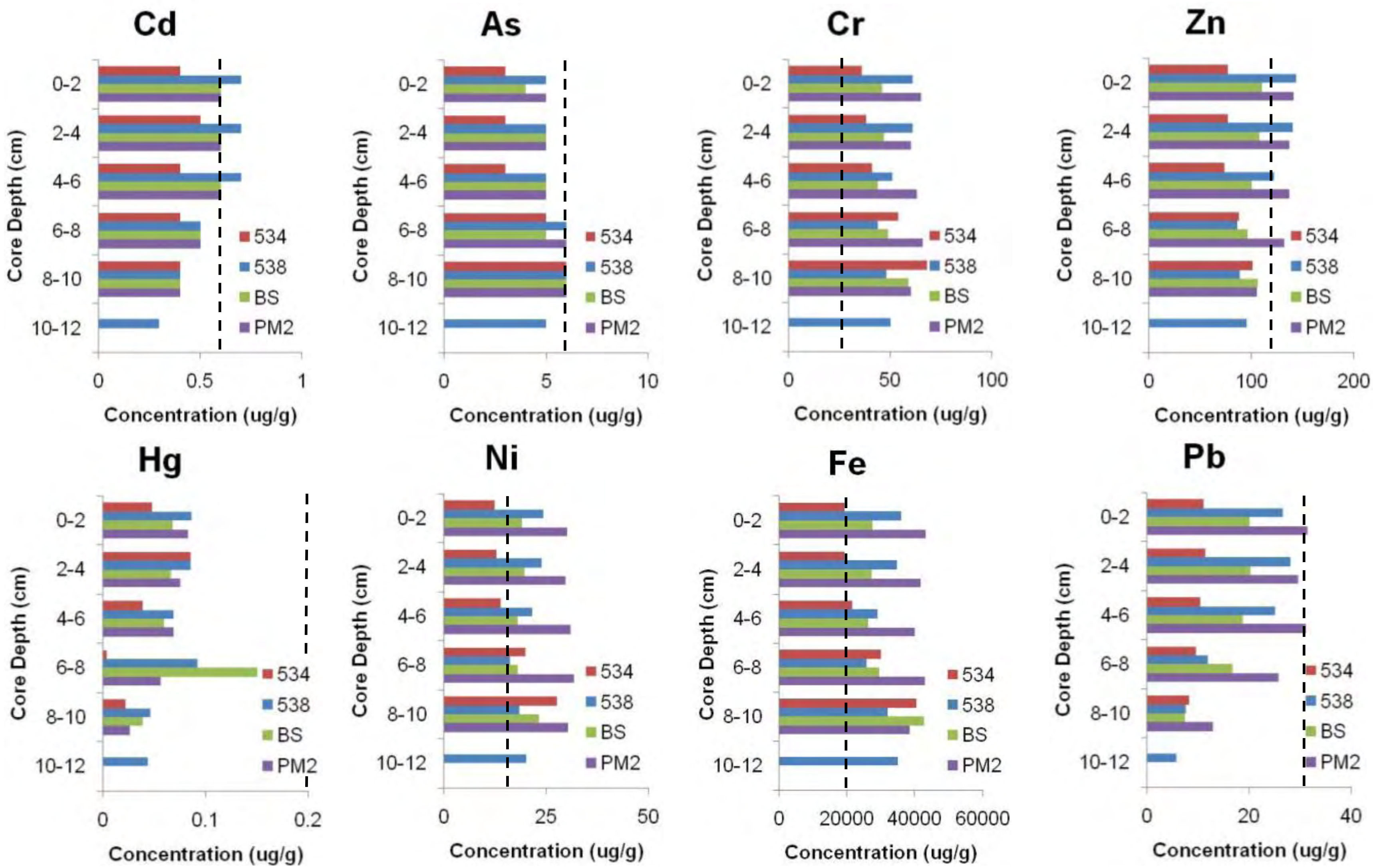
Source: J. Milne, 2009. NWRI

Figure 7. Loss on ignition (%) in 2 cm sections of sediment cores, 2008.



Source: J. Milne, 2009. NWRI

Figure 8. Metal concentrations (μg/g) in 2 cm sections of sediment cores at three sites in Sturgeon Bay and one in Hogg Bay, 2008. Dashed lines represent the Lowest Effect Level according to Provincial Sediment Quality Guidelines.



Source: J. Milne, 2009. NWRI

Figure 9. Surficial sediment total phosphorus (μg/g), 1980.

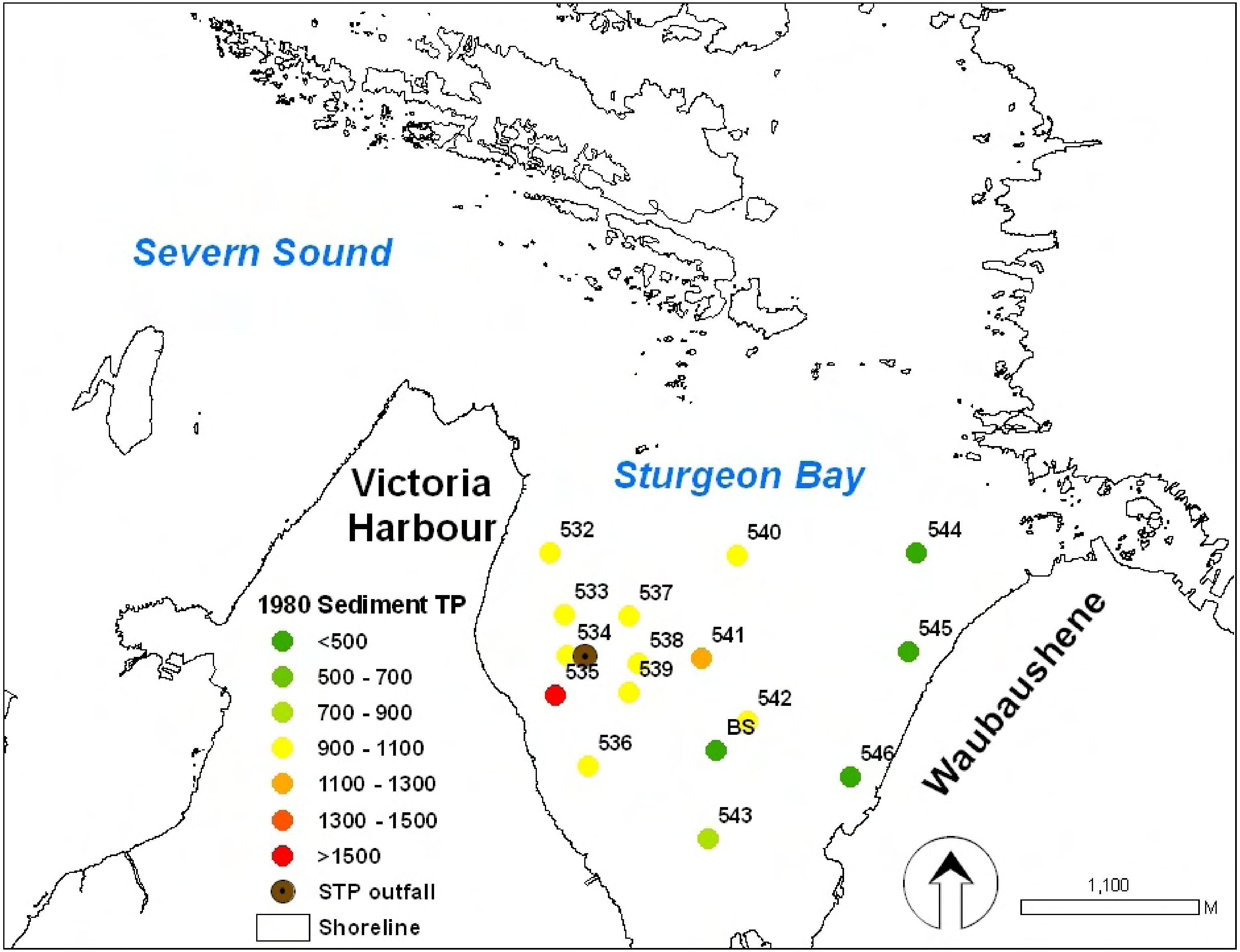


Figure 10. Surficial sediment total phosphorus (µg/g), 2008.

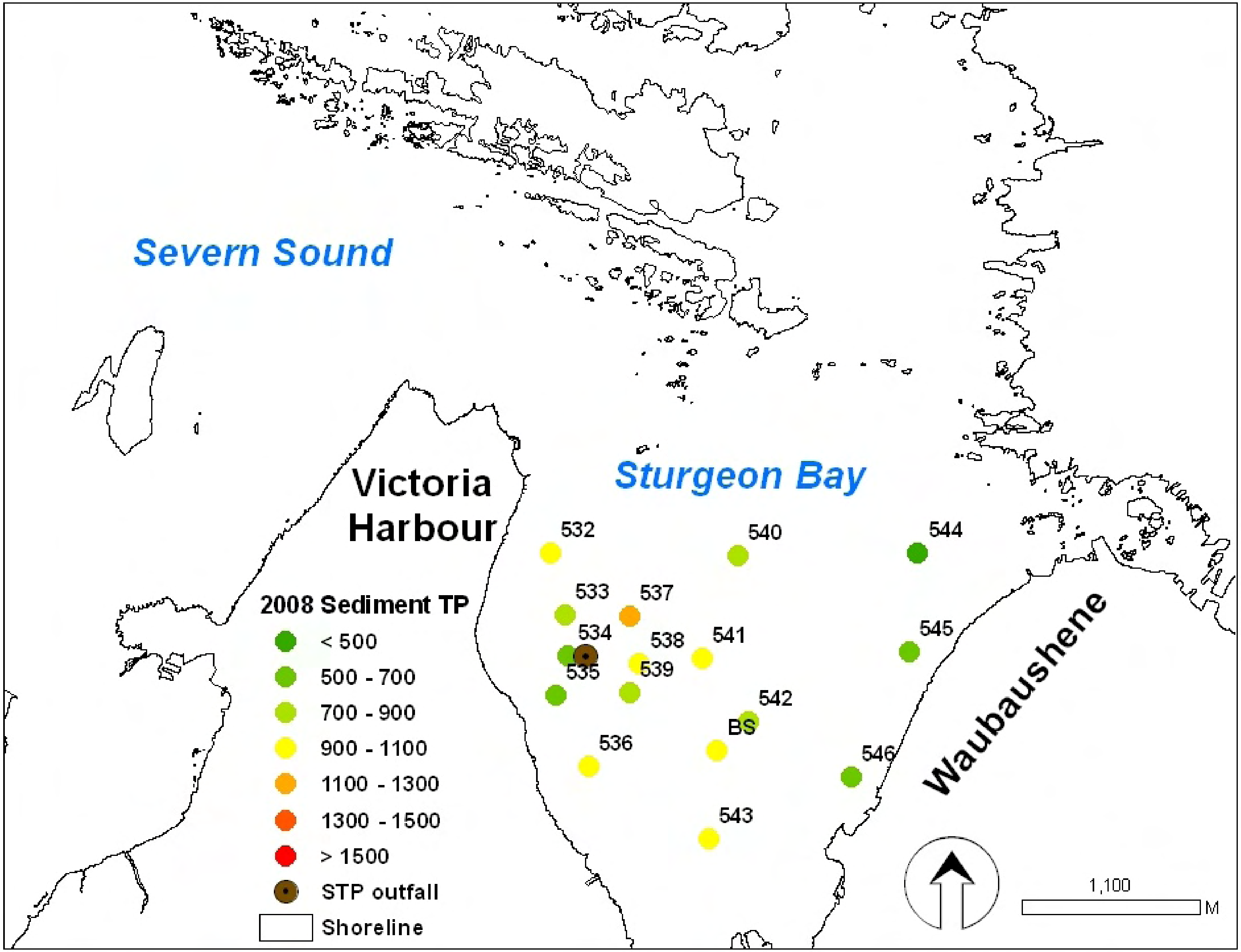
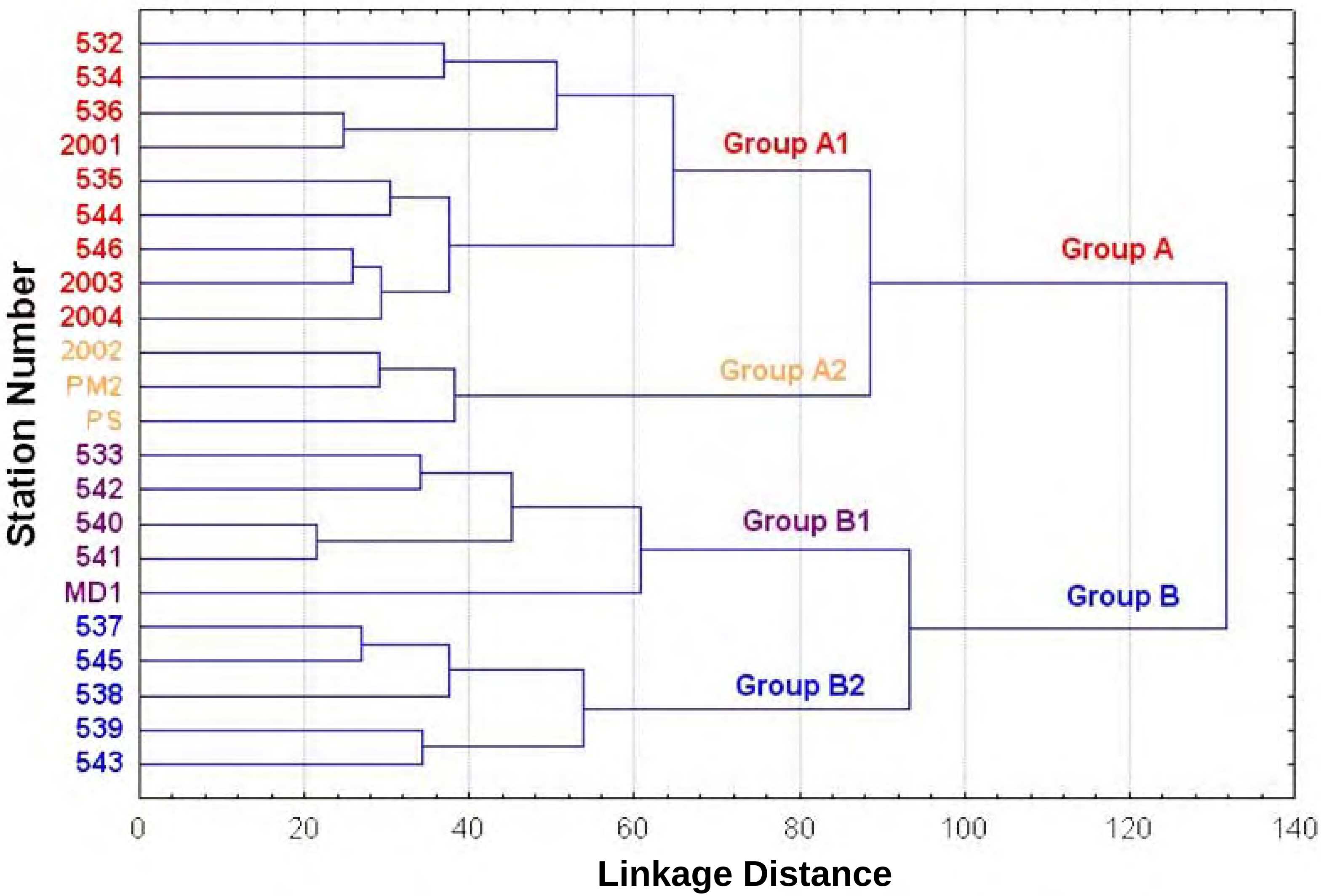
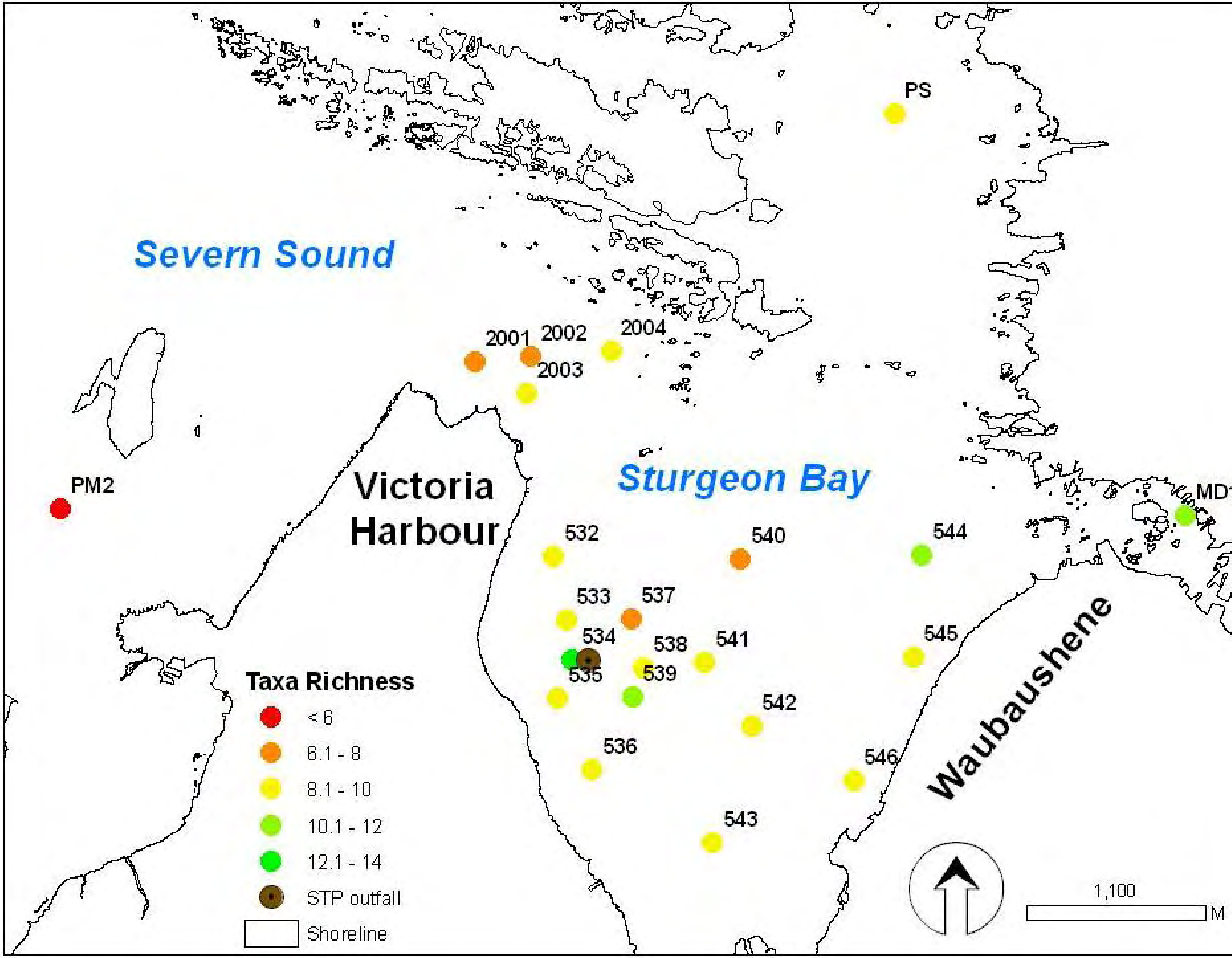


Figure 11. Cluster analysis of 2008 Sturgeon Bay benthic invertebrate sites using Ward's method (city block distances).



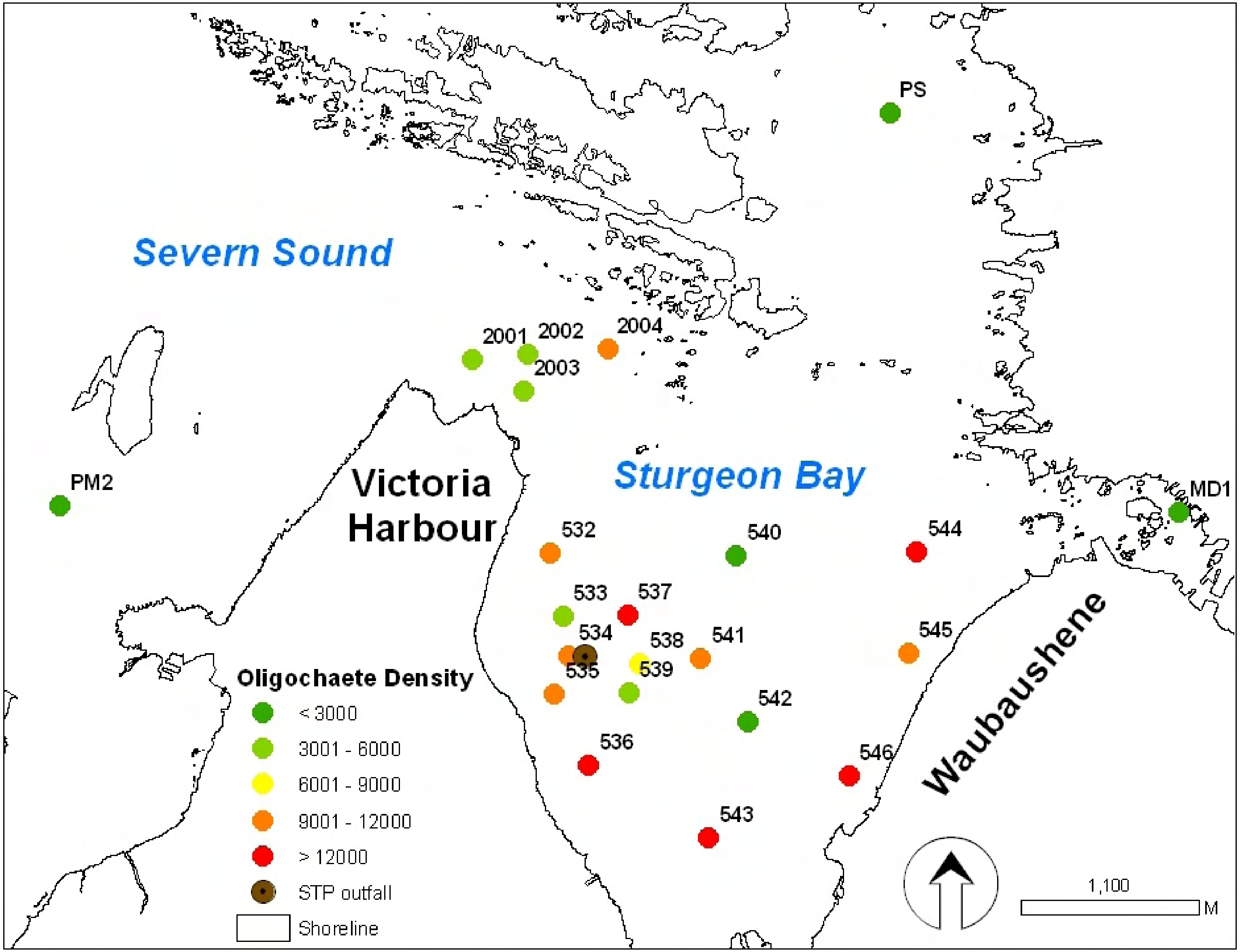
Source: J. Ciborowski, 2008.
University of Windsor

Figure 12. Mean taxa richness (*n*=3) for each benthic invertebrate station in August 2008.



