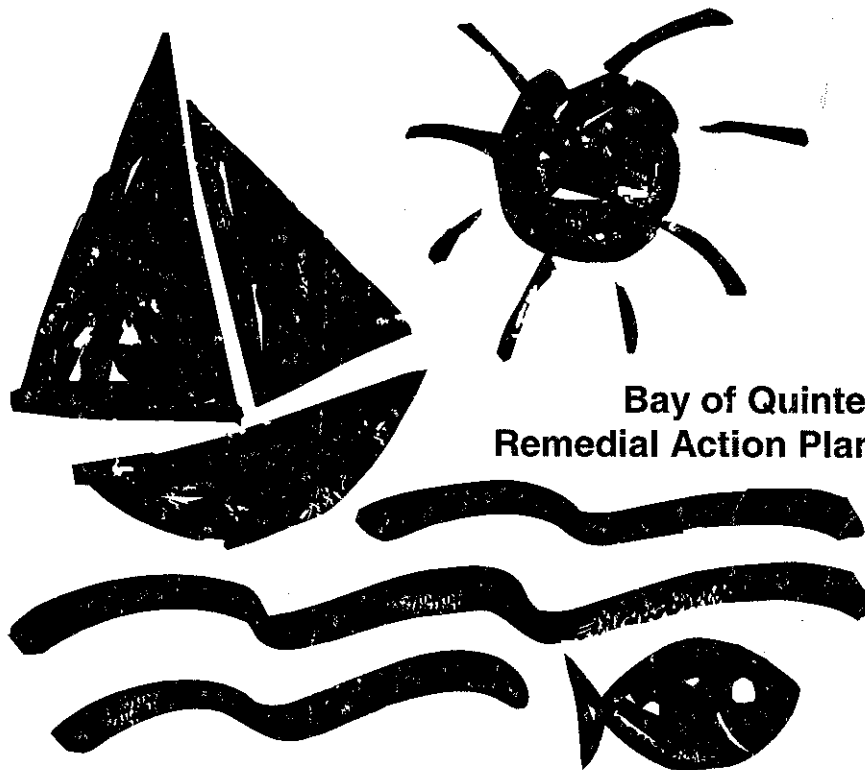


# **THE BIG CLEANUP**



**Bay of Quinte  
Remedial Action Plan**

**MONITORING REPORT #14**

**PROJECT QUINTE ANNUAL REPORT 2003**

**Bay of Quinte RAP Restoration Council / Project Quinte**

**July 2005**

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**BAY OF QUINTE REMEDIAL ACTION PLAN  
MONITORING REPORT #14**

**PROJECT QUINTE ANNUAL REPORT  
2003**

*prepared by*

*Project Quinte members*

*in support of the Bay of Quinte Remedial Action Plan*

Bay of Quinte Remedial Action Plan  
Kingston, Ontario, Canada.

July 2005

Editors Note:

This report does not constitute publication. Many of the results are preliminary findings. The information has been provided to assist and guide the Bay of Quinte Remedial Action Plan. The information and findings cannot be used in any manner or quoted without the consent of the individual authors. Individual authors should be contacted prior to any other proposed application of the data herein.

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## FOREWORD

### BAY OF QUINTE REMEDIAL ACTION PLAN MONITORING REPORT #13

#### 2003 PROJECT QUINTE ANNUAL REPORT

In 1985, the Great Lakes Water Quality Board of the International Joint Commission (IJC) identified 42 **Areas of Concern** in the Great Lakes basin where the beneficial uses of the water were impaired. The Board recommended that the appropriate jurisdictions and government agencies prepare, submit and implement a Remedial Action Plan (RAP) in each area to restore the water uses.

The Bay of Quinte was designated as one of the Areas of concern. Ten of 14 beneficial uses described in Annex 2 of the *Great lakes Water Quality Agreement (revised 1987)* are impaired. The impaired uses include beach postings, eutrophication or undesirable algae, restrictions on fish consumption, taste and odour problems in drinking water, etc. The contributing factors are excessive phosphorus loadings, persistent toxic contaminants, bacteriological contamination, as well as alterations and destruction of shorelines, wetland and fish habitat.

The preparation of the Bay of Quinte RAP was initiated in 1986 with the formation of a joint federal-provincial Coordinating Committee. A Public Advisory Committee (PAC) was established in 1988. The PAC provided public commentary and community liaison to RAP development, programs and projects. This fruitful partnership contributed to the creation of RAP Stage 1 (1990) and Stage 2 (1993) reports, a series of technical documents, and numerous public outreach resources

In 1997, the Bay of Quinte RAP was reorganized. A new, locally managed implementation group was formed called the Restoration Council to provide a local voice to facilitate and oversee cleanup actions. The PAC also evolved and became a distinct incorporated entity known as Quinte Watershed Cleanup but still committed to on-going RAP progress.