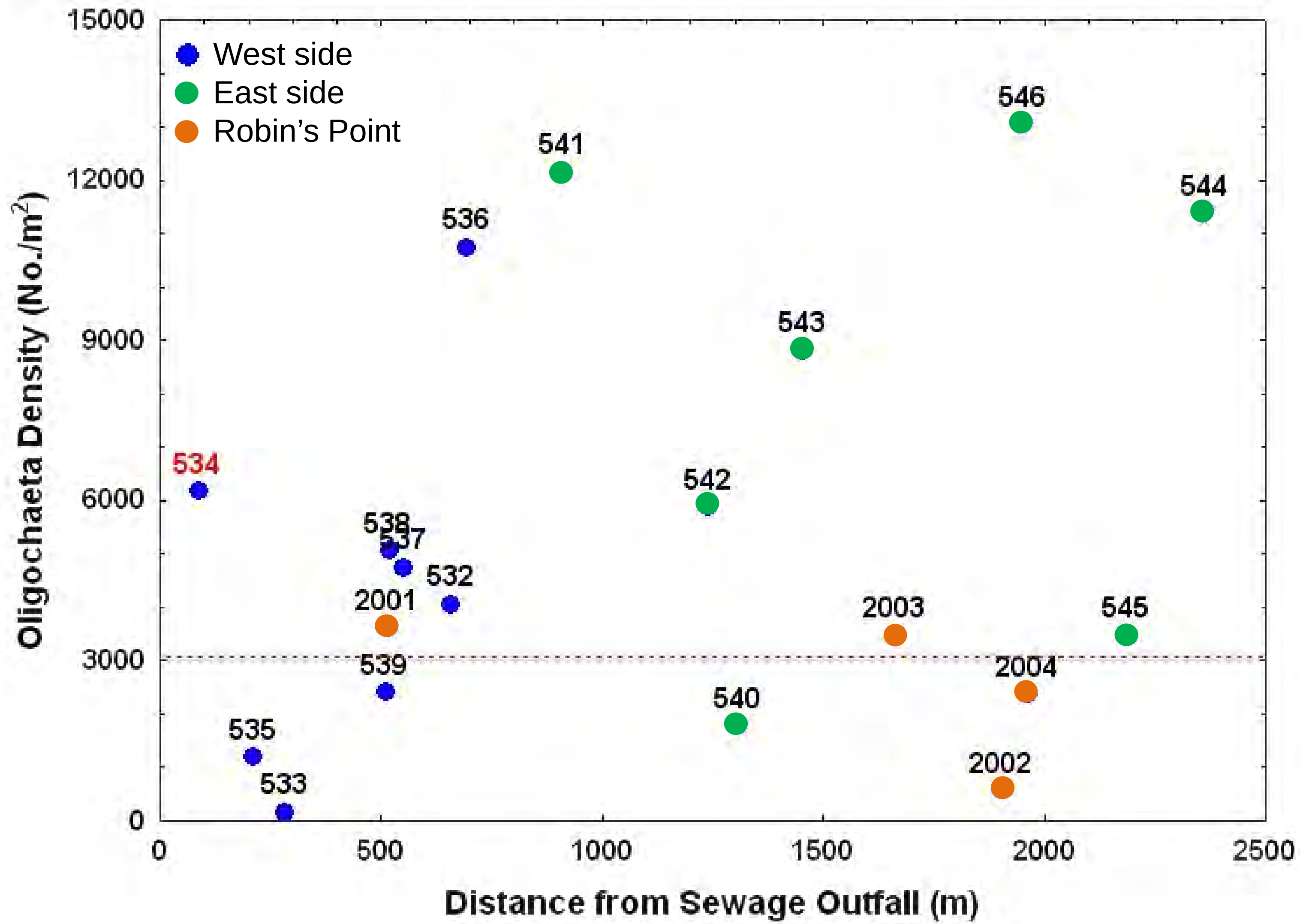
Source: J. Ciborowski, 2008.
University of Windsor

Figure 13. Oligochaete (worm) density (#/m^2) in Sturgeon Bay, August 2008.



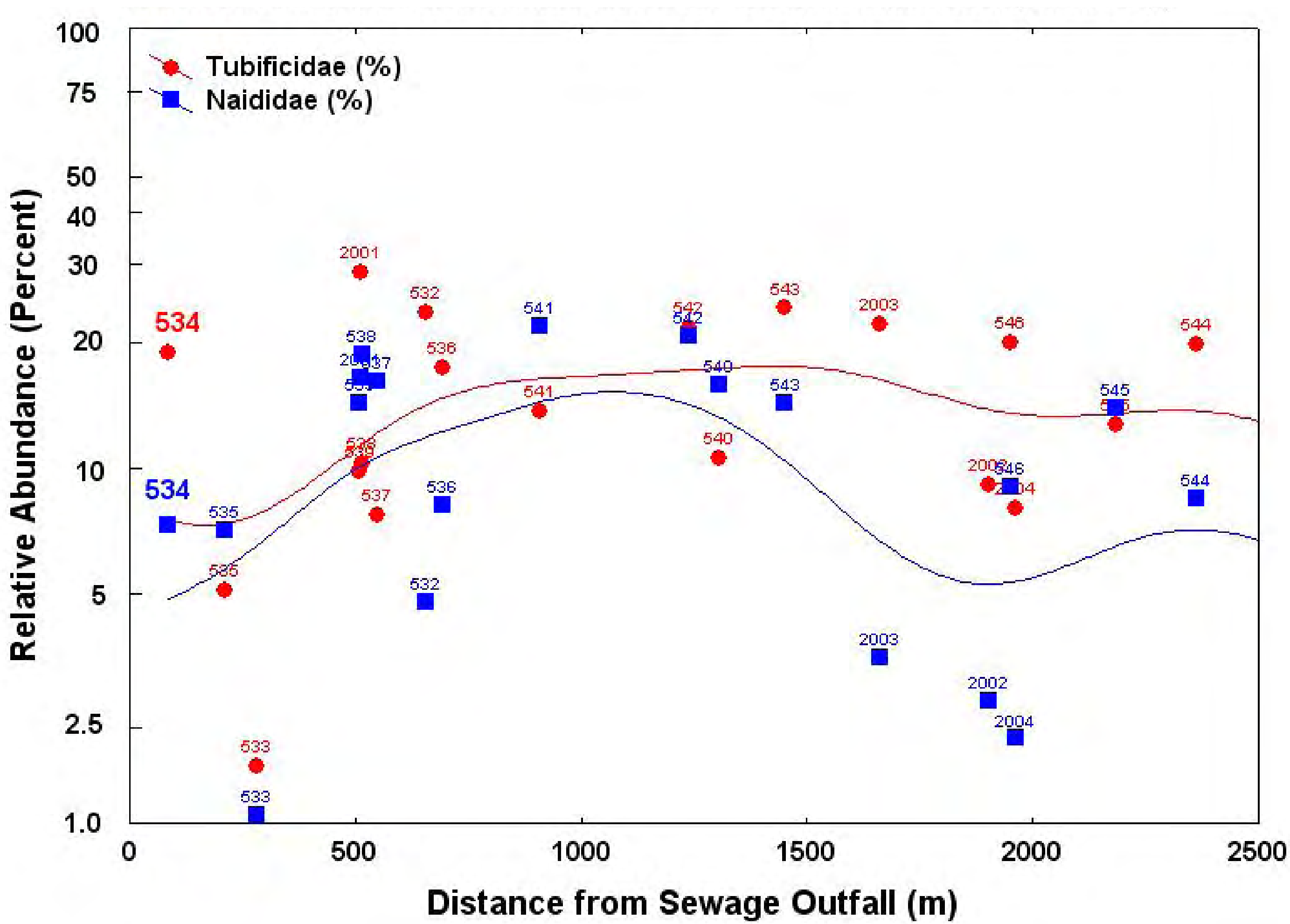
Source: J. Ciborowski, 2008.
University of Windsor

Figure 14. Densities of Oligochaeta (#/m^2) at sites versus distance from the sewage outfall. No significant correlation was found. Densities >3000/m^2 (dashed line) suggest eutrophic conditions.



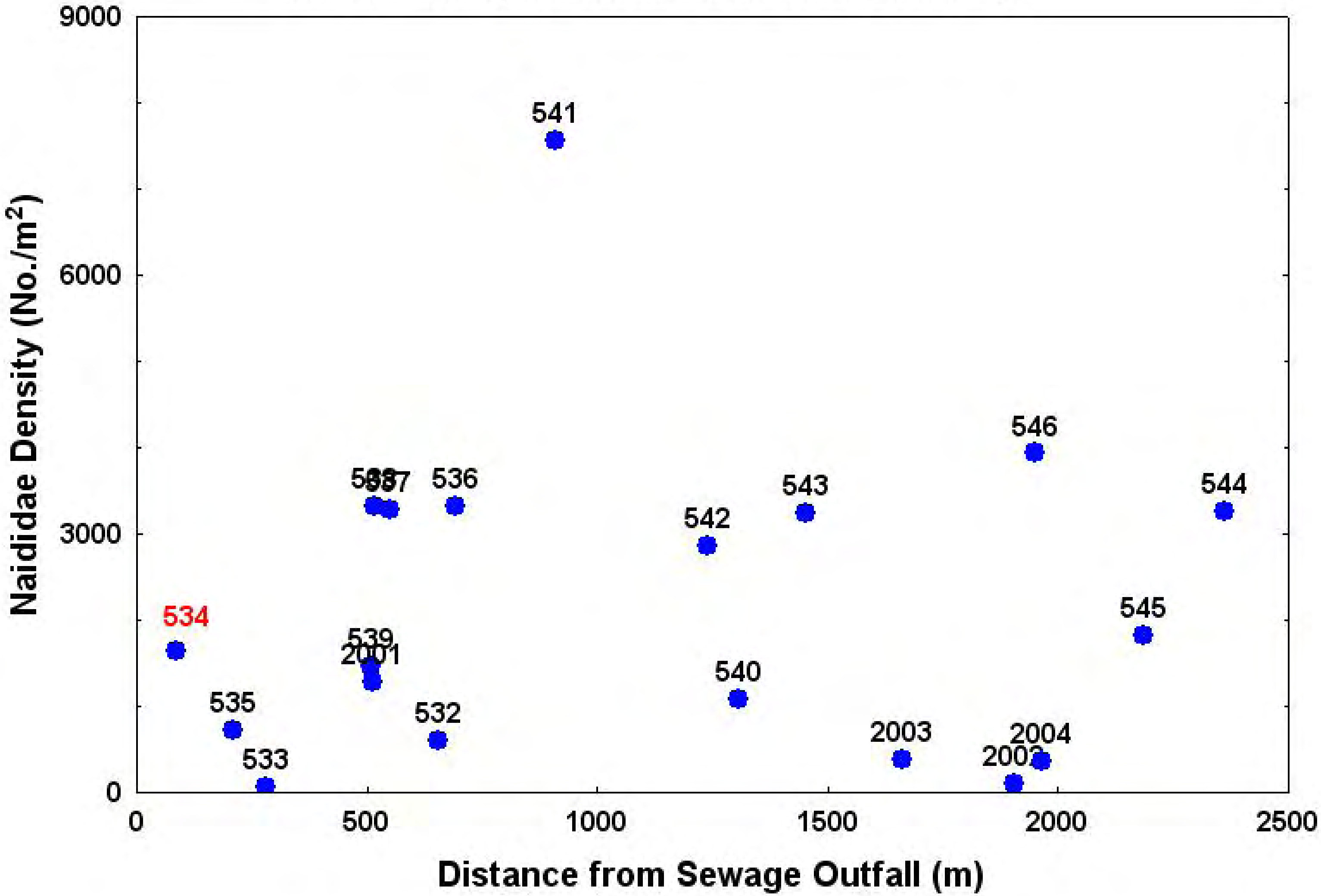
Source: J. Ciborowski, 2008.
University of Windsor

Figure 15. Relative abundances of Tubificidae and Naididae sludge worms (% - note log scale) with distance from the sewage outfall (m). No significant correlation was found. Tubificids were more abundant than naidids at most sites, indicating moderate eutrophication.



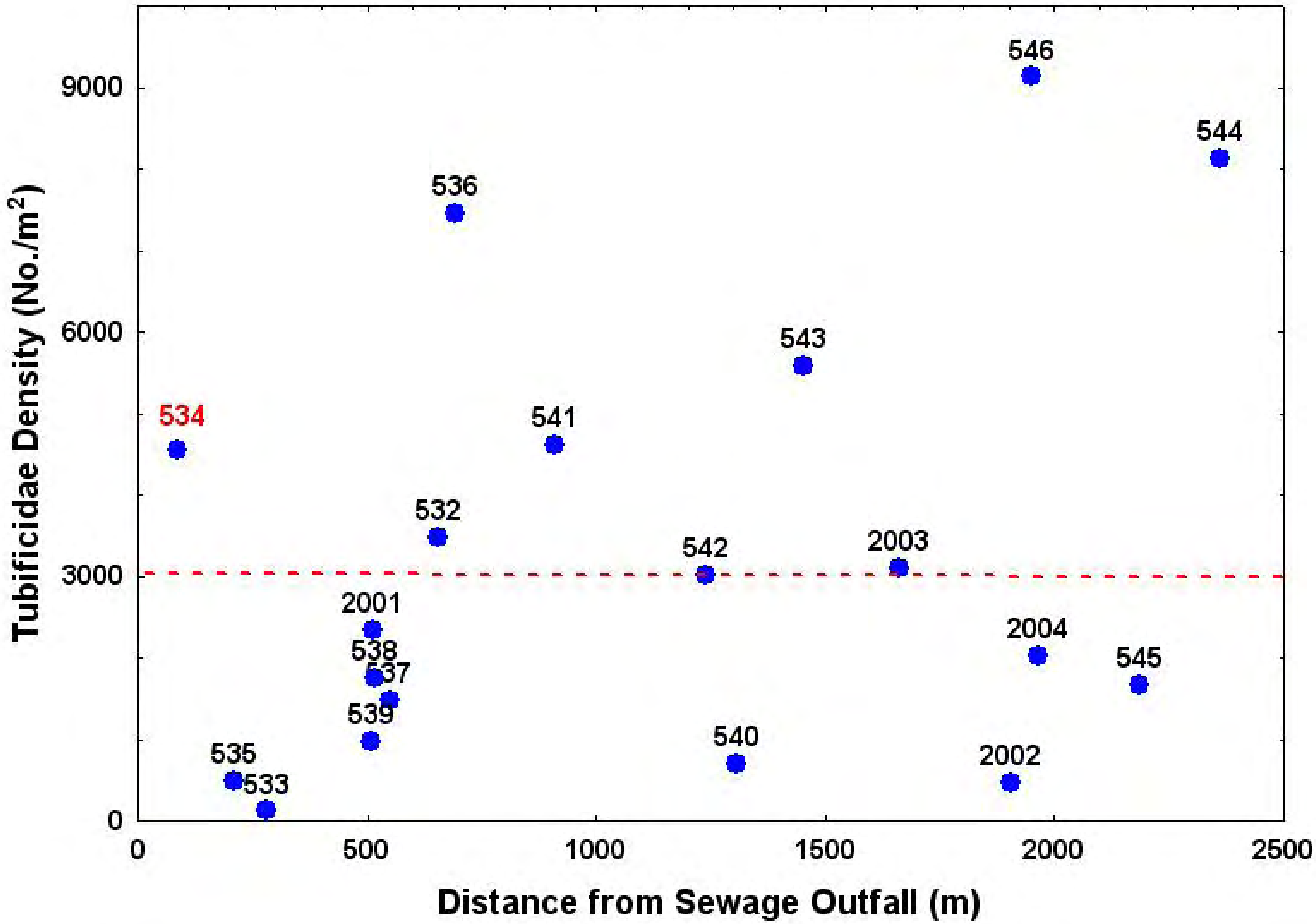
Source: J. Ciborowski, 2008.
University of Windsor

Figure 16. Densities of Naididae (sludge worms) ($No./m^2$) with distance from the sewage outfall (m). No significant correlation was found.



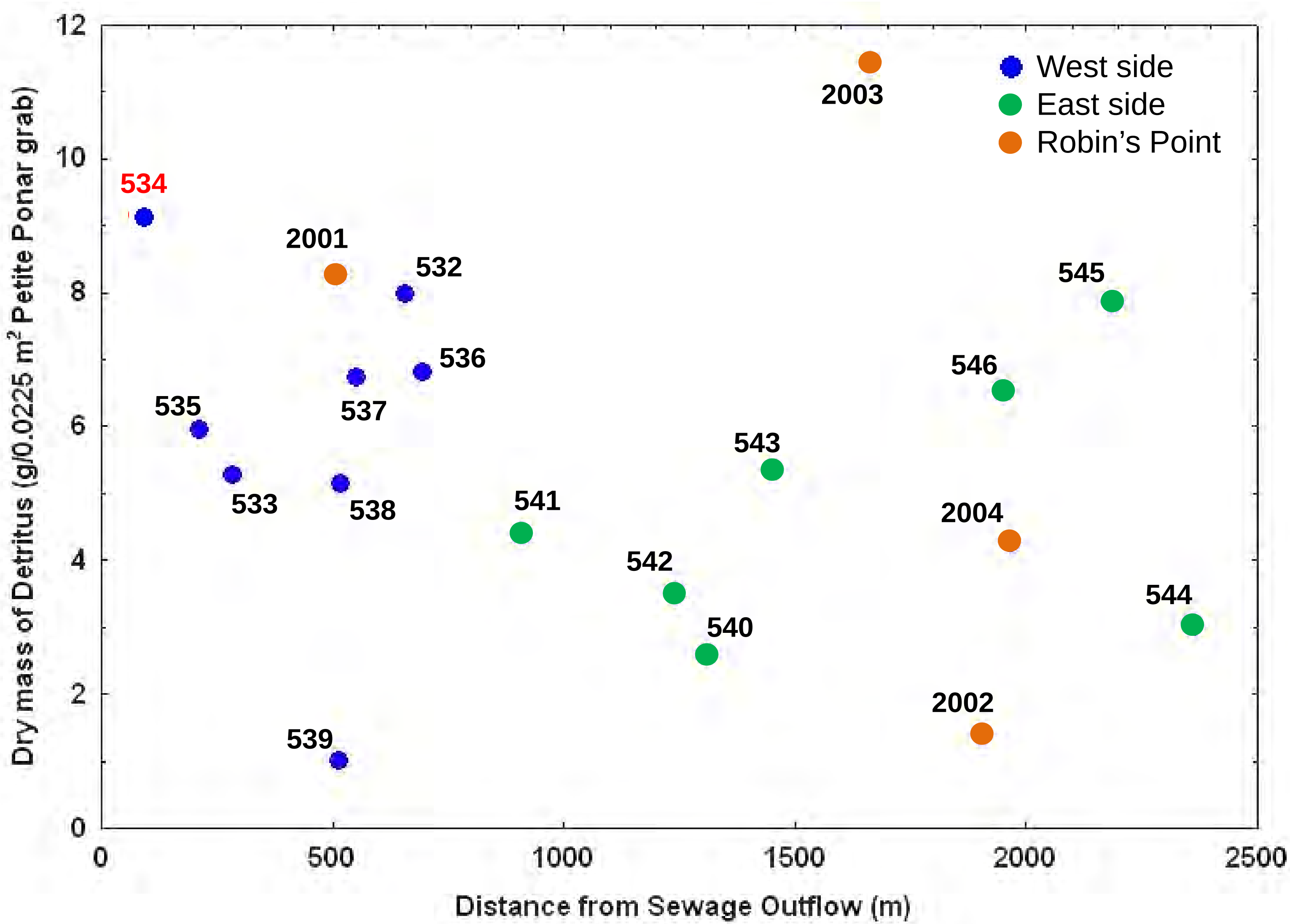
Source: J. Ciborowski, 2008.
University of Windsor

Figure 17. Densities of Tubificidae (sludge worms) (No./m^2) with distance from the sewage outfall (m). No significant correlation was found. Densities suggest that many sites (densities >3000/m^2) are moderately eutrophic.