The Bay of Quinte RAP Restoration Council is assisted by two organizations: (i) Quinte Watershed Cleanup (QWC) and (ii) Project Quinte scientists. The Bay of Quinte RAP program relies on the QWC for public input and Project Quinte scientists for ongoing scientific and technical advice. The contributions from both groups cannot be understated. The Bay of Quinte RAP has progressed smoothly, met the expectations of the public-at-large and incorporated an ecosystem approach because of the two organizations.

Project Quinte is a long-term, multi-agency research and monitoring project. The project's original objectives included studying, comparing and evaluating the Bay of Quinte limnological attributes (biological, chemical and physical) before and after phosphorus control

was implemented at municipal sewage treatment plants thus reducing phosphorus loads to the bay. Project Quinte began in 1972 and continues today. The time between 1972 and 1977 is referred to as the **pre-phosphorus control period**, while post-1977 is the **post-phosphorus control period**. Changes in water quality, as well as aquatic communities (e.g. phytoplankton, zooplankton, benthic and fish) between pre- and post-periods have been compared. Phosphorus control strategies were assessed. Finally, long-term ecosystem responses within the Bay of Quinte were examined and described. This information has been reported annually in a Project Quinte Annual Report. A summary of the research was also presented in **Special Publication No. 86 of the Canadian Journal of Fisheries and Aquatic Sciences in 1986** and in many papers in the scientific literature.

A major focus of Project Quinte is to assess changes in lower trophic level productivity in response to the invasion of the bay by zebra mussels that began in 1994. The response to invasion of the bay by both zebra mussels and other non-native species of both zooplankton and fish and how changes are transferred up the food chain is currently being addressed. Clearly, managing both the fishery and phosphorus loadings during alterations in the food chain presents a challenge that requires the yearly productivity assessment provided by Project Quinte.

This report is the fourteenth in a series of water quality monitoring reports produced by the Bay of Quinte RAP. At this time, the information is **background reference material**. The information has been compiled and reported so that (1) the Bay of Quinte RAP Restoration Council and QWC can formulate abatement and remedial options, and (2) as a means to monitor remedial actions and report progress.

By way of this foreword, the Bay of Quinte **RAP Restoration Council** notifies potential users that **this report does not constitute publication. Many of the results are preliminary findings. The information has been provided to assist and guide the Bay of Quinte Remedial Action Plan. The information and findings cannot be used in any manner or quoted without the consent of the individual authors. Individual authors should be contacted prior to any other proposed application of the data herein.**

The Bay of Quinte RAP, when completed, will contain a summary of the findings and conclusions of these reports.

## **PREFACE**

This report has been prepared as part of the Bay of Quinte RAP under the auspices of the Canada-Ontario Great Lakes Remedial Action Plan program. Financial assistance and technical sponsorship for the investigations and research was provided by Fisheries and Oceans Canada, Environment Canada, the Ontario Ministry of the Environment and the Ontario Ministry of Natural Resources.

This report is the 14th in the Bay of Quinte RAP monitoring report series. It is part of the investigations, remedial action assessment and ecosystem monitoring conducted in support of the Bay of Quinte Remedial Action Plan. The report presents preliminary findings and data. The information presented does not necessarily represent the view or policies of the sponsoring agencies.

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## INTRODUCTION

Project Quinte is a co-operative, multi-agency, research and monitoring project between the federal (Department of Fisheries & Oceans) and provincial governments (Ontario Ministry of Natural Resources, Ontario Ministry of the Environment) that has investigated the long-term effects of the reduction in point-source phosphorus (P) loadings (Minns et al. 1986), food-chain influences (Nicholls and Hurley 1989), and more recently zebra mussel colonization (RAP monitoring reports Nos.7-12) on trophic dynamics of the entire bay ecosystem.

The Bay of Quinte is one of 42 severely impaired ecosystems (Area of Concern - AOC) on the Great Lakes. Annex 2 of the Revised Great Lakes Water Quality Agreement of 1978 outlined a three stage Remedial Action Plan process that called for the identification of impaired beneficial uses (Stage I), their causes and a plan to be implemented (stage II) to restore these uses. The third and final stage of the RAP process requires monitoring to measure the success of RAP implementation that should ultimately lead to delisting the Bay of Quinte as an AOC. Project Quinte has been invaluable to stage three of the Remedial Action Plan (RAP), supporting an essential, continuing program of research and monitoring in the bay. Project Quinte has contributed long-term data that was used to produce comprehensive assessments of the status of two impaired beneficial uses, phytoplankton (Nicholls, Monitoring Report #11) and zooplankton (Johannsson and Nicholls, Monitoring Report #12)

Project Quinte presented the first evidence of the impact of zebra mussels on the Bay of Quinte ecosystem in the 1995 monitoring report. Since that time we have observed variable impact, both spatially and inter-annually, of this invader on physical, chemical and biological properties of the bay (e.g. transparency, phosphorus, and lower trophic level biomass and production). There are no other Great Lakes studies that have the benefit of the extensive multi-trophic level database that exists for the Bay of Quinte to determine ecosystem level impacts of Dreissenid mussels. We stand to learn a great deal about the impacts of this exotic species on fisheries productivity in the Bay of Quinte that may be of use in other ecosystems where background data is not as extensive.