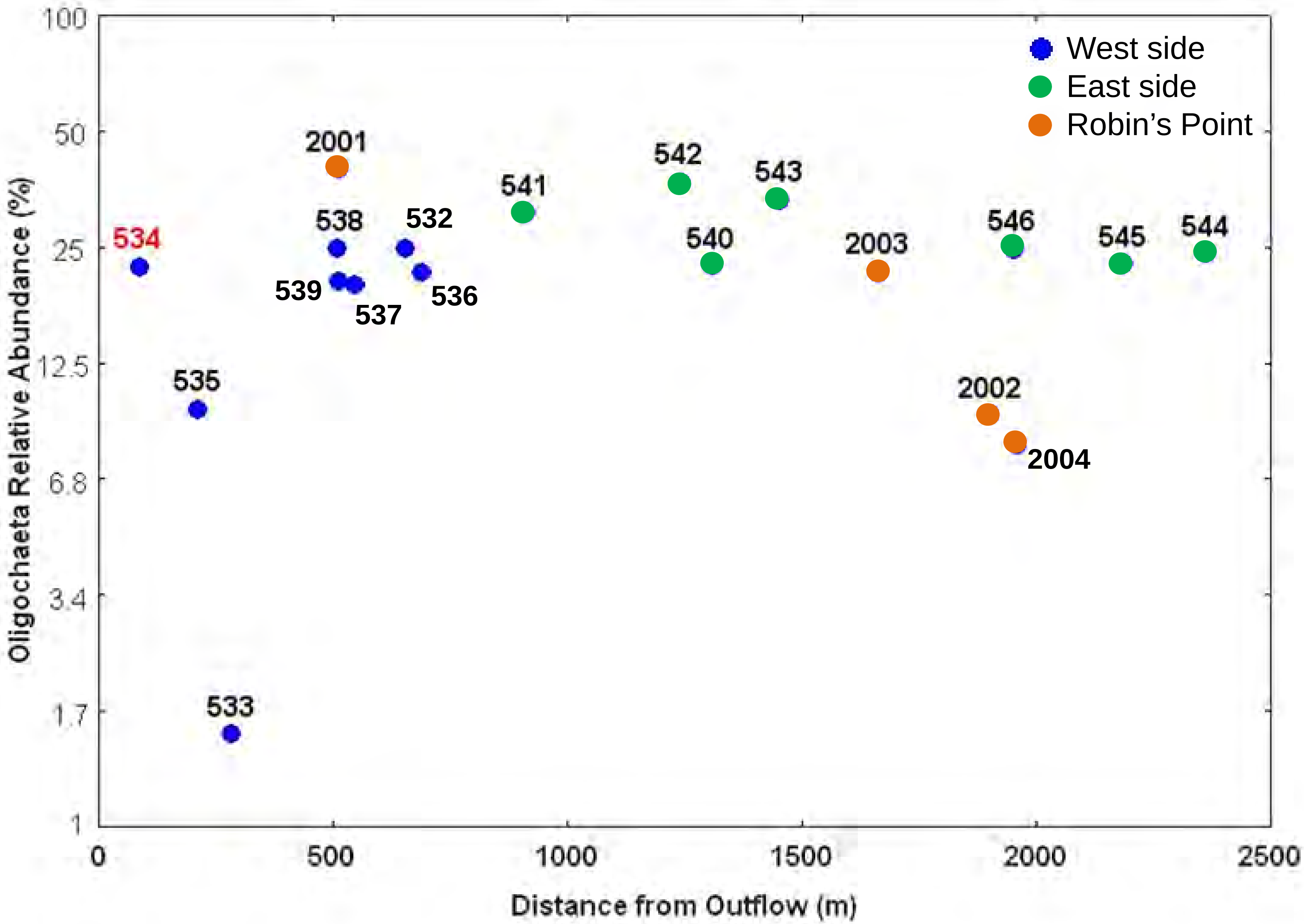
Source: J. Ciborowski, 2008.
University of Windsor

Figure 18. Dry mass of detritus ($g/0.0225m^2$) versus distance (m) from sewage outflow. No significant correlation was found.



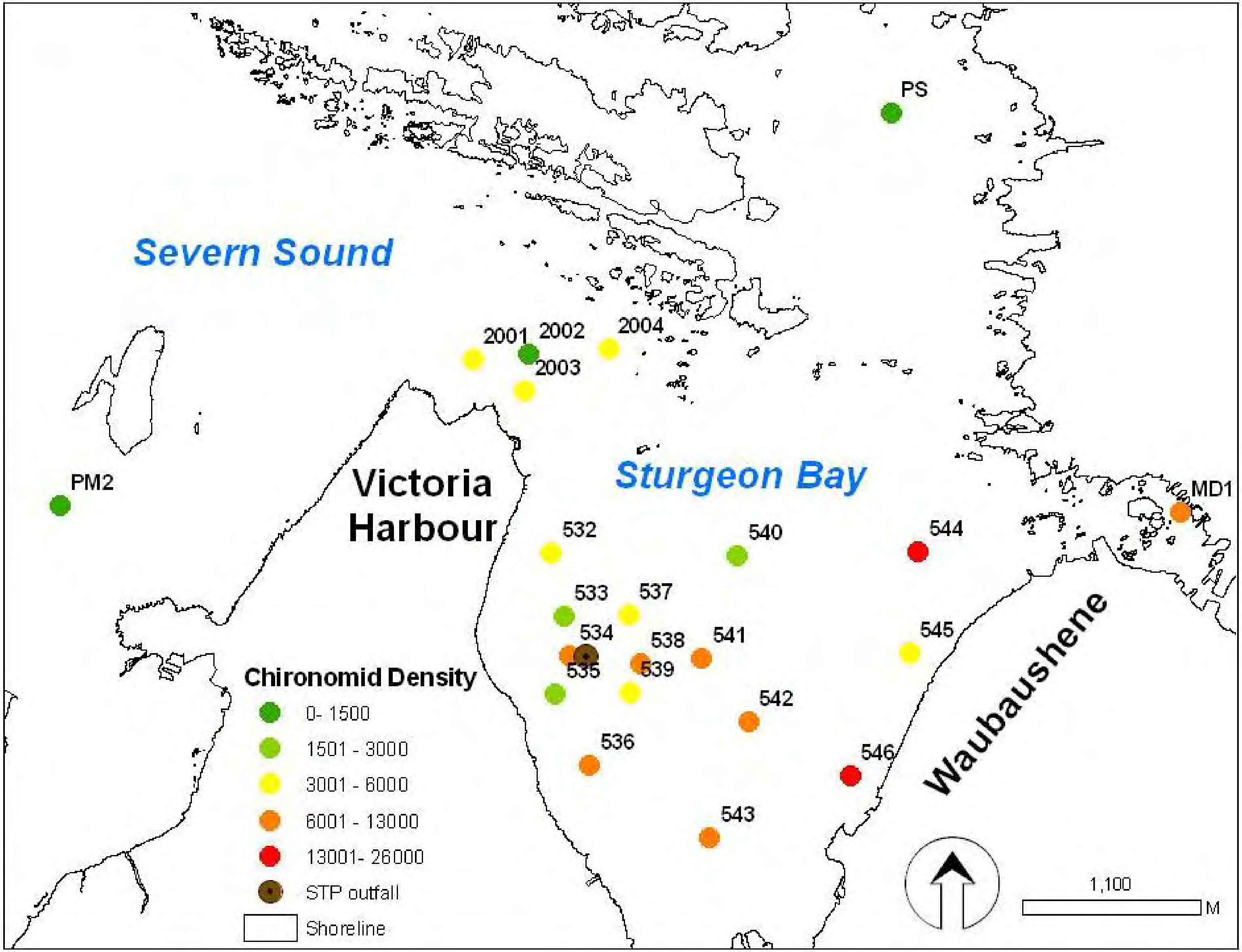
Source: J. Ciborowski, 2008.
University of Windsor

Figure 19. Relative abundances of Oligochaeta (%) with distance from the sewage outfall (m). No significant correlation was found.



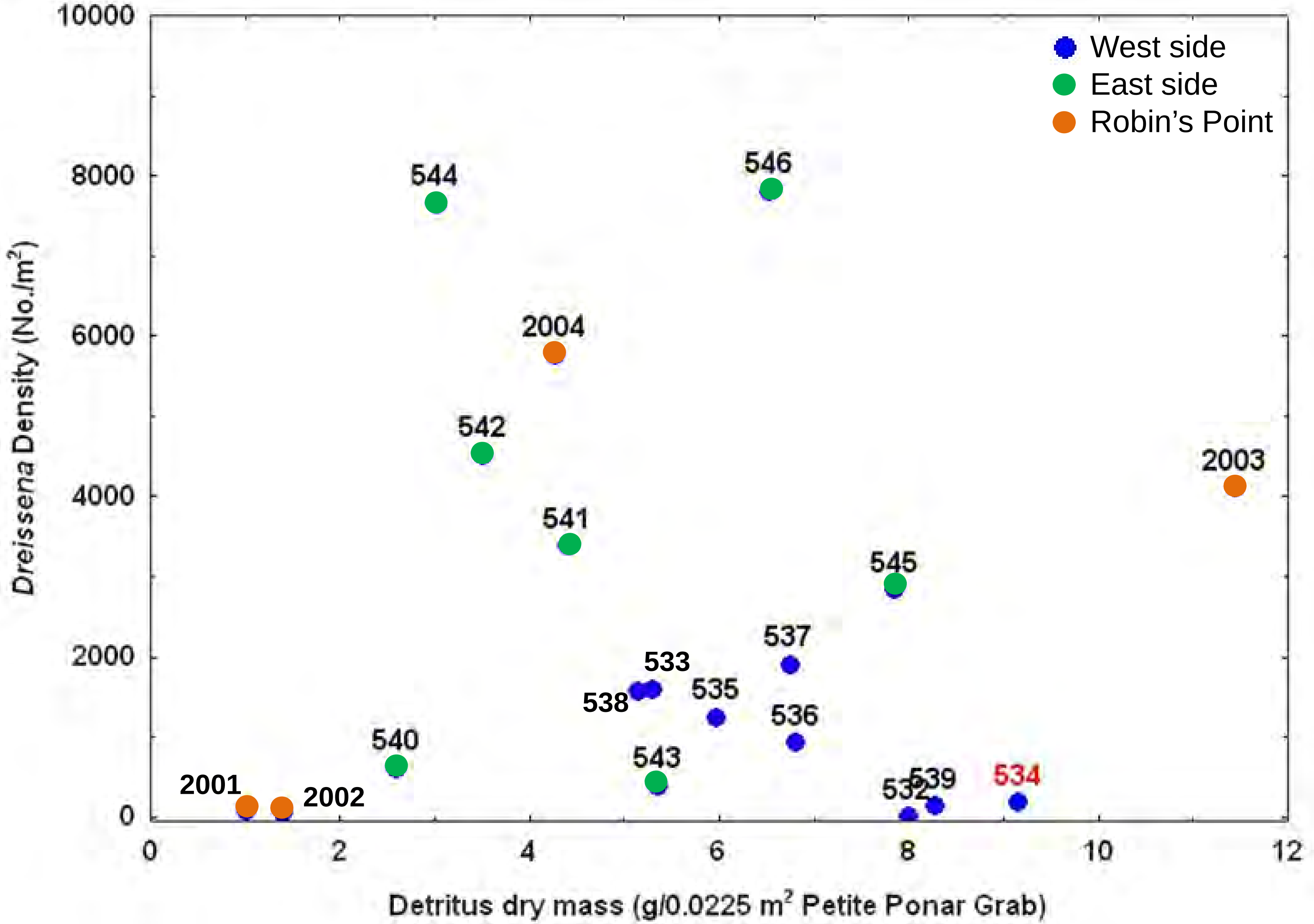
Source: J. Ciborowski, 2008.
University of Windsor

Figure 20. Chironomid density (#/m^2) in Sturgeon Bay, August 2008.



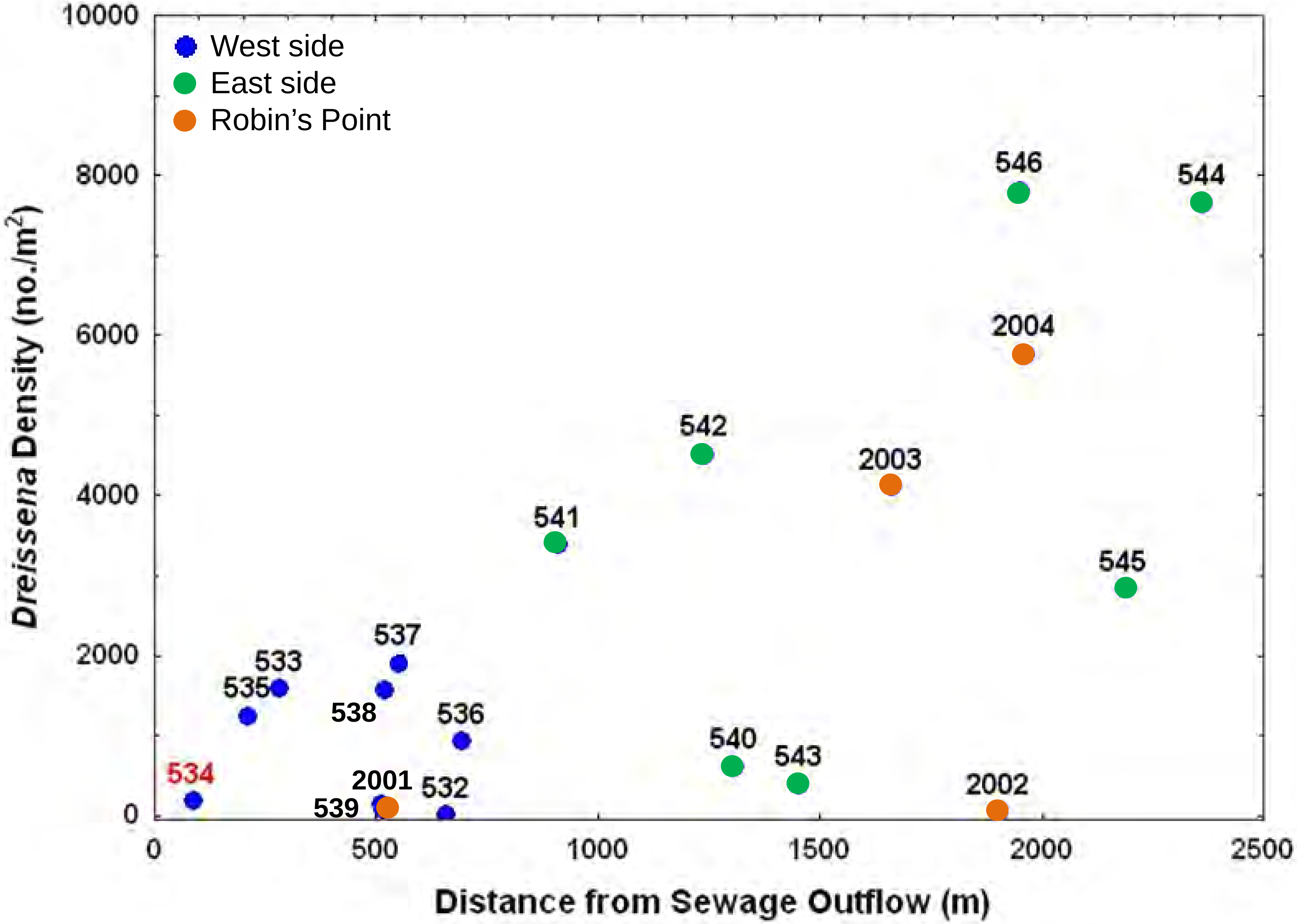
Source: J. Ciborowski, 2008.
University of Windsor

Figure 21. Densities of *Dreissena* (#/m^2) versus the dry mass of detritus (g/0.0225 m^2) at sites in Sturgeon Bay. No significant correlation was found.



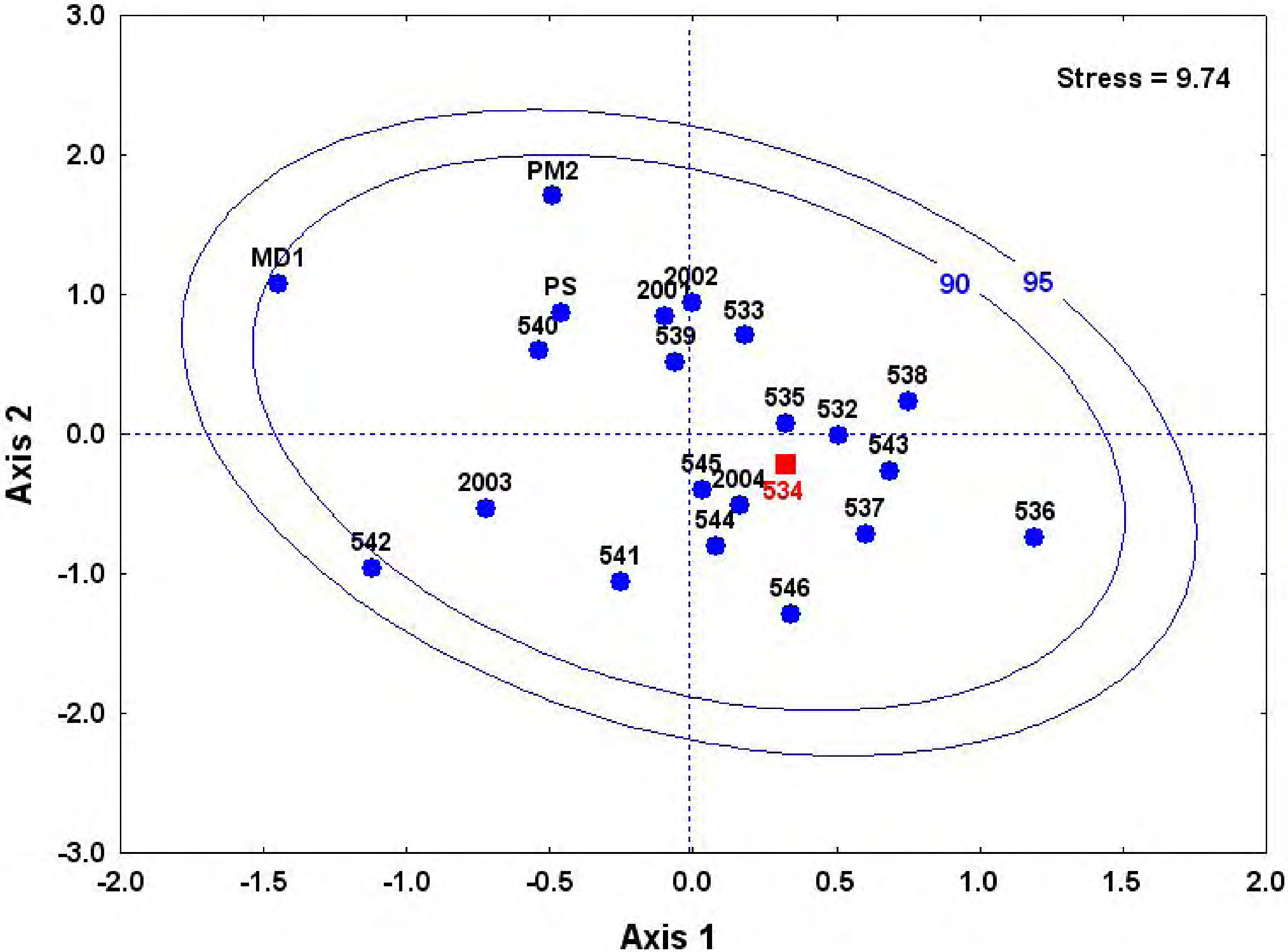
Source: J. Ciborowski, 2008.
University of Windsor

Figure 22. Densities of *Dreissena* (#/m^2) versus distance from sewage outfall (m).



Source: J. Ciborowski, 2008.
University of Windsor

Figure 23. NMS ordination showing benthic community comparison of Sturgeon Bay and vicinity (2008) with the Great Lakes reference community (represented by the 90% and 95% confidence ellipses). Points outside the ellipses are increasingly different from the reference community.



Source: J. Ciborowski, 2008.
University of Windsor

Figure 24. Daily temperature (°C) from drinking water intakes in Hogg and Sturgeon Bay, 2006-2010. Trends in mean summer and winter temperatures are also shown.

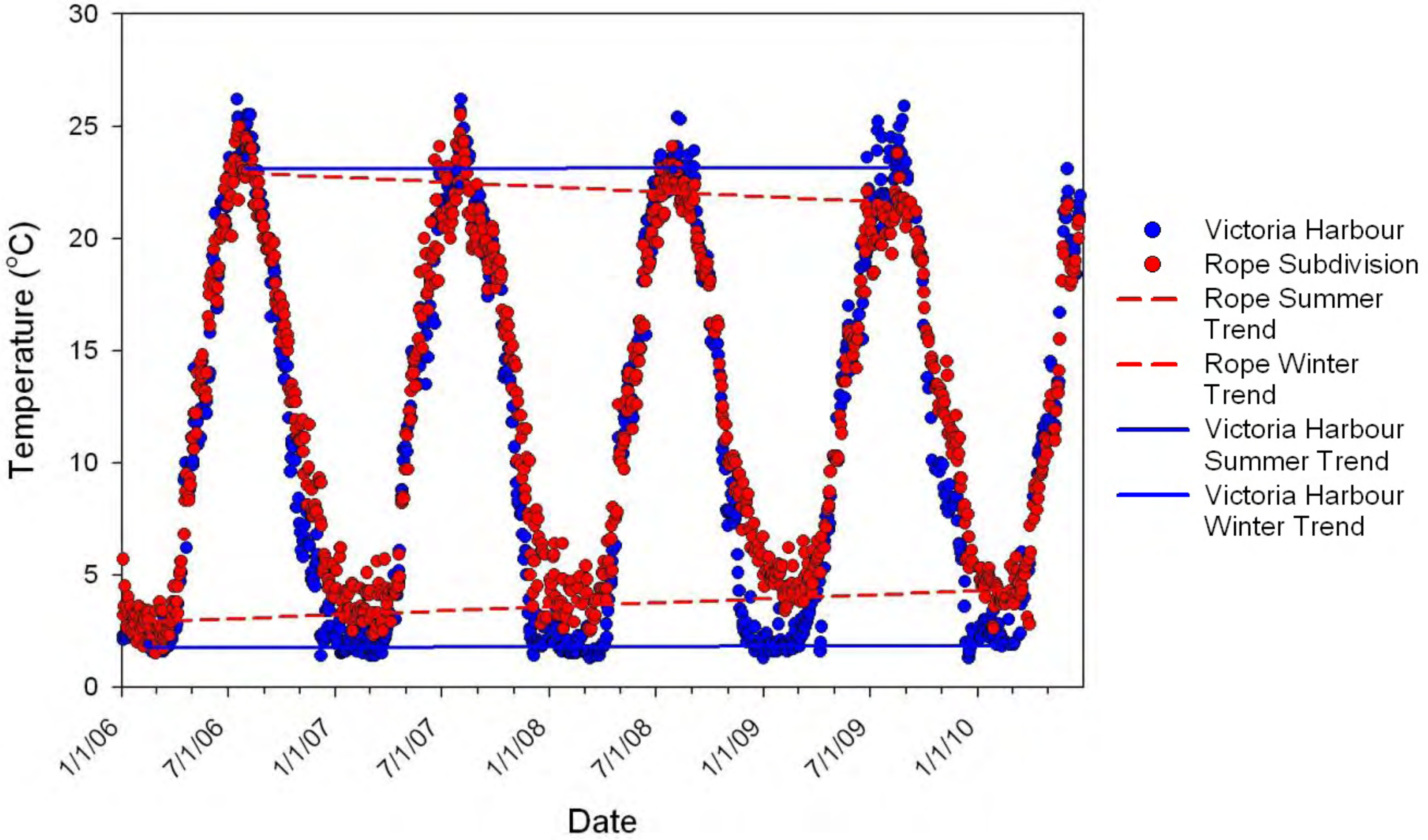


Figure 25. Long term trends in mean annual euphotic zone TP of Sturgeon Bay (BS), Hogg Bay (PM2), and open Severn Sound (P4), 1969 -2008.

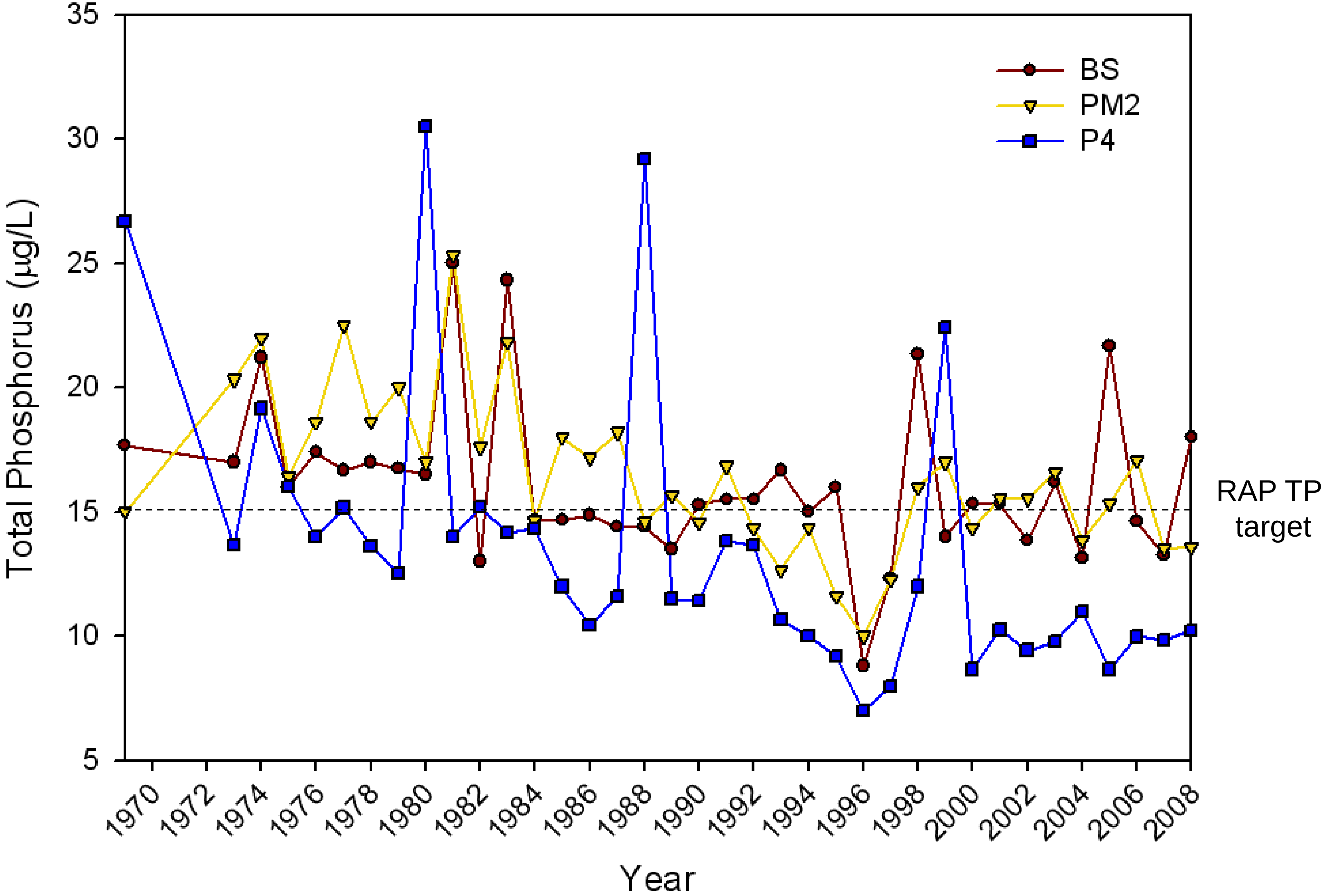


Figure 26. Comparison of mean TP (+ 95% confidence limits) at 3 long term stations, among four time periods. These correspond to pre-WWTP commissioning ('69-'84), post-WWTP and pre-zebra mussel establishment ('85-'94), post-zebra mussel and high water levels ('95-'99) and low water levels ('00-'08).

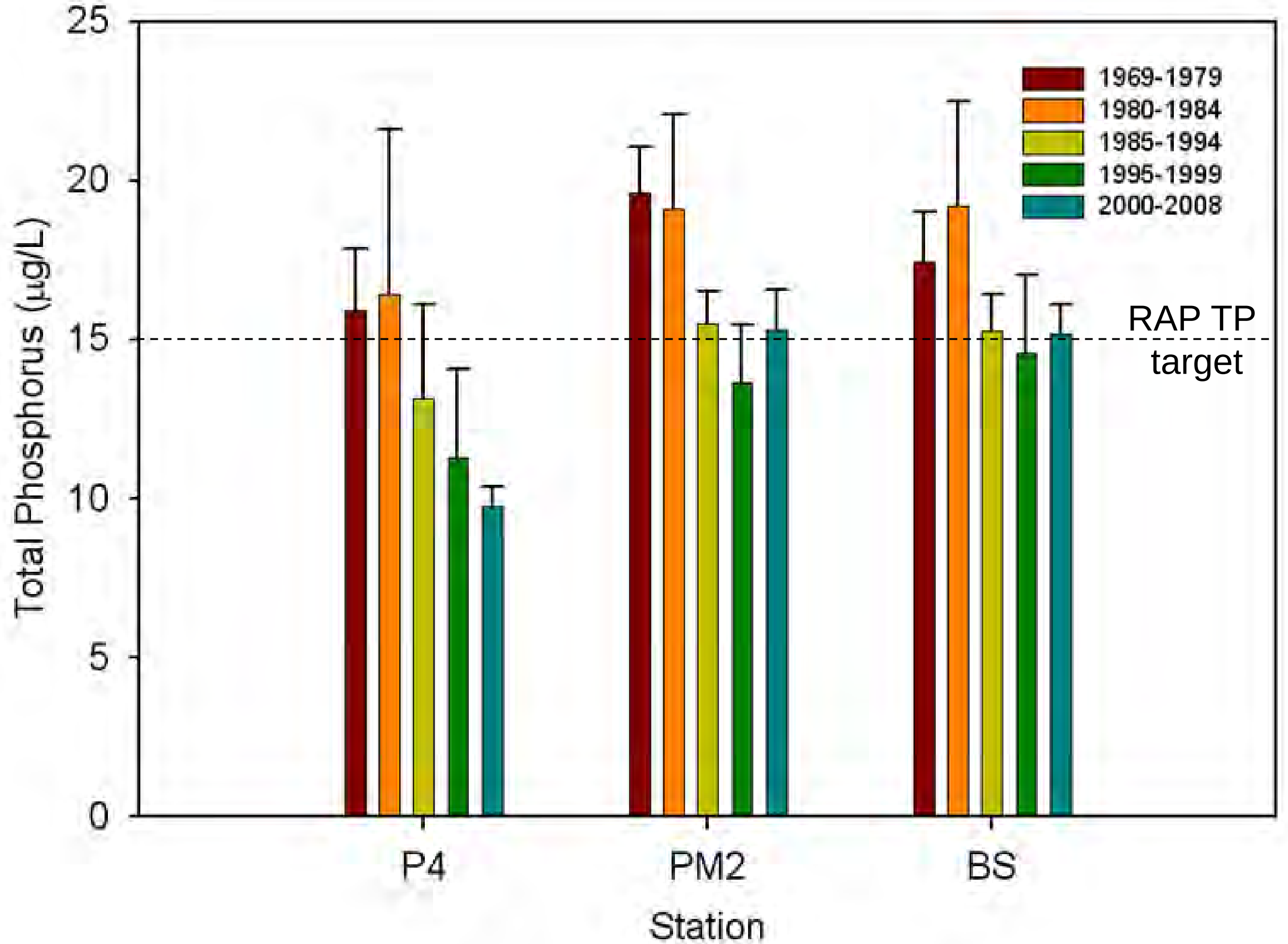


Figure 27. Comparison of mean summer TP (+ 95% confidence limits) at five stations within Sturgeon Bay among three time periods. These correspond to pre-WWTP commissioning, post-WWTP commissioning and pre-zebra mussel establishment, and post-zebra mussels.

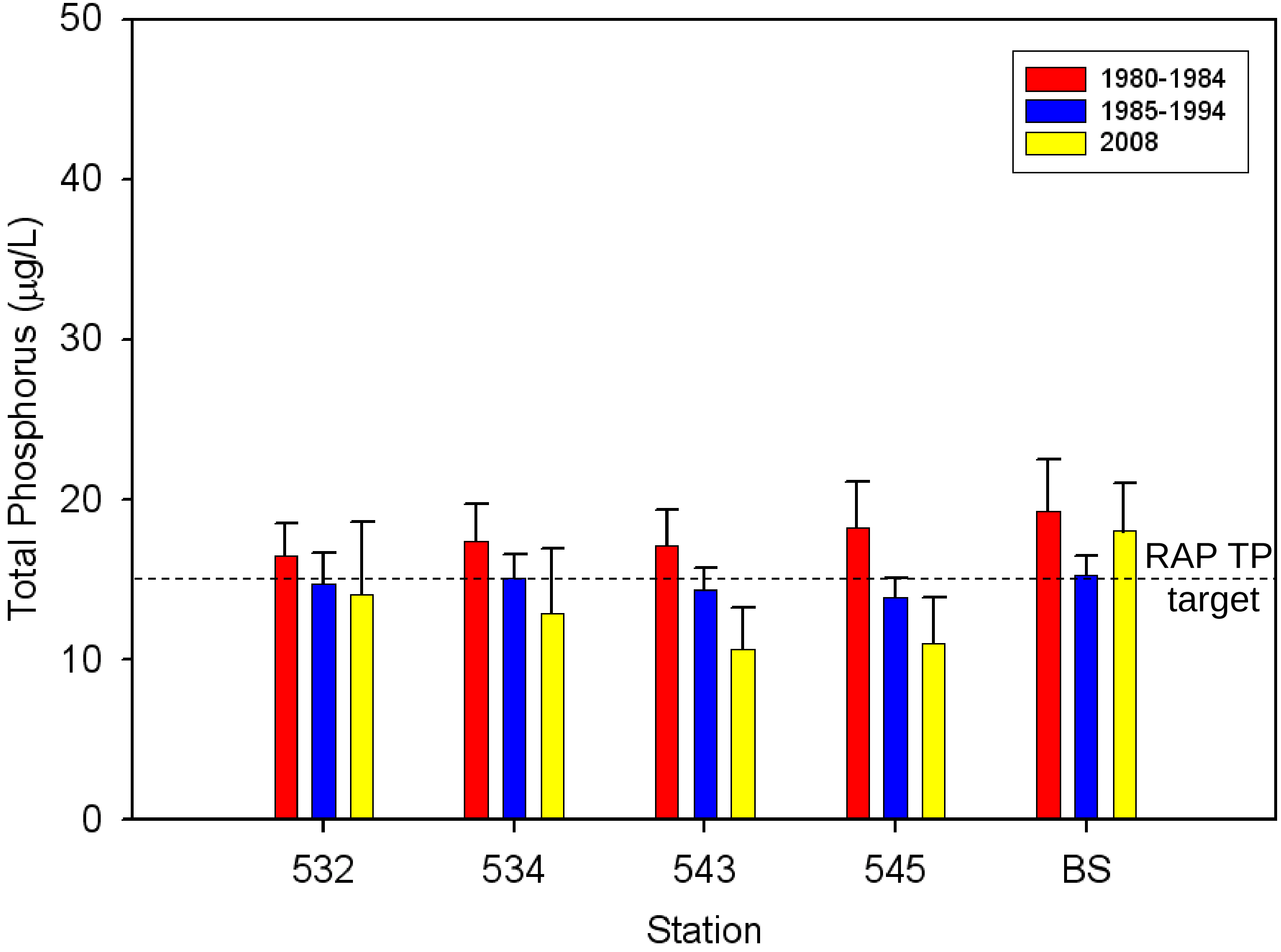


Figure 28. Mean euphotic zone TP concentration in Sturgeon Bay, summer 2008.

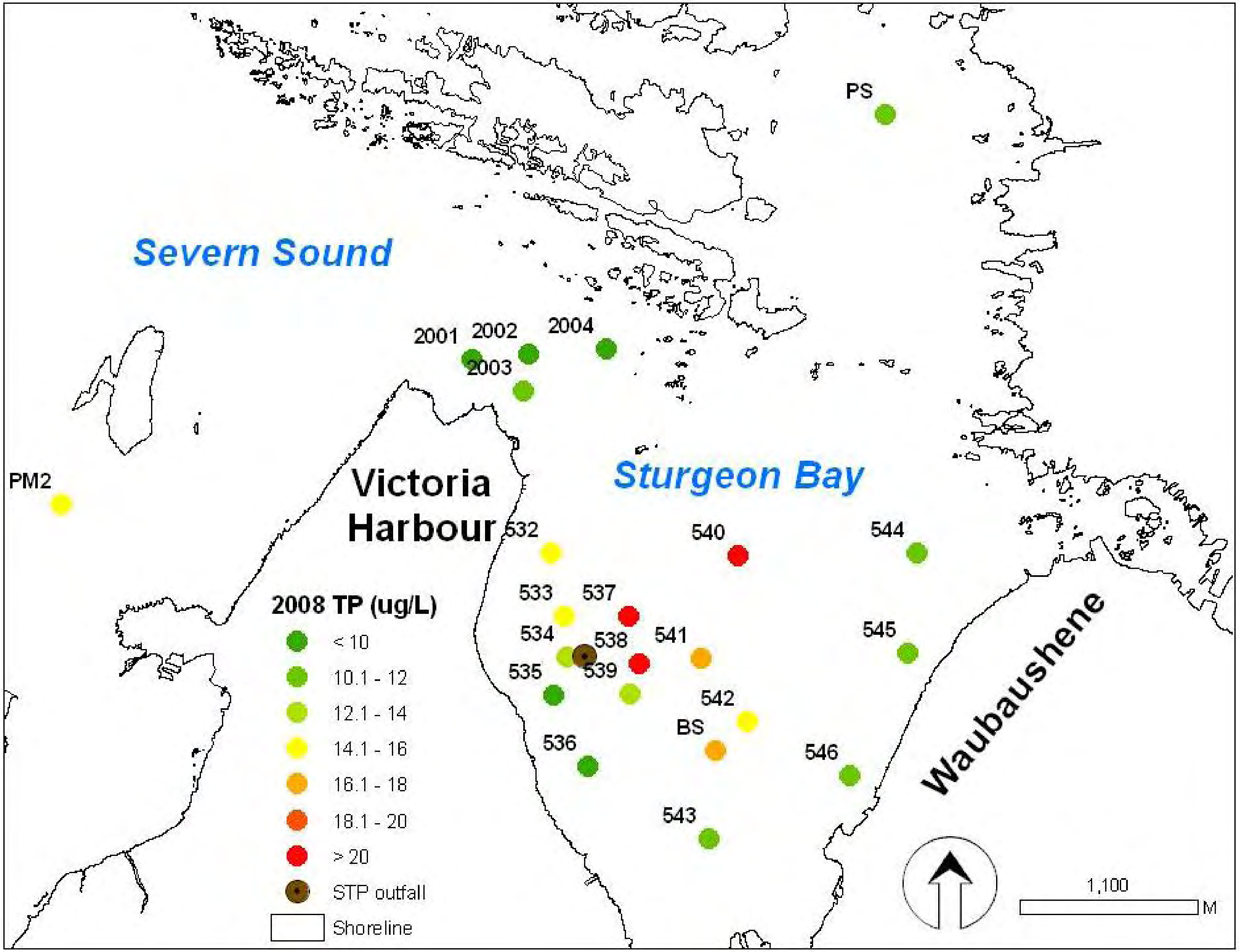


Figure 29. Mean euphotic zone TP concentration in Sturgeon Bay, summer 1980.

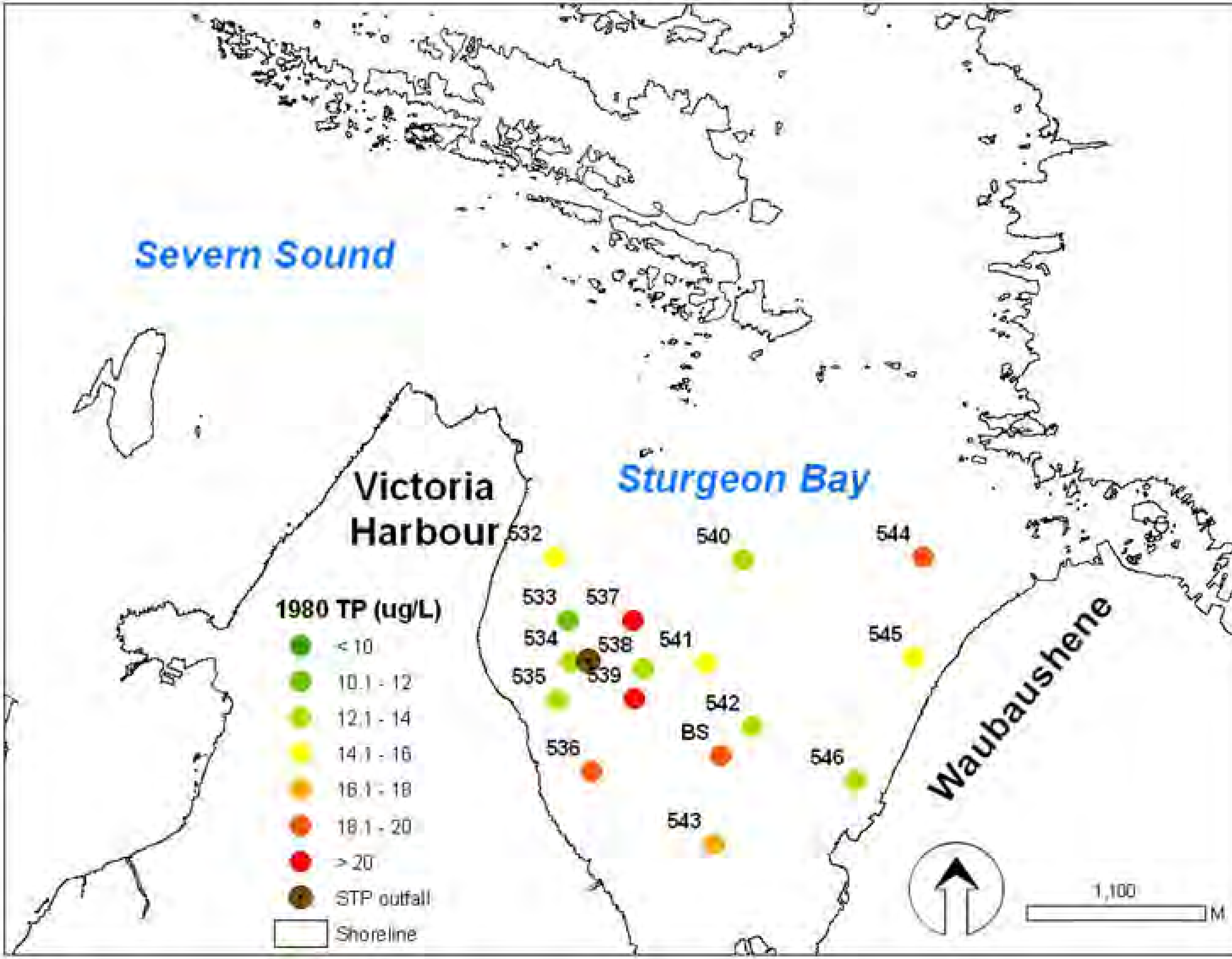


Figure 30. Euphotic zone TP concentration at Station BS versus daily P load from the WWTP, 2003-2008. No significant relationship was found.