The scope of the work in Project Quinte is rare in freshwater ecosystem research, now encompassing multi-year, multi-trophic level data from bacteria to fish. These data are being used to develop an ecosystem model for the bay that is being compared to a similar model being developed for Oneida Lake, another productive ecosystem that has undergone similar invasions by exotic species and declines in key fish species. See the chapter by Koops et al. in this report for a synopsis of the second year's progress on the ecosystem modeling project funded by the Great Lakes Fisheries Commission. Long-term data sets for biomass, species composition and production for all trophic levels provide a unique opportunity to model trophic interactions in the bay and determine how various factors are impacting important fish populations.

An investigation on the spatial and seasonal extent of taste and odour and algal toxicity problems in the bay was conducted for the first time in 2003 and is reported here by Dr. Susan Watson of Environment Canada. Proliferation of the cyanobacteria *Microcystis* has been a common occurrence in many parts of the Great Lakes including the Bay of Quinte since zebra mussels have been established. This alga produces the neuro-toxin microcystin, a potential health threat. Initiating a pilot study in 2003 on the extent of this problem in the bay was considered a high priority.

This report provides a detailed summary of the results and highlights for the 2003 field season, prepared by various scientists studying the bay. Please contact these individuals directly if further explanation or detail is required.

### **Link to the Remedial Action Plan**

Progress towards restoration goals must be measured in order to delist impaired beneficial uses. The ongoing monitoring provided by Project Quinte is invaluable in assessing restoration progress as the federal government attempts to delist this AOC. The restoration goals originally set as part of the stage II development were considered to be the interim. Project Quinte has been instrumental in developing more realistic goals for phytoplankton, zooplankton, benthos and other related beneficial uses. Information on listing criteria and delisting goals has been summarized in the report, "Bay of Quinte RAP Monitoring and Delisting Strategy IBU Assessment Statements 2003" prepared for the Bay of Quinte Restoration Council under contract to Murray German Consulting and Fred Stride Environmental.

## ECOSYSTEM MODELLING: COMPARING THE BAY OF QUINTE AND ONEIDA LAKE

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The Bay of Quinte ecosystem has experienced a number of significant changes, including phosphorus control and reduced nutrient loadings, invasion by exotic species, increased water clarity and macrophyte coverage, and changing abundances of key fish species. The implementation of phosphorus control measures in the mid-1970's resulted in reduced nutrient loadings to the bay and increased water clarity, which allowed an expansion of the existing macrophyte beds. Starting in the early 1990's, invasion by the zebra mussel (*Dreissena polymorpha*) further increased water clarity, accelerating the spread of submerged macrophytes. Current macrophyte coverage in the bay is extensive and impacts the abundance of some fishes. Other recent invaders (e.g. *Cercopagis pengoi* and the round goby, *Neogobius melanostomus*) are expected to further modify energy flow in the Bay of Quinte ecosystem.

Fish populations are exhibiting the impacts of these ecosystem changes. As the water column clears and macrophyte coverage expands, a reduction in the abundance of walleye (*Sander vitreus*) and increased abundance of sunfishes (*Lepomis* sp.) and smallmouth bass (*Micropterus dolomieu*) have been observed. This is of particular concern to the walleye fishery which declined through the 1990s.

Many hypotheses have been proposed to account for the impact of these ecosystem changes. Because of the many variables at multiple trophic levels that interact to influence ecosystem dynamics, the development of an ecosystem model is needed to evaluate the proposed hypotheses. The approach chosen for this task was Ecopath with Ecosim (EwE, available at [www.ecopath.org](http://www.ecopath.org)).

## Modelling Approach – Ecopath with Ecosim

The Ecopath with Ecosim (EwE) modelling approach is a two step process. The first step (Ecopath) is the construction of a mass balanced model of the ecosystem, the second step (Ecosim) uses the balanced model to run time dynamic simulations to explore potential ecosystem impacts of future changes and management strategies.