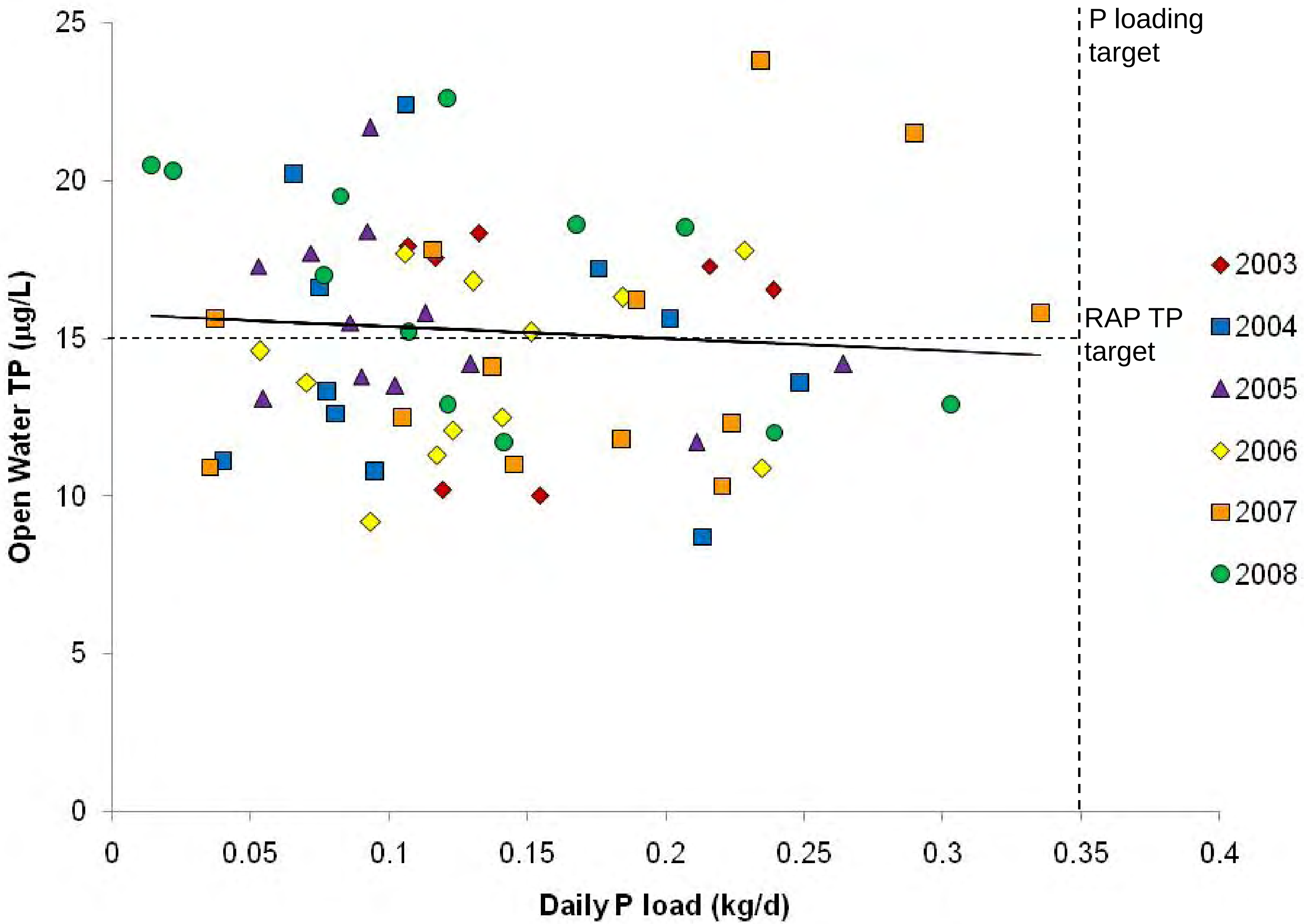


Figure 31. Comparison of mean ammonia (± 95% confidence limits) at 3 long term stations (A) and Sturgeon Bay stations (B), among different time periods. These correspond to pre-WWTP commissioning (’69-’84), post-WWTP and pre-zebra mussel establishment (’85-’94), post-zebra mussel and high water levels (’95-’99) and low water levels (’00-’08).

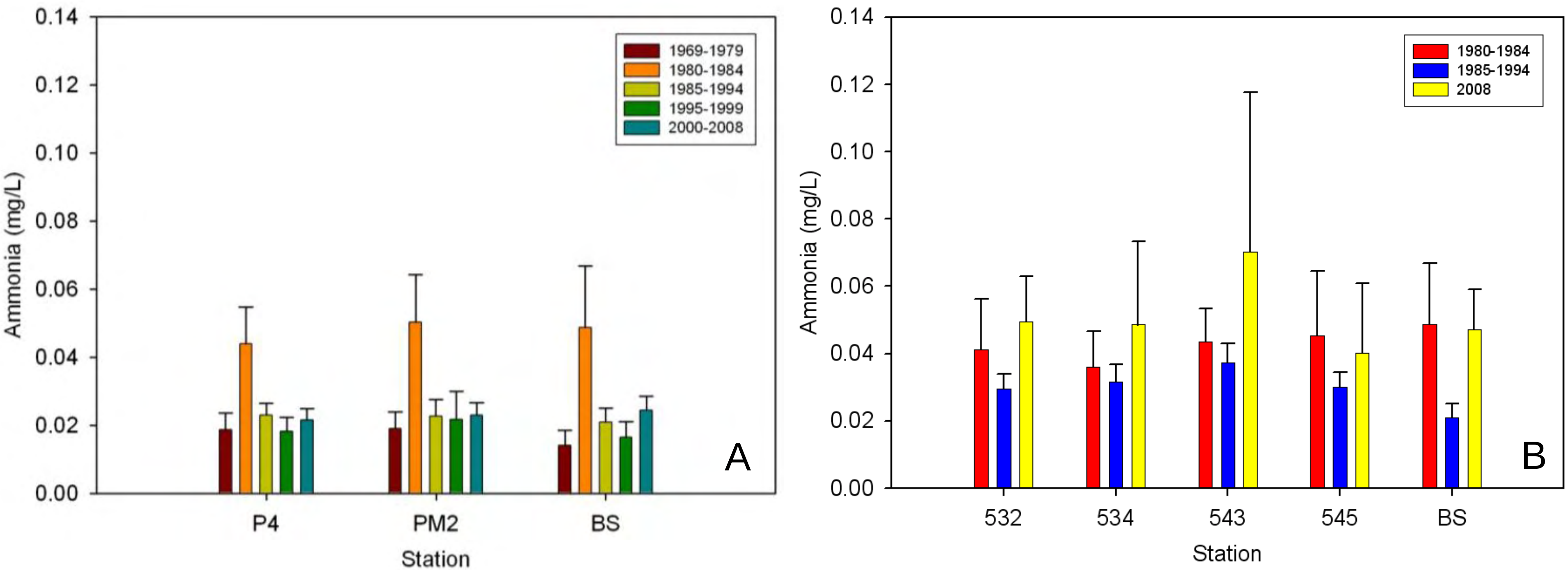


Figure 32. Mean euphotic zone ammonia concentration in Sturgeon Bay, summer 2008.

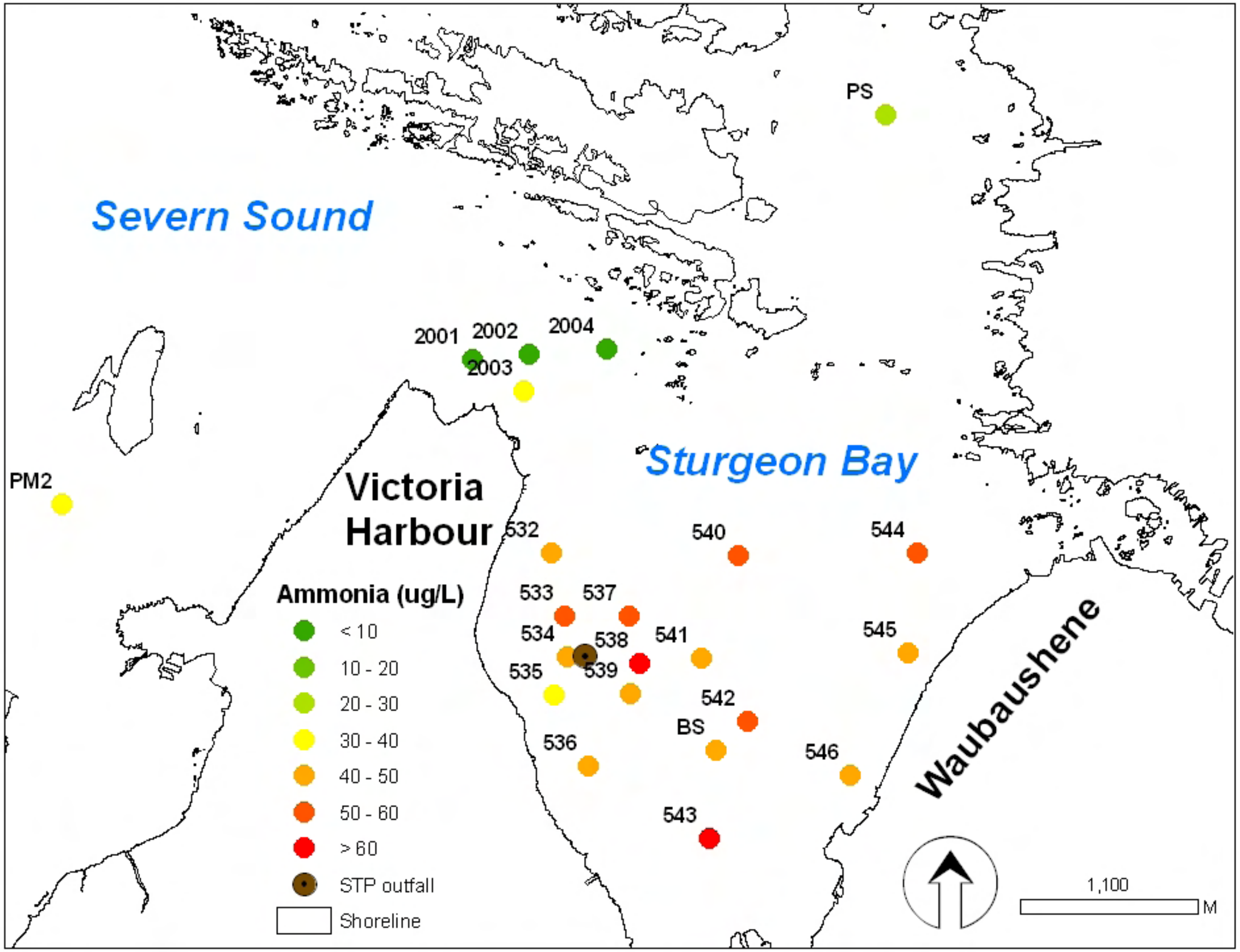


Figure 33. Comparison of mean nitrate (± 95% confidence limits) at 3 long term stations (A) and Sturgeon Bay stations (B), among different time periods. These correspond to pre-WWTP commissioning ('69-'84), post-WWTP and pre-zebra mussel establishment ('85-'94), post-zebra mussel and high water levels ('95-'99) and low water levels ('00-'08).

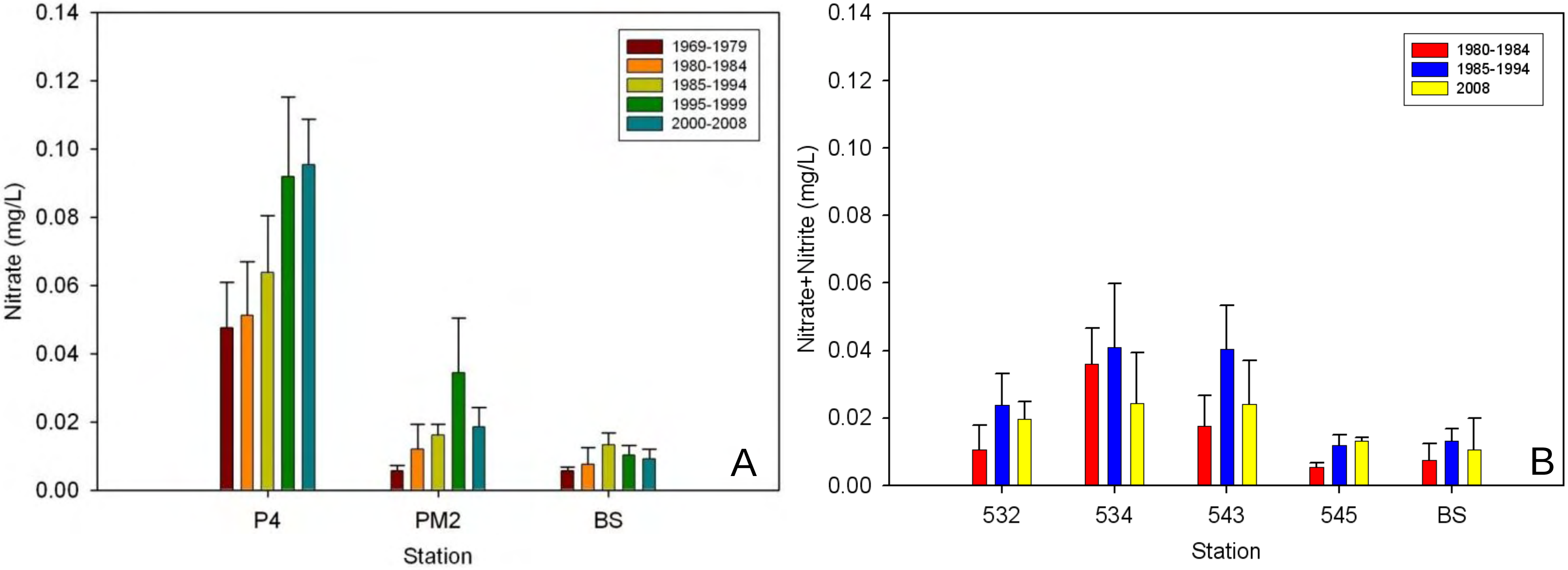


Figure 34. Mean euphotic zone nitrate concentration in Sturgeon Bay, summer 2008.

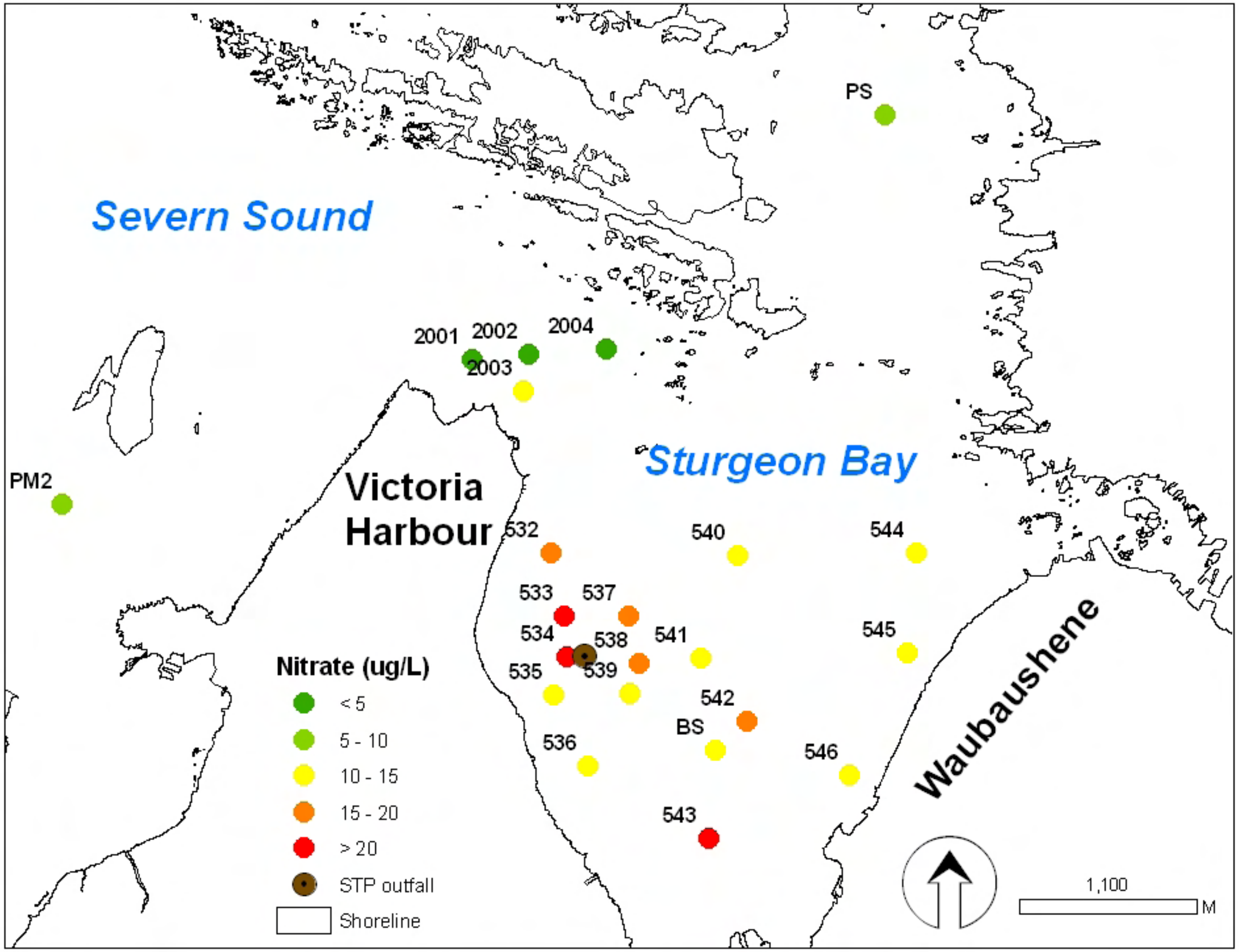


Figure 35. Trends in total phytoplankton biovolume in Severn Sound at five long term stations from 1973-2008.

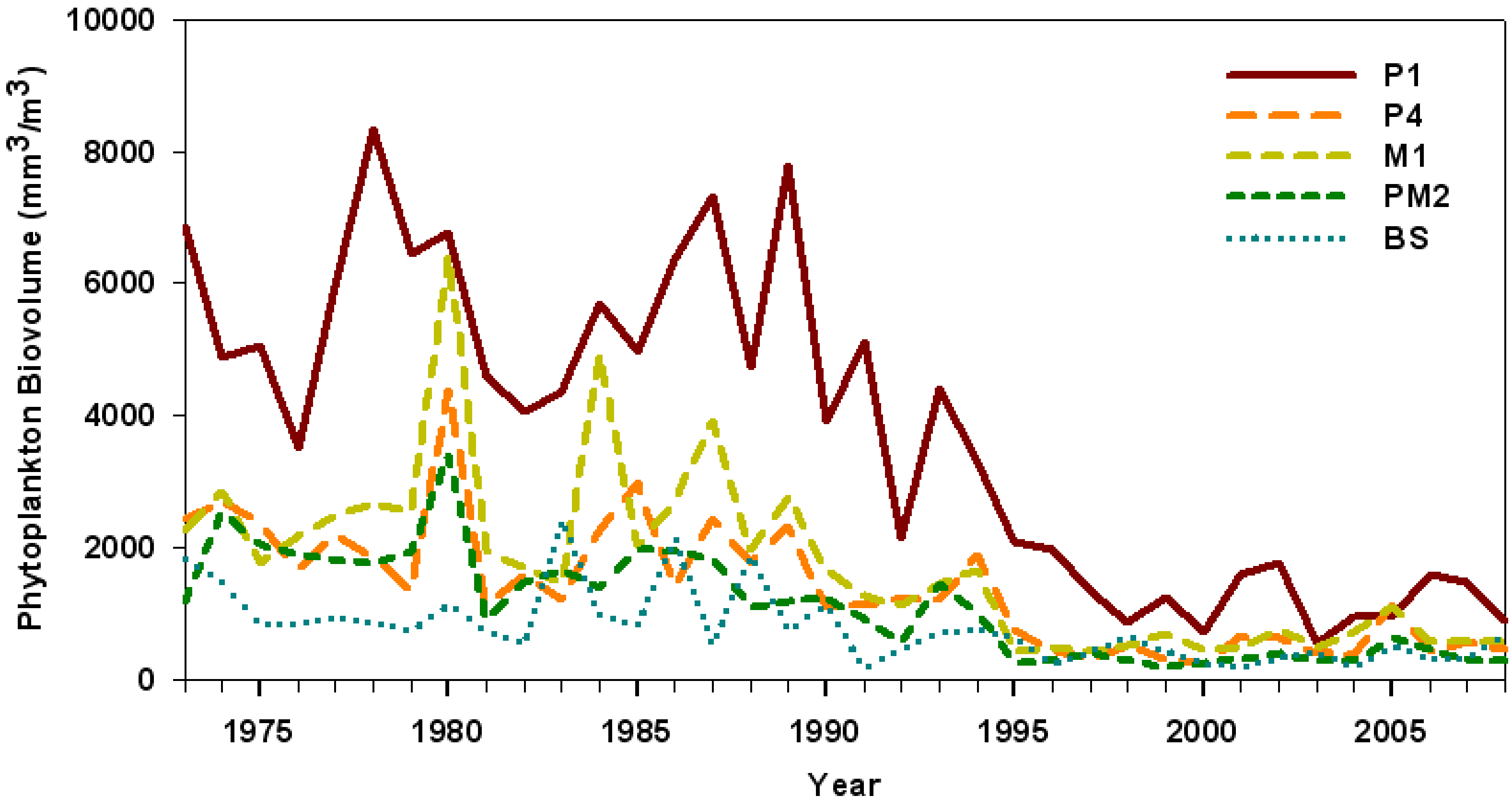


Figure 36. 2008 seasonal phytoplankton community composition in Severn Sound by division in terms of biovolume (mm^3/m^3).

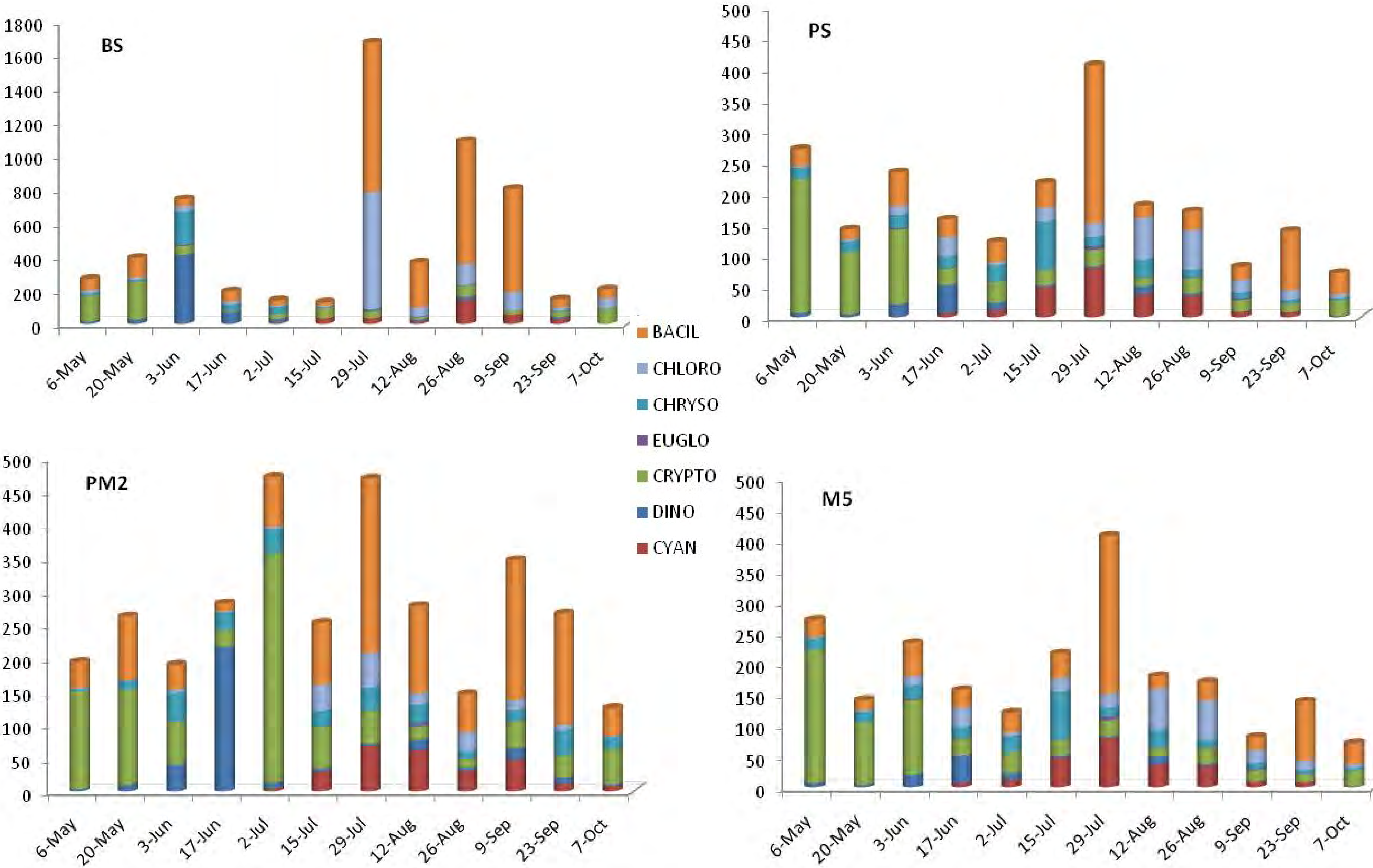


Figure 37. Seasonal biovolume (mm^3/m^3) for common phytoplankton genera in Sturgeon Bay (Station BS) during 2008.

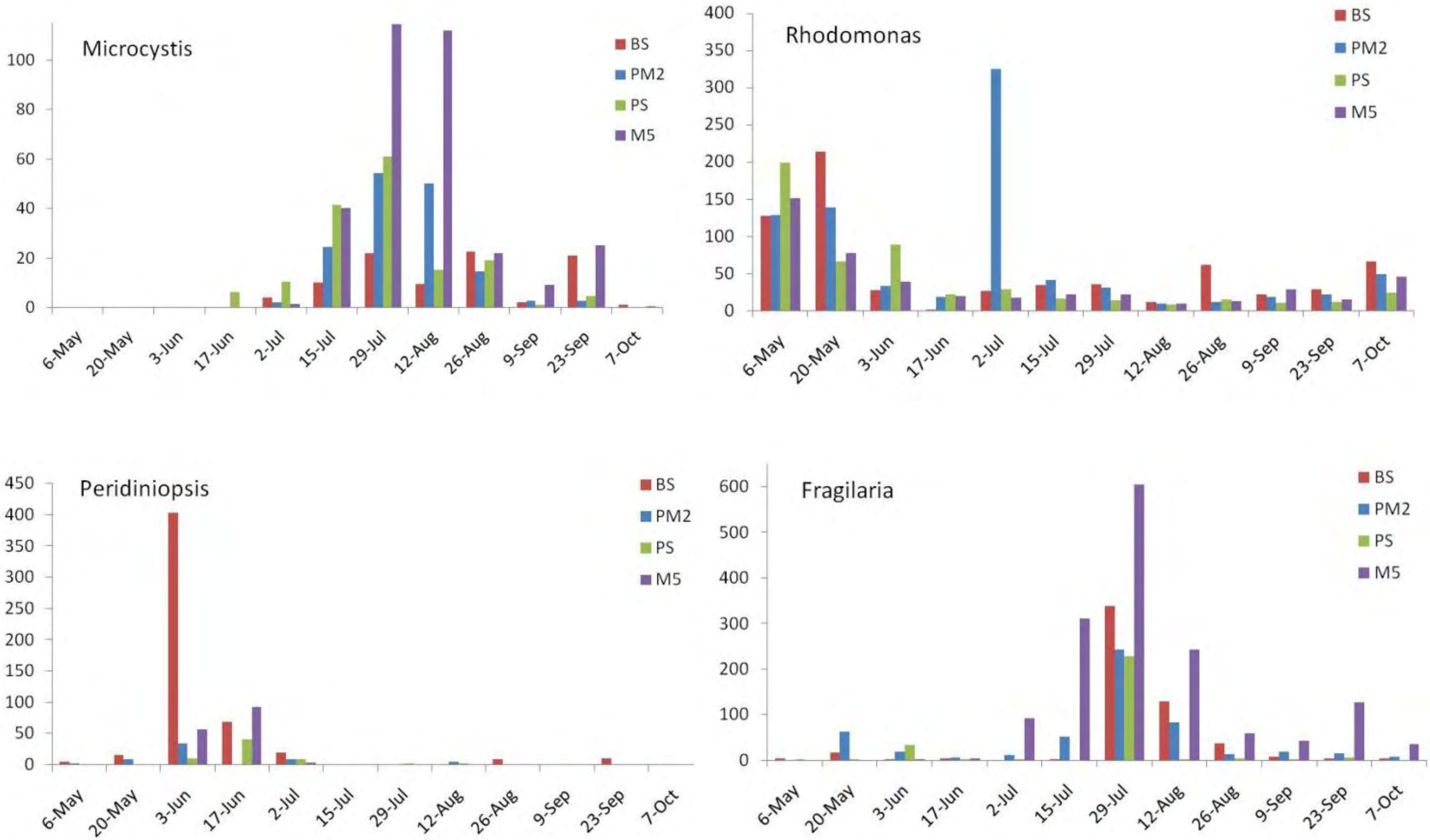


Figure 38. NMS ordination of zooplankton community densities from 1988-2008 in Sturgeon Bay (Station BS). Years clustered into two groups: 1988-94 and 1995-2005. 1991 and 2008 were anomalous years.

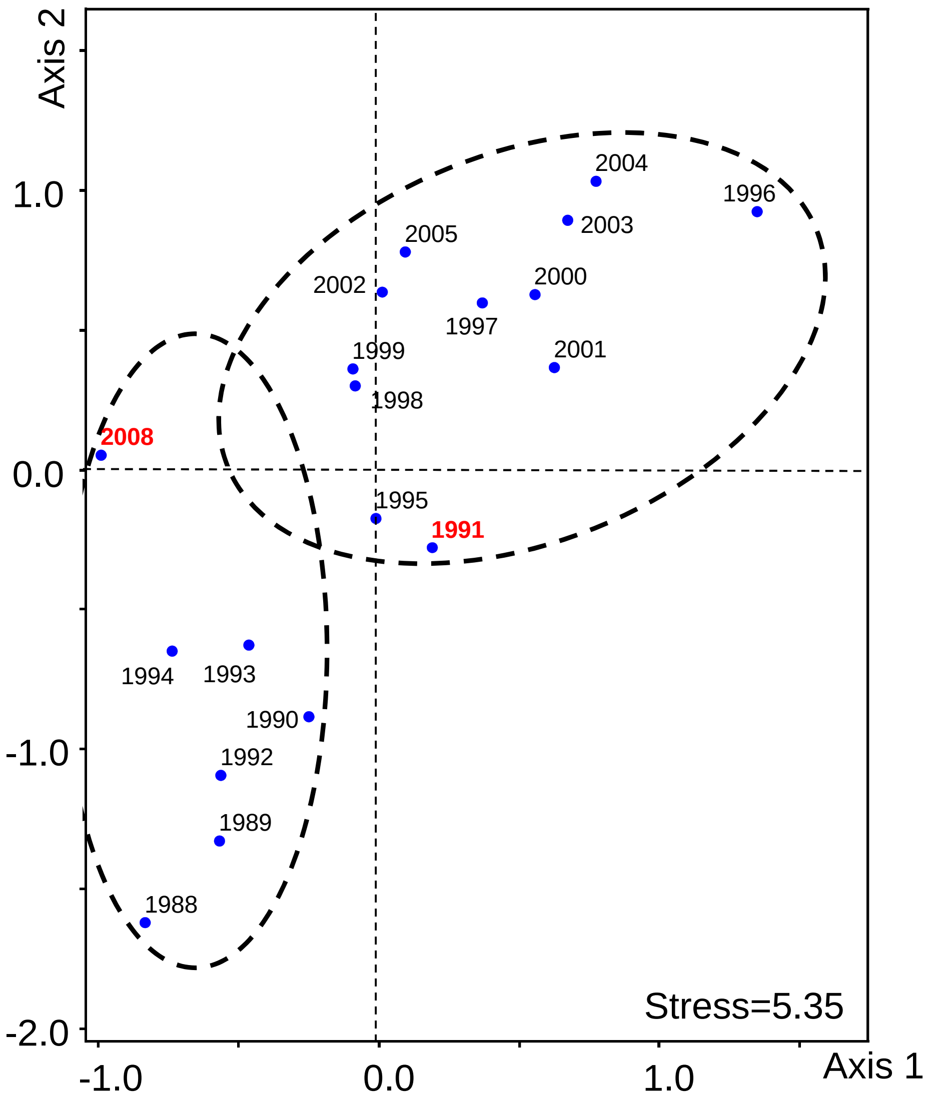
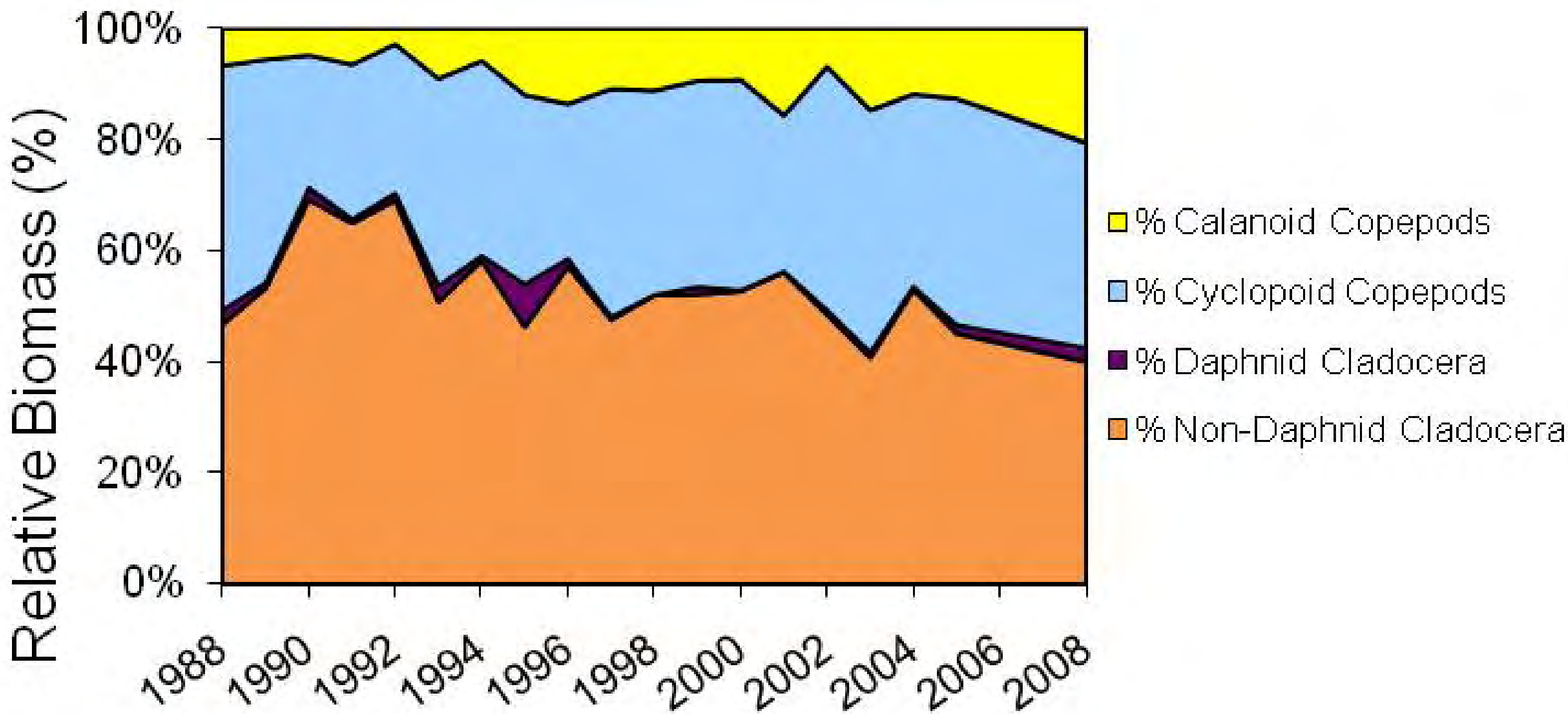


Figure 39. Relative biomass (%) of crustacean zooplankton from 1988-2008 in Sturgeon Bay (Station BS). Taxa were categorized into four groups: calanoid and cyclopoid copepods, and daphnid and non-daphnid cladocerans.



Appendices A-K

corresponding with the report:

Sediment Quality, Benthos Community Structure and Water Quality of Sturgeon Bay, Severn Sound, in Relation to the Proposed Upgrade of the Victoria Harbour Wastewater Treatment Plant

February 2011

Appendix A. Sediment core chemistry taken on October 7, 2008 in Sturgeon Bay and surrounding stations. Samples were taken and analyzed by Environment Canada.

Station	Core Section (cm)	Pore Water Ammonia (mg/L)	Loss on Ignition (%)	Total Phosphorus (µg/g)
533	0-2	0.11	9	
533	2-4	0.10	9	
533	4-6	0.80	8	
533	6-8	0.11	7	
533	8-10	0.16	6	
533	10-12	0.23	6	
534	0-2	0.11	8	1240
534	2-4	0.54	8	1240
534	4-6	1.36	8	1140
534	6-8	1.56	8	899
534	8-10	1.68	9	804
535	0-2	0.19	9	
535	2-4	0.22	10	
535	4-6	0.16	10	
535	6-8	0.59	9	
535	8-10	0.39	8	
537	0-2	0.28	9	
537	2-4	0.22	7	
537	4-6	0.87	6	
537	6-8	0.24	9	
537	8-10	0.22	11	
537	10-12	0.36	11	
538	0-2	0.27	16	1190
538	2-4	1.10	14	972
538	4-6	1.41	11	955
538	6-8	0.92	8	931
538	8-10	0.46	8	906
538	10-12	0.49	9	870
539	0-2	0.12	12	
539	2-4	0.16	9	
539	4-6	0.17	7	
539	6-8	0.22	8	
539	8-10	0.20	9	
BS	0-2	0.13	13	1140
BS	2-4	0.34	12	958
BS	4-6	1.51	10	941
BS	6-8	1.51	9	940
BS	8-10	1.02	9	1000
PM2	0-2	0.11	12	1300
PM2	2-4	0.83	11	1160
PM2	4-6	1.10	11	1180
PM2	6-8	1.36	11	1280
PM2	8-10	1.22	10	910
PS	0-2	0.15	19	
PS	2-4		18	
PS	4-6	1.22	19	
PS	6-8	1.46	18	
PS	8-10	1.51	17	
PS	10-12	1.56	15	
PS	12-14	1.74	12	
PS	14-16	1.62	11	

Appendix B. Bulk sediment metals chemistry (µg/g) of sediment core sections from selected sites in the Sturgeon Bay area, collected October 7, 2008. Values preceded by "<" are less than the method detection limit. Bold values exceed Provincial Lowest Effect Levels. Relevant guidelines are also given. Samples were taken and analyzed by Environment Canada.

Station	Core section	As	Be	Bi	Cd	Co	Ga	La	Li	Mo	Ni	Pb	Rb	Sb	Tl	U
534	0-2	3	0.48	0.3	0.4	7.9	6.23	28.7	10.2	<0.5	12.5	11.1	19.4	0.1	0.175	0.88
534	2-4	3	0.48	0.3	0.5	8.0	6.44	30.3	10.6	<0.5	12.8	11.4	20.2	0.1	0.177	0.95
534	4-6	3	0.55	0.2	0.4	8.6	6.96	30.4	11.1	<0.5	13.8	10.5	22.5	<0.1	0.188	1.10
534	6-8	5	0.80	0.1	0.4	10.4	9.35	45.2	17.6	0.5	19.8	9.6	36.0	0.1	0.244	1.58
534	8-10	**6**	1.12	0.1	0.4	13.2	12.30	56.9	24.3	0.5	27.6	8.2	51.6	0.1	0.319	1.93
538	0-2	5	0.89	0.2	**0.7**	12.7	10.20	40.1	19.7	0.6	24.2	26.5	42.6	0.2	0.309	1.33
538	2-4	5	0.90	0.2	**0.7**	12.6	10.40	41.8	19.4	0.6	23.9	28.0	42.6	0.2	0.314	1.34
538	4-6	5	0.72	0.1	**0.7**	11.5	8.68	38.9	16.8	0.6	21.5	25.1	31.8	0.2	0.253	1.21
538	6-8	**6**	0.61	0.1	0.5	10.4	7.69	38.1	14.2	<0.5	16.2	12.0	26.0	0.2	0.196	1.14
538	8-10	**6**	0.67	0.1	0.4	12.7	8.62	44.0	15.7	<0.5	18.5	7.6	29.3	0.1	0.196	1.13
538	10-12	5	0.68	0.1	0.3	13.9	8.83	48.0	16.5	<0.5	20.1	5.7	30.2	0.1	0.209	1.09
BS	0-2	4	0.63	0.1	**0.6**	10.4	7.62	36.3	15.1	0.5	19.0	20.0	28.4	0.2	0.217	0.98
BS	2-4	5	0.67	0.1	**0.6**	11.0	8.13	38.0	15.3	0.6	19.6	20.2	29.3	0.2	0.231	1.11
BS	4-6	5	0.63	0.1	**0.6**	10.5	7.71	37.8	14.3	0.5	18.1	18.8	26.7	0.1	0.217	1.06
BS	6-8	5	0.69	0.1	0.5	11.2	8.74	41.2	15.2	0.5	18.1	16.7	31.0	0.1	0.221	1.18
BS	8-10	**6**	0.87	0.1	0.4	15.1	10.50	54.4	19.7	<0.5	23.2	7.5	38.2	0.1	0.245	1.23
PM2	0-2	5	0.99	0.2	**0.6**	13.9	10.60	44.6	23.0	<0.5	30.1	**31.4**	45.3	0.2	0.269	1.25
PM2	2-4	5	0.93	0.2	**0.6**	13.6	10.20	43.4	21.8	<0.5	29.7	29.5	41.0	0.2	0.261	1.25
PM2	4-6	5	1.01	0.2	**0.6**	13.9	10.70	46.7	23.6	<0.5	30.9	**31.1**	45.8	0.2	0.287	1.36
PM2	6-8	**6**	1.03	0.2	0.5	14.2	11.30	48.8	24.3	<0.5	**31.8**	25.8	47.0	0.2	0.301	1.56
PM2	8-10	**6**	0.99	0.1	0.4	13.6	10.60	53.9	23.8	0.5	30.3	13.0	40.8	0.2	0.299	1.81
533	0-6	3	0.54	0.1	0.5	8.5	6.98	32.7	11.9	<0.5	14.3	14.1	23.8	0.1	0.192	0.99
535	0-6	4	0.50	0.1	0.4	9.0	6.18	33.5	11.3	<0.5	14.4	11.8	20.2	0.1	0.164	0.86
537	0-6	5	0.49	0.1	0.5	8.6	6.33	32.1	11.9	0.5	15.1	14.7	20.8	0.1	0.182	1.04
539	0-6	**6**	0.63	0.1	0.5	10.7	7.54	39.1	14.2	0.5	18.3	14.1	25.5	0.1	0.198	1.12
PS	0-6	**8**	0.78	0.2	**1.1**	11.9	9.04	39.2	16.7	<0.5	21.4	**38.2**	32.5	0.2	0.260	1.60
CCME ISQG		5.9			0.6							35				
CCME PEL		17			3.5							91.3				
LEL		**6**			**0.6**						**16**	**31**				
SEL		33			10						75	250				
GSC		1			0.66						14	9				

Station	Core section	Al	Ba	Cr	Cu	Fe	Mn	Sr	V	Zn	Ca	Mg	Na	K	Se	Hg
534	0-2	11200	106	**36**	13	19300	490	40	37	77	9590	3440	697	3200	1	0.048
534	2-4	11600	102	**38**	13	19200	474	39	39	77	8780	3400	650	3180	1	0.085
534	4-6	12800	109	**41**	12	**21600**	512	37	41	74	8810	4050	792	3740	1	0.039
534	6-8	20200	171	**54**	**20**	**30100**	519	43	61	88	8730	6460	746	5010	1	<0.004
534	8-10	29400	250	**68**	**26**	**40500**	607	48	80	101	9520	9440	898	7190	1	0.022
538	0-2	23700	265	**61**	**21**	**35900**	930	70	66	**144**	17800	8180	1040	5980	1	0.086
538	2-4	23300	254	**61**	**20**	**34700**	838	64	64	**140**	16200	7720	955	5960	1	0.085
538	4-6	16600	190	**51**	**18**	**29100**	650	49	54	**122**	13500	5950	679	4370	1	0.069
538	6-8	13400	146	**44**	12	**25800**	492	33	48	86	8400	4530	599	3600	1	0.092
538	8-10	16000	166	**48**	13	**32000**	542	35	52	89	8530	5420	605	3970	1	0.046
538	10-12	16700	185	**50**	13	**35000**	570	35	53	95	8550	5870	530	3900	1	0.044
BS	0-2	14600	233	**46**	**17**	**27600**	978	91	49	110	25500	5860	699	4030	1	0.068
BS	2-4	15000	187	**47**	**17**	**27200**	674	71	51	108	19400	5600	677	4190	1	0.066
BS	4-6	13900	167	**44**	15	**26200**	560	59	50	100	16400	5050	611	3690	1	0.060
BS	6-8	17200	163	**49**	14	**29400**	585	44	56	96	12300	5560	729	4550	1	0.150
BS	8-10	22800	226	**59**	**16**	**42700**	658	41	63	106	10600	7910	662	4650	1	0.039
PM2	0-2	23100	255	**65**	**24**	**43200**	1880	49	68	**141**	12200	10000	875	5630	1	0.083
PM2	2-4	21800	229	**60**	**23**	**41800**	1470	47	64	**137**	11500	10100	784	5020	1	0.075
PM2	4-6	22100	247	**63**	**24**	**40000**	1360	47	66	**137**	12100	9810	783	5490	1	0.069
PM2	6-8	24500	259	**66**	**26**	**43000**	1290	50	74	**132**	12000	10100	807	6000	1	0.056
PM2	8-10	21600	235	**60**	**29**	**38400**	914	43	72	105	8750	8890	673	4640	1	0.026
533	0-6	12800	125	**42**	12	**21300**	557	42	42	82	12200	4010	730	3870	1	0.091
535	0-6	9530	131	**36**	12	19800	483	60	35	74	18300	3470	<500	2690	1	0.043
537	0-6	8720	121	**36**	13	18600	442	29	40	79	7840	3150	<500	2690	1	0.038
539	0-6	12000	151	**42**	15	**25500**	498	35	46	89	9200	4340	<500	3190	1	0.043
PS	0-6	19200	171	**55**	**18**	**28500**	837	43	55	**148**	11400	5670	843	4790	1	0.084
CCME ISQG				37.3	35.7					123						0.17
CCME PEL				90	197					315						0.486
LEL				**26**	**16**	**20000**				**120**						**0.2**
SEL				110	110	40000				820						2
GSC				60.4	20					103						0.129

Appendix C. Pearson correlation values (r) and *p*-values for sediment chemistry parameters at all stations within Sturgeon Bay versus station distance from the outfall. Values in red are significant at α=0.05.

		LOI	TOC	TP	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
2008	*r*	-0.41	-0.39	-0.47	-0.28	-0.15	*	-0.15	-0.42	-0.21	-0.42	-0.19	-0.36	-0.32	-0.36
n=16	*p*	0.10	0.12	0.06	0.28	0.57	*	0.58	0.09	0.41	0.10	0.47	0.15	0.21	0.15
1994	*r*	0.47	0.62	-0.16			0.68	0.74	0.76				0.71	0.68	0.72
n=12	*p*	0.11	0.03	0.60			0.06	0.04	0.03				0.05	0.06	0.04
1988	*r*	0.28	0.24	-0.39	0.34		-0.34	0.36	0.25	0.31	-0.02	0.23	0.25	0.21	0.29
n=12	*p*	0.36	0.43	0.19	0.26		0.25	0.22	0.40	0.30	0.94	0.44	0.40	0.49	0.34
1980	*r*	0.45	0.09	-0.35			-0.18	0.35	0.28	0.30	-0.36			0.31	0.25
n=12	*p*	0.12	0.76	0.24			0.55	0.24	0.35	0.32	0.22			0.31	0.40

* Cd data were below detection limit.

Appendix D. Pearson correlation matrix (*r*) and *p*-values for sediment chemistry parameters in 2008, 1994, 1988 and 1980. Data from all stations within Sturgeon Bay were pooled for analysis. Values in red are significant at α=0.05. Identical rows and columns of parameters were used for all years, even if data were not available, to allow for easy comparisons of between-year changes in correlations.

2008 *n*=16

	TOC	TKN	TP	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
LOI	0.994	0.925	0.622	0.896	0.534	*	0.729	0.882	0.849	0.990	0.824	0.899	0.938	0.918
p	<0.001	<0.001	0.008	<0.001	0.027	*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TOC		0.926	0.575	0.915	0.566	*	0.898	0.924	0.897	0.988	0.944	0.902	0.943	0.919
p		<0.001	0.016	<0.001	0.018	*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TKN			0.768	0.762	0.442	*	0.732	0.818	0.741	0.930	0.836	0.783	0.850	0.826
p			<0.001	<0.001	0.076	*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TP				0.486	0.393	*	0.475	0.370	0.481	0.626	0.503	0.510	0.517	0.542
p				0.048	0.119	*	0.540	0.144	0.506	0.007	0.040	0.037	0.034	0.025
Al					0.694	*	0.905	0.847	0.985	0.911	0.921	0.988	0.927	0.953
p					0.002	*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
As						*	0.835	0.346	0.771	0.532	0.762	0.655	0.509	0.585
p						*	<0.001	0.174	<0.001	0.028	<0.001	0.004	0.037	0.014
Cd							0.741	-0.101	0.516	0.211	0.636	0.318	0.136	0.221
p							<0.001	0.700	0.034	0.416	0.006	0.214	0.603	0.394
Cr								0.566	0.955	0.747	0.958	0.860	0.733	0.787
p								0.018	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu									0.765	0.901	0.679	0.891	0.951	0.922
p									<0.001	<0.001	0.003	<0.001	<0.001	<0.001
Fe										0.863	0.946	0.961	0.878	0.907
p										<0.001	<0.001	<0.001	<0.001	<0.001
Hg											0.852	0.921	0.964	0.949
p											<0.001	<0.001	<0.001	<0.001
Mn												0.889	0.835	0.858
p												<0.001	<0.001	<0.001
Ni													0.951	0.977
p													<0.001	<0.001
Pb														0.982
p														<0.001

* Cd data were below detection limit.

1994 *n*=12

	TOC	TKN	TP	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
LOI	0.829	0.863	-0.215			0.593	0.857	0.906				0.837	0.828	0.859
p	<0.001	<0.001	0.481			0.033	<0.001	<0.001				<0.001	<0.001	<0.001
TOC		0.955	-0.205			0.481	0.840	0.857				0.813	0.799	0.832
p		<0.001	0.502			0.096	<0.001	<0.001				<0.001	0.001	<0.001
TKN			-0.244			0.565	0.806	0.859				0.808	0.830	0.840
p			0.422			0.044	<0.001	<0.001				<0.001	<0.001	<0.001
TP						-0.380	-0.262	-0.306				-0.290	-0.350	-0.320
p						0.200	0.387	0.309				0.337	0.241	0.287
Al														
p														
As														
p														
Cd							0.376	0.428				0.340	0.390	0.381
p							0.359	0.290				0.410	0.340	0.352
Cr								0.990				0.992	0.975	0.991
p								<0.001				<0.001	<0.001	<0.001
Cu												0.986	0.977	0.993
p												<0.001	<0.001	<0.001
Fe														
p														
Hg														
p														
Mn														
p														
Ni													0.988	0.996
p													<0.001	<0.001
Pb														0.994
p														<0.001

NB - not all variables were measured in 1994

1988* *n*=15

	TOC	TKN	TP	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
LOI	0.989	0.975	0.320	0.885		0.063	0.909	0.920	0.919	0.503	0.873	0.913	0.852	0.903
p	<0.001	<0.001	>0.050	<0.001		>0.050	<0.001	<0.001	<0.001	<0.050	<0.001	<0.001	<0.001	<0.001
TOC		0.970	0.371	0.881		0.060	0.897	0.910	0.911	0.458	0.828	0.898	0.802	0.876
p		<0.001	>0.050	<0.001		>0.050	<0.001	<0.001	<0.001	>0.050	<0.001	<0.001	<0.001	<0.001
TKN			0.323	0.892		-0.041	0.913	0.917	0.917	0.378	0.813	0.911	0.815	0.900
p			>0.050	<0.001		>0.050	<0.001	<0.001	<0.001	>0.050	<0.001	<0.001	<0.001	<0.001
TP				0.354		-0.161	0.319	0.377	0.332	0.355	0.224	0.370	0.142	0.217
p				>0.050		>0.050	>0.050	>0.050	>0.050	>0.050	>0.050	>0.050	>0.050	>0.050
Al						-0.189	0.987	0.970	0.987	0.442	0.853	0.977	0.847	0.944
p						>0.050	<0.001	<0.001	<0.001	>0.050	<0.001	<0.001	<0.001	<0.001
As														
p														
Cd							-0.092	-0.079	-0.059	0.214	0.173	-0.051	0.212	0.029
p							>0.050	>0.050	>0.050	>0.050	>0.050	>0.050	>0.050	>0.050
Cr								0.984	0.989	0.458	0.892	0.989	0.891	0.967
p								<0.001	<0.001	>0.050	<0.001	<0.001	<0.001	<0.001
Cu									0.973	0.518	0.881	0.992	0.897	0.970
p									<0.001	<0.050	<0.001	<0.001	<0.001	<0.001
Fe										0.465	0.884	0.981	0.885	0.961
p										>0.050	<0.001	<0.001	<0.001	<0.001
Hg											0.636	0.523	0.628	0.533
p											<0.050	<0.050	<0.050	<0.050
Mn												0.905	0.960	0.923
p												<0.001	<0.001	<0.001
Ni													0.920	0.981
p													<0.001	<0.001
Pb														0.965
p														<0.001

*from Krantzberg and Sherman 1995
NB - As was not measured in 1988

1980 *n*=12

	TOC	TKN	TP	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
LOI	0.862	0.943	0.047			0.482	0.866	0.933	0.900	0.383			0.951	0.943
p	<0.001	<0.001	0.879			0.095	<0.001	<0.001	<0.001	0.196			<0.001	<0.001
TOC		0.935	0.197			0.442	0.707	0.810	0.746	0.507			0.859	0.823
p		<0.001	0.519			0.131	0.007	<0.001	0.003	0.077			<0.001	<0.001
TKN			0.144			0.530	0.823	0.936	0.875	0.562			0.945	0.955
p			0.639			0.063	<0.001	<0.001	<0.001	0.046			<0.001	<0.001
TP						-0.053	0.288	0.115	0.210	0.291			0.163	0.138
p						0.864	0.340	0.708	0.491	0.335			0.595	0.653
Al														
p														
As														
p														
Cd							0.426	0.583	0.489	0.490			0.508	0.598
p							0.147	0.037	0.090	0.089			0.076	0.031
Cr								0.911	0.978	0.463			0.923	0.912
p								<0.001	<0.001	0.111			<0.001	<0.001
Cu									0.960	0.497			0.967	0.987
p									<0.001	0.084			<0.001	<0.001
Fe										0.454			0.944	0.961
p										0.119			<0.001	<0.001
Hg													0.499	0.531
p													0.083	0.062
Mn														
p														
Ni														
p														
Pb														0.971
p														<0.001

NB - not all variables were measured in 1980

Appendix E. Median monthly temperatures (°C) from water intakes at Victoria Harbour and Rope subdivision from Jan 2006 – Jun 2010. Data were provided by Tay Township.

Year	Month	Median Temperature		Year	Month	Median Temperature		Year	Month	Median Temperature	
		Victoria Harbour	Rope Subdivision			Victoria Harbour	Rope Subdivision			Victoria Harbour	Rope Subdivision
2006	Jan	2.35	3.2	2008	Jan	2	3.9	2010	Jan	2.6	4.8
	Feb	2.1	2.65		Feb	1.6	4.4		Feb	2	4
	Mar	1.9	2.75		Mar	1.5	3.9		Mar	3.85	4.8
	Apr	5.9	5.6		Apr	3.9	6.05		Apr	10.85	9.4
	May	12.2	13.3		May	12.6	12.65		May	13.6	13.1
	Jun	20.2	19.7		Jun	19.7	18.9		Jun	20.9	18.9
	Jul	23.6	23		Jul	22.65	22.55				
	Aug	23	22.5		Aug	23.05	21.9				
	Sep	18.1	19		Sep	19.2	19.2				
	Oct	10.8	13.2		Oct	12.65	13.6				
	Nov	6.1	9		Nov	6.6	9.3				
	Dec	2.55	5.5		Dec	2	6.7				
2007	Jan	1.75	4.15	2009	Jan	1.9	5.1				
	Feb	1.85	3.5		Feb	1.85	4.2				
	Mar	1.85	3.35		Mar	3.15	4.85				
	Apr	4.85	4.5		Apr	6.25	6.9				
	May	14.2	14		May	13.9	13.6				
	Jun	17.5	19.3		Jun	17.1	17.6				
	Jul	22.2	21.7		Jul	21.9	20.25				
	Aug	22.4	22.1		Aug	23.5	21.4				
	Sep	19.35	19.6		Sep	20.15	19.7				
	Oct	14.85	16.45		Oct	10.05	14.3				
	Nov	7.25	10.15		Nov	8.4	11.4				
	Dec	2	5.6		Dec	2.5	7.5				

Appendix F. Annual mean values for Secchi disc depth, chlorophyll *a* and water chemistry for three long term open water stations in Severn Sound.

Station BS

Year	Secchi (m)	Chl *a* (µg/L)	TP (µg/L)	NH_3 (mg/L)	TKN (mg/L)	NO_3 (mg/L)	TN (mg/L)	TN:TP
1969	2.8		21	0.026	0.418	0.015	0.433	21.02
1973	2.7	2.1	17	0.009	0.366	0.012	0.383	22.52
1974	2.1	1.9	20	0.013	0.379	0.007	0.379	18.95
1975	2.6	2.9	18	0.020	0.358	0.007	0.367	20.00
1976	2.9	2.3	18	0.007	0.377	0.005	0.394	21.79
1977	2.3	1.8	17	0.009	0.400	0.004	0.419	24.32
1978	2.3	2.9	18	0.011	0.431	0.035	0.470	26.58
1979	2.5	3.4	18	0.011	0.393	0.005	0.410	23.12
1980	2.5	3.6	20	0.022	0.415	0.006	0.421	21.41
1981	2.1	3.8	33	0.040	0.428	0.057	0.494	14.87
1982	2.7	2.1	15	0.036	0.391	0.003	0.409	28.23
1983	2.2	2.8	22	0.065	0.435	0.005	0.442	19.85
1984	2.6	3.4	14	0.025	0.374	0.012	0.390	28.34
1985	2.8	3.4	15	0.033	0.360	0.014	0.388	26.11
1986		4.9	18	0.041	0.413	0.015	0.426	24.16
1987	2.7	2.7	15	0.042	0.348	0.021	0.378	25.17
1988	2.2	6.3	19	0.024	0.435	0.024	0.485	25.37
1989	2.4	2.9	15	0.013	0.422	0.032	0.454	29.45
1990	2.3	4.5	16	0.019	0.403	0.012	0.439	27.29
1991	2.3	2.3	15	0.013	0.409	0.011	0.425	29.31
1992	2.4	2.1	17	0.013	0.445	0.010	0.461	26.83
1993	2.1	2.4	18	0.019	0.442	0.007	0.456	25.88
1994	2.3	3.6	19	0.029	0.427	0.028	0.457	23.78
1995	1.9	3.9	16	0.033	0.394	0.021	0.416	25.52
1996	3.2	1.5	11	0.022	0.357	0.011	0.411	39.15
1997	3.2	1.0	13	0.029	0.373	0.031	0.404	31.91
1998	3.0	3.2	15	0.013	0.415	0.006	0.434	28.06
1999	2.5	2.7	14	0.013	0.398	0.017	0.416	30.38
2000	2.7	2.4	13.2	0.019	0.412	0.016	0.431	32.59
2001	2.3	1.7	15.1	0.025	0.391	0.028	0.417	27.63
2002	2.5	1.7	13.8	0.018	0.388	0.028	0.415	30.20
2003	2.2	1.7	14.9	0.019	0.439	0.028	0.476	31.88
2004	2.3	1.4	13.9	0.020	0.373	0.013	0.394	28.40
2005	2.3	2.0	15.6	0.025	0.404	0.008	0.432	27.71
2006	2.8	1.1	14.0	0.044	0.380	0.009	0.400	28.57
2007	2.6	1.2	14.5	0.027	0.389	0.003	0.400	27.60
2008	2.2	1.7	16.8	0.044	0.440	0.013	0.462	27.49

Station PM2

Year	Secchi (m)	Chl *a* (µg/L)	TP (µg/L)	NH_3 (mg/L)	TKN (mg/L)	NO_3 (mg/L)	TN (mg/L)	TN:TP
1969	2.3		23	0.035	0.378	0.017	0.395	17.53
1973	2.8	2.6	22	0.013	0.307	0.026	0.338	15.60
1974	2.5	2.3	25	0.019	0.344	0.021	0.346	14.01
1975	2.6	3.7	17	0.020	0.334	0.022	0.355	21.47
1976	3.4	3.3	18	0.022	0.321	0.014	0.342	19.10
1977	2.6	2.1	19	0.012	0.364	0.016	0.391	20.48
1978	2.7	3.8	18	0.014	0.383	0.030	0.414	23.26
1979	2.4	4.6	21	0.018	0.376	0.030	0.406	19.05
1980	2.0	5.2	18	0.031	0.407	0.018	0.425	23.61
1981	2.6	3.6	24	0.047	0.330	0.039	0.369	15.50
1982	3.0	3.2	18	0.038	0.350	0.051	0.401	22.28
1983	2.6	3.5	21	0.053	0.349	0.015	0.364	17.63
1984	2.3	5.0	17	0.032	0.360	0.021	0.398	23.77
1985	2.0	4.1	17	0.044	0.351	0.046	0.398	23.21
1986		4.7	17	0.039	0.361	0.053	0.400	23.81
1987	2.4	3.4	15	0.034	0.336	0.039	0.394	26.97
1988	2.2	5.9	16	0.021	0.380	0.043	0.443	27.52
1989	2.3	4.2	17	0.013	0.383	0.053	0.436	25.92
1990	2.3	5.4	15	0.018	0.373	0.026	0.418	27.51
1991	2.2	2.6	17	0.014	0.371	0.027	0.397	23.79
1992	2.3	2.6	15	0.014	0.381	0.047	0.428	28.52
1993	2.3	3.2	15	0.019	0.384	0.023	0.419	27.41
1994	2.5	3.7	15	0.024	0.362	0.038	0.400	26.99
1995	3.8	2.1	12	0.026	0.288	0.111	0.399	34.67
1996	3.7	1.2	10	0.027	0.327	0.051	0.411	41.06
1997	3.8	1.3	12	0.028	0.334	0.086	0.409	34.68
1998	3.8	2.3	13	0.009	0.332	0.056	0.388	28.80
1999	3.9	2.1	14	0.009	0.322	0.042	0.364	25.70
2000	3.9	2.0	11.0	0.016	0.357	0.065	0.422	38.26
2001	3.2	2.0	12.1	0.016	0.308	0.095	0.403	33.37
2002	3.3	2.5	14.4	0.020	0.335	0.054	0.389	27.10
2003	2.7	2.0	16.5	0.012	0.360	0.074	0.434	26.29
2004	3.8	1.9	13.7	0.020	0.330	0.073	0.403	29.32
2005	3.1	2.1	14.3	0.020	0.331	0.040	0.371	25.94
2006	3.4	0.9	12.6	0.040	0.326	0.052	0.378	29.94
2007	3.2	0.8	12.7	0.030	0.326	0.047	0.373	29.41
2008	3.3	1.0	12.8	0.035	0.364	0.040	0.403	31.41

Station P4

Year	Secchi (m)	Chl *a* (µg/L)	TP (µg/L)	NH_3 (mg/L)	TKN (mg/L)	NO_3 (mg/L)	TN (mg/L)	TN:TP
1969	3.4		26	0.042	0.325	0.034	0.359	13.81
1973	4.4	2.3	15	0.013	0.257	0.076	0.333	21.81
1974	3.7	2.5	17	0.026	0.296	0.080	0.380	22.21
1975	3.8	5.1	15	0.016	0.293	0.052	0.344	23.32
1976	4.2	3.9	15	0.010	0.293	0.057	0.350	23.33
1977	3.8	1.8	16	0.013	0.369	0.066	0.436	27.36
1978	3.6	3.7	14	0.018	0.309	0.062	0.371	26.95
1979	3.9	3.4	18	0.019	0.334	0.080	0.414	23.24
1980	3.0	4.5	15	0.028	0.330	0.043	0.373	25.17
1981	3.6	3.6	16	0.048	0.295	0.076	0.469	28.73
1982	3.9	3.5	17	0.052	0.309	0.085	0.394	23.37
1983	3.9	3.1	14	0.037	0.314	0.060	0.373	26.95
1984	3.2	5.0	15	0.035	0.330	0.070	0.400	26.02
1985	3.5	4.6	11	0.032	0.301	0.103	0.404	37.92
1986	3.2	3.7	11	0.029	0.295	0.109	0.404	36.69
1987	2.9	3.2	11	0.036	0.285	0.063	0.396	37.74
1988	3.0	5.3	12	0.023	0.321	0.083	0.404	32.75
1989	3.4	4.3	12	0.017	0.327	0.089	0.416	34.92
1990	3.1	4.3	11	0.019	0.329	0.110	0.440	39.96
1991	3.0	4.2	14	0.014	0.341	0.074	0.435	31.52
1992	3.2	2.4	12	0.013	0.336	0.103	0.439	36.32
1993	3.0	3.6	12	0.018	0.351	0.089	0.440	37.23
1994	3.1	3.2	12	0.022	0.312	0.091	0.403	34.74
1995	4.3	2.7	9	0.023	0.284	0.146	0.439	47.01
1996	5.1	2.0	8	0.021	0.264	0.141	0.405	52.07
1997	4.8	1.9	8	0.021	0.274	0.168	0.448	57.48
1998	4.8	2.8	10	0.009	0.283	0.100	0.384	38.38
1999	4.8	2.7	12	0.011	0.268	0.099	0.385	33.37
2000	5.1	2.3	7.2	0.009	0.277	0.167	0.444	61.55
2001	4.3	2.3	7.3	0.016	0.268	0.138	0.406	55.83
2002	3.8	2.6	9.0	0.017	0.285	0.140	0.425	47.13
2003	4.0	2.4	8.6	0.019	0.301	0.160	0.461	53.33
2004	3.8	2.1	10.7	0.018	0.272	0.155	0.427	40.05
2005	3.7	2.9	9.4	0.017	0.279	0.098	0.377	40.16
2006	4.1	1.2	8.9	0.036	0.272	0.114	0.386	43.36
2007	4.1	1.1	8.6	0.026	0.279	0.113	0.392	45.57
2008	4.2	1.7	9.7	0.035	0.324	0.098	0.444	45.87

Appendix G. Daily sewage flow, sewage TP concentration and TP load at the Victoria Harbour WWTP from 2003-2008. TP from station BS is also included. WWTP data were provided by Tay Township.

Year	WWTP Record date	Closest Open Water Sampling date	Stn BS TP (µg/L)	Sewage Flow (1000 m^3)	Sewage TP (g/m^3)	Daily TP Load (kg)
2003	20-May-03	22-May-03	17.54	1.946	0.06	0.117
2003	2-Jun-03	3-Jun-03	17.29	1.659	0.13	0.216
2003	17-Jun-03	17-Jun-03	16.54	1.837	0.13	0.239
2003	2-Jul-03	8-Jul-03	17.92	1.336	0.08	0.107
2003	28-Jul-03	29-Jul-03	18.33	1.205	0.11	0.133
2003	19-Aug-03	19-Aug-03	12.90	1.162	0.61	
2003	3-Sep-03	9-Sep-03	10.20	1.196	0.10	0.120
2003	30-Sep-03	30-Sep-03	10.00	1.548	0.10	0.155
2004	4-May-04	11-May-04	17.20	2.199	0.08	0.176
2004	17-May-04	25-May-04	13.60	2.071	0.12	0.249
2004	15-Jun-04	22-Jun-04	8.70	2.133	0.10	0.213
2004	28-Jun-04	6-Jul-04	22.40	1.769	0.06	0.106
2004	13-Jul-04	20-Jul-04	15.60	1.550	0.13	0.202
2004	27-Jul-04	3-Aug-04	16.60	1.498	0.05	0.075
2004	10-Aug-04	17-Aug-04	12.60	1.345	0.06	0.081
2004	23-Aug-04	31-Aug-04	13.30	1.552	0.05	0.078
2004	8-Sep-04	14-Sep-04	11.10	1.340	0.03	0.040
2004	22-Sep-04	28-Sep-04	10.80	1.355	0.07	0.095
2004	5-Oct-04	12-Oct-04	20.20	1.312	0.05	0.066
2005	9-May-05	3-May-05	14.20	2.159	0.06	0.130
2005	26-May-05	19-May-05	13.10	1.815	0.03	0.054
2005	7-Jun-05	31-May-05	17.30	1.760	0.03	0.053
2005	15-Jun-05	14-Jun-05	14.20	3.774	0.07	0.264
2005	30-Jun-05	28-Jun-05	13.80	2.247	0.04	0.090
2005	11-Jul-05	12-Jul-05	15.80	2.261	0.05	0.113
2005	26-Jul-05	26-Jul-05	21.70	1.550	0.06	0.093
2005	8-Aug-05	9-Aug-05	17.70	1.796	0.04	0.072
2005	23-Aug-05	23-Aug-05	13.50	1.706	0.06	0.102
2005	14-Sep-05	6-Sep-05	18.40	1.537	0.06	0.092
2005	27-Sep-05	20-Sep-05	15.50	1.230	0.07	0.086
2005	13-Oct-05	6-Oct-05	11.70	1.319	0.16	0.211
2006	2-May-06	2-May-06	13.60	1.760	0.04	0.070
2006	9-May-06	18-May-06	12.50	1.760	0.08	0.141
2006	23-May-06	30-May-06	12.10	1.760	0.07	0.123
2006	7-Jun-06	13-Jun-06	17.70	1.512	0.07	0.106
2006	20-Jun-06	27-Jun-06	15.20	1.512	0.10	0.151

2006	5-Jul-06	11-Jul-06	17.80	1.631	0.14	0.228
2006	18-Jul-06	25-Jul-06	16.80	1.631	0.08	0.130
2006	1-Aug-06	8-Aug-06	16.30	1.677	0.11	0.184
2006	15-Aug-06	22-Aug-06	10.90	1.677	0.14	0.235
2006	29-Aug-06	5-Sep-06	11.30	1.677	0.07	0.117
2006	14-Sep-06	19-Sep-06	14.60	1.334	0.04	0.053
2006	26-Sep-06	3-Oct-06	9.20	1.334	0.07	0.093
2007	24-Apr-07	1-May-07	15.60	0.620	0.06	0.037
2007	8-May-07	15-May-07	14.10	1.373	0.10	0.137
2007	22-May-07	29-May-07	10.90	1.179	0.03	0.035
2007	5-Jun-07	12-Jun-07	12.50	1.749	0.06	0.105
2007	19-Jun-07	26-Jun-07	17.80	1.450	0.08	0.116
2007	10-Jul-07	10-Jul-07	11.00	1.453	0.10	0.145
2007	24-Jul-07	24-Jul-07	11.80	1.416	0.13	0.184
2007	2-Aug-07	7-Aug-07	12.30	1.398	0.16	0.224
2007	14-Aug-07	28-Aug-07	15.80	1.398	0.24	0.336
2007	29-Aug-07	4-Sep-07	23.80	1.465	0.16	0.234
2007	11-Sep-07	18-Sep-07	10.30	1.695	0.13	0.220
2007	25-Sep-07	2-Oct-07	16.20	1.579	0.12	0.189
2007	9-Oct-07	16-Oct-07	21.50	1.526	0.19	0.290
2008	6-May-08	6-May-08	17.00	1.910	0.04	0.076
2008	20-May-08	20-May-08	12.00	1.709	0.14	0.239
2008	3-Jun-08	6-Jun-08	12.90	1.515	0.20	0.303
2008	17-Jun-08	17-Jun-08	15.20	1.340	0.08	0.107
2008	2-Jul-08	2-Jul-08	22.60	1.513	0.08	0.121
2008	20-Jul-08	15-Jul-08	19.50	1.651	0.05	0.083
2008	29-Jul-08	29-Jul-08	20.50	0.958	<0.03	0.014
2008	12-Aug-08	12-Aug-08	11.70	1.414	0.10	0.141
2008	26-Aug-08	26-Aug-08	20.30	1.468	<0.03	0.022
2008	9-Sep-08	9-Sep-08	18.50	1.293	0.16	0.207
2008	23-Sep-08	23-Sep-08	12.90	1.213	0.10	0.121
2008	7-Oct-08	7-Oct-08	18.60	1.525	0.11	0.168

Appendix H. Total phytoplankton biovolume (mm^3/m^3) from seasonally recombined samples for P1, P4, M1, PM2 and BS from1973-2008.

Year	P1	P4	M1	PM2	BS
1973	6853	2430	2254	1180	1822
1974	4871	2711	2847	2550	1471
1975	5036	2381	1765	2039	826
1976	3515	1670	2163	1892	829
1977	5955	2193	2470	1801	918
1978	8324	1848	2661	1770	862
1979	6438	1355	2541	1941	739
1980	6771	4389	6417	3399	1132
1981	4589	1117	1963	898	731
1982	4049	1596	1680	1474	530
1983	4343	1200	1459	1657	2424
1984	5689	2271	4919	1378	974
1985	4961	2978	2017	1985	821
1986	6357	1424	2716	1936	2130
1987	7310	2423	3906	1828	523
1988	4716	1774	1975	1101	1875
1989	7774	2328	2777	1184	723
1990	3922	1084	1647	1220	1140
1991	5098	1136	1258	916	157
1992	2129	1219	1123	574	466
1993	4403	1195	1456	1453	715
1994	3266	1873	1653	1001	747
1995	2076	740	417	245	628
1996	1966	440	477	272	231
1997	1320	302	426	397	418
1998	863	515	505	290	647
1999	1246	297	686	178	406
2000	729	228	455	249	234
2001	1597	646	478	313	182
2002	1749	613	757	395	315
2003	545	403	490	267	412
2004	943	358	727	283	169
2005	949	1123	1109	623	498
2006	1592	423	561	452	311
2007	1468	563	573	298	315
2008	904	444	561	274	684

Appendix I. Seasonal and average biovolume (mm^3/m^3) for seven algal divisions at BS, PM2, PS and M5 in 2008.

Station	Division	6-May	20-May	3-Jun	17-Jun	2-Jul	15-Jul	29-Jul	12-Aug	26-Aug	9-Sep	23-Sep	7-Oct	Seasonal Average
BS	Cyanophyte	0.06	2.05	2.13	0.57	7.72	32.24	31.75	12.09	141.10	53.60	28.88	1.29	26.12
	Dinophyte	12.32	23.59	409.66	68.16	21.14	0	0	12.21	19.41	0	10.47	0.55	48.13
	Cryptophyte	154.31	224.93	51.10	8.39	31.21	60.15	42.91	14.98	65.50	23.48	34.34	86.06	66.45
	Euglenophyte	0	0	7.22	3.25	0.87	1.64	5.54	3.71	1.82	0	0.46	0	2.04
	Chrysophyte	13.75	11.98	196.61	34.69	39.14	4.10	6.77	0.90	3.32	0.66	5.43	2.61	26.66
	Chlorophyte	18.13	13.63	33.01	18.73	7.39	8.10	696.15	51.68	125.32	111.35	16.03	61.08	96.72
	Bacillariophyte	68.71	117.97	41.38	61.14	33.30	23.29	890.24	268.29	729.93	613.23	51.01	55.34	246.15
	TOTAL	**267.28**	**394.15**	**741.11**	**194.93**	**140.77**	**129.52**	**1673.36**	**363.86**	**1086.40**	**802.32**	**146.62**	**206.93**	**512.27**
PM2	Cyanophyte	0	0.39	0.02	0.25	4.76	29.03	68.06	61.43	30.18	47.06	11.67	8.58	21.79
	Dinophyte	3.25	9.50	40.63	216.34	8.27	4.77	2.88	15.97	5.12	17.24	9.27	1.96	27.93
	Cryptophyte	146.32	142.18	63.84	24.36	343.69	62.20	49.79	18.97	12.71	40.81	32.63	52.63	82.51
	Euglenophyte	0	0	0	0.21	0.12	0.81	0.29	5.74	0.59	0.40	0.39	0	0.71
	Chrysophyte	3.58	13.40	43.06	26.59	35.68	24.03	34.54	26.85	11.65	16.47	37.86	17.72	24.29
	Chlorophyte	1.72	0.88	5.24	2.20	3.59	38.45	51.34	18.14	28.52	15.39	7.77	1.57	14.57
	Bacillariophyte	39.33	95.92	37.32	12.05	75.02	93.93	262.28	130.60	57.07	209.36	167.27	42.38	101.88
	TOTAL	**194.20**	**262.27**	**190.11**	**282.00**	**471.13**	**253.22**	**469.18**	**277.70**	**145.84**	**346.73**	**266.86**	**124.84**	**273.67**
PS	Cyanophyte	0.02	0.15	0.53	6.67	11.52	48.05	79.27	36.79	34.71	8.39	7.70	0.93	19.56
	Dinophyte	6.47	4.09	20.05	45.07	11.23	2.97	2.69	13.02	2.90	0.48	0.24	0.78	9.17
	Cryptophyte	216.58	100.59	120.57	26.71	34.21	25.31	26.57	13.24	25.85	18.67	13.07	25.21	53.88
	Euglenophyte	0	0	2.25	0.77	0.14	0.18	6.07	0.49	1.22	2.67	0	0	1.15
	Chrysophyte	18.46	17.21	21.74	18.59	26.42	77.71	14.48	29.66	11.89	9.10	6.66	4.10	21.34
	Chlorophyte	1.90	2.87	14.28	31.11	4.79	22.72	21.96	66.87	63.30	20.96	15.48	5.59	22.65
	Bacillariophyte	27.72	16.55	54.39	28.54	32.66	39.86	255.83	19.87	30.55	21.07	95.65	34.82	54.79
	TOTAL	**271.15**	**141.46**	**233.81**	**157.46**	**120.97**	**216.80**	**406.87**	**179.94**	**170.42**	**81.34**	**138.80**	**71.43**	**182.54**
M5	Cyanophyte	0	0	0.01	1.69	44.76	156.72	136.44	54.05	18.48	54.74	9.75	0.93	39.80
	Dinophyte	3.19	64.98	96.00	3.65	0	7.96	4.80	22.73	11.01	14.48	13.18	0.78	20.23
	Cryptophyte	82.71	63.91	37.67	51.10	92.00	44.51	16.22	28.78	50.21	55.14	101.99	25.21	54.12
	Euglenophyte	0	0	0	0	0	0.43	0	2.93	0	0	0	0	0.28
	Chrysophyte	15.06	48.81	54.03	27.75	12.13	128.52	13.83	21.57	17.60	69.77	26.21	4.10	36.62
	Chlorophyte	3.79	3.82	2.81	5.97	19.07	36.24	35.02	23.20	11.38	27.01	3.86	5.59	14.81
	Bacillariophyte	2.00	17.27	47.87	267.68	349.36	630.11	267.43	98.20	84.25	502.03	214.25	34.82	209.61
	TOTAL	**106.75**	**198.79**	**238.39**	**357.84**	**517.32**	**1004.49**	**473.74**	**251.46**	**192.93**	**723.17**	**369.24**	**71.43**	**375.46**

Appendix J. Seasonal biovolume (mm^3/m^3) of select genera at BS, PM2, PS and M5 in 2008.

	Station	6-May	20-May	3-Jun	17-Jun	2-Jul	15-Jul	29-Jul	12-Aug	26-Aug	9-Sep	23-Sep	7-Oct
Microcystis	BS	0	0	0	0	4.24	10.20	22.15	9.40	22.68	2.35	21.16	1.14
(Cyanophyte)	PM2	0	0	0	0.25	2.35	24.50	54.51	50.25	14.67	2.93	2.71	0.40
	PS	0	0	0	6.26	10.45	41.67	61.22	15.34	19.12	1.36	4.88	0.27
	M5	0	0	0	0	1.69	40.40	114.42	112.03	22.17	9.29	25.17	0.57
Peridiniopsis	BS	5.14	15.65	402.92	68.16	19.04	0	0	0	9.42	0	10.47	0
(Dinophyte)	PM2	1.52	8.28	34.40	0	8.27	1.10	1.15	4.24	0.86	0	0.47	0.58
	PS	0.54	0	10.74	40.83	9.44	0	2.69	2.49	0	0.48	0.24	0.78
	M5	0	1.35	57.11	92.81	3.65	0	0	0	0	0	0.34	0.97
Rhodomonas	BS	127.76	213.82	27.52	1.29	25.85	33.86	34.82	11.50	61.35	21.93	28.81	65.49
(Cryptophyte)	PM2	128.83	138.17	32.66	18.31	325.09	41.07	30.24	8.67	11.26	17.82	21.45	49.21
	PS	199.39	66.42	88.13	22.18	28.54	15.44	14.25	8.53	14.54	10.04	11.22	24.27
	M5	151.44	77.11	38.39	19.48	17.55	21.88	21.88	9.58	12.44	28.13	14.39	45.89
Fragilaria	BS	3.09	16.61	2.49	4.52	0	1.79	338.78	128.89	37.63	8.28	3.16	3.37
(Bacillariophyte)	PM2	0.98	62.40	18.00	6.42	11.14	51.26	243.94	83.46	13.09	19.04	15.06	7.06
	PS	2.77	1.87	33.81	2.12	2.90	0.49	229.05	1.56	3.57	1.29	5.28	0.14
	M5	0	0.47	1.53	4.08	92.24	310.22	605.18	242.15	59.46	42.72	127.73	34.56

Appendix K. Relative biomass of calanoid copepod, cyclopoid copepod, daphnid cladoceran, and non-daphnid cladoceran zooplankton, and total biomass (mg/m^3) at station BS from 1988-2008. Data for 2006 and 2007 are unavailable.

Year	% Calanoid Copepods	% Cyclopoid Copepods	% Daphnid Cladocera	% Non-Daphnid Cladocera	Total Biomass (mg/m^3)
1988	6.74	43.95	17.98	31.29	80.05
1989	5.61	40.20	19.56	34.62	68.37
1990	4.35	23.53	12.57	59.55	77.31
1991	6.50	27.83	4.77	60.90	34.00
1992	2.81	26.90	28.46	41.82	70.01
1993	9.08	37.35	5.96	47.61	46.30
1994	5.85	35.12	2.96	56.08	40.09
1995	12.04	34.06	9.19	44.71	21.49
1996	13.64	27.87	3.35	55.13	18.19
1997	10.93	41.06	1.14	46.87	21.27
1998	11.21	36.82	7.93	44.04	30.57
1999	9.47	37.11	8.67	44.76	26.89
2000	9.32	37.91	8.48	44.30	18.43
2001	15.73	28.10	0.64	55.53	16.24
2002	6.90	43.83	7.86	41.41	17.21
2003	14.78	43.61	2.20	39.40	11.45
2004	11.88	34.68	1.11	52.33	10.50
2005	12.70	40.73	3.69	42.87	21.11
2008	20.68	36.90	4.18	38.24	22.78