Mass balance in Ecopath is achieved by solving the master equation (Christensen et al., 2000):

$$[Production] - [Predation] - [Catch] - [Accumulation] - [Migration] - [Other Mortality] = 0$$

$$P_i - M2_i - Y_i - BA_i - E_i - MO_i = 0$$

This equation must be solved simultaneously for each group (species or functional group) in the model.  $P_i$  is the total production in group  $i$ ,  $M2_i$  is the total predation on group  $i$  determined by the consumption of group  $i$  by each of its predators as specified in the diet matrix,  $Y_i$  is the total fishery catch of group  $i$ ,  $BA_i$  is the biomass accumulation of group  $i$ ,  $E_i$  is the net migration of group  $i$ , and  $MO_i$  represents the 'other mortality' on group  $i$ . Other mortality is calculated from the 'ecotrophic efficiency' term specifying the proportion of production used within the ecosystem model, i.e. the proportion of  $P_i$  that is accounted for by  $M2_i$ ,  $Y_i$ ,  $BA_i$  and  $E_i$ .

The user must specify the diet composition, biomass accumulation, fishery catches and net migration for each group. In addition, the user must specify three of the following four parameters: production to biomass ratio ( $P/B$ ), consumption to biomass ratio ( $Q/B$ ), biomass ( $B$ ), and ecotrophic efficiency ( $EE$ ). By only specifying three parameters, one parameter is free to be estimated by the EwE software to bring the model into mass balance. Usually, but not always, the  $EE$  parameter is left unspecified as it is often the most difficult to estimate, and since it can only range between 0 and 1 it provides an easy check for mass-balance.

In most cases, initial inputs of parameter values will not result in a balanced model. Therefore, it is necessary to adjust parameter values to bring the model into mass-balance. When

adjusting parameter values, having estimates of uncertainty about the input values can ensure that these values are not adjusted unrealistically. A balanced model is one subset of possible parameter values that can represent the ecosystem. Further evaluation of the parameter values is then needed.

### **Comparative Modelling Project**

Funding was secured through the Great Lakes Fishery Commission (GLFC). This project will conduct comparative ecosystem modelling of the Bay of Quinte and Oneida Lake ecosystems. These two ecosystems have been intensely studied and there exists long-term data (approaching 30 years) for many components of these ecosystems. This provides the project team with the data necessary to estimate many of the model components. In addition, both the Bay of Quinte and Oneida Lake are shallow, eutrophic systems that have undergone reductions in productivity due to phosphorus control and zebra mussel invasion, and both experienced a decline in walleye abundances through the 1990s. This project started in September 2002; however, it builds upon modelling started in 2000-2001 (Millard and Minns 2003).

### **Project Objectives**

The Quinte-Oneida comparative ecosystem modelling project is using a combination of ecosystem and population modelling approaches to answer the pressing question "Why did walleye stocks decline in both the Oneida Lake and eastern Lake Ontario Bay of Quinte ecosystems?" The project has the following three main elements which are being applied equally to the Bay of Quinte and Oneida Lake:

1. Whole ecosystem mass balance modelling with emphasis on comparisons between the Bay of Quinte and Oneida Lake.
2. Detailed population modelling of key fish stocks (walleye and yellow perch) present in both ecosystems and contributing significantly to fisheries production.
3. Food web analysis using stable isotopes with a primary focus on key fish stocks in both systems with and without the presence of dreissenids (see chapter by J. Bowman).

The present chapter focuses on the first element – the ecosystem modelling.

### 2003 Progress

During 2003, the Quinte-Oneida project team held two workshops. The first workshop was at the Canada Centre for Inland Waters, Burlington, ON (30 April – 1 May). Initial presentations on comparisons of each ecosystem group were made in preparation for the Ecosystem Comparison to be held at IAGLR 2003. The data needed to parameterize the Ecopath models were identified along with a deadline that would allow initial models to be balanced before the second workshop. Revisions to the initial list of ecosystem groups (Koops et al. 2004) were made (Table 1).

The Quinte-Oneida project team organized and presented a half-day scientific session at the 46<sup>th</sup> Annual Conference on Great Lakes Research held at DePaul University in Chicago (22-26 June). The theme of the session was "Ecosystem Comparison: The Bay of Quinte, Lake Ontario and Oneida Lake". All the papers presented in the session were by personnel involved in the Quinte-Oneida comparative modelling project. Presentations spanned all trophic levels and encompassed topics such as the importance of detritus and the microbial food web in the Quinte Ecopath model, long-term changes in sources of primary production in the two ecosystems, factors controlling zooplankton production, comparison of changing benthos communities, comparison of nearshore and offshore habitats in the Bay of Quinte and several papers describing the fisheries of the two ecosystems. This session served the purpose of bringing researchers together from both ecosystems to ask questions and synthesize data. The papers on the microbial food web and sources of primary production were of particular importance as they dealt directly with gaps in the Ecopath model

The second project workshop was held at the Isaiah Tubbs Resort and Conference Centre, Picton, ON (22-23 October). At this time, initial balanced Ecopath models for the post-dreissenid invasion time period (post-1995 for Quinte and post-1992 for Oneida) were presented and discussed. The models had a total of 37 ecosystem groups (Table 1, Figure 1) spread across detritus, primary producers, zooplankton, benthos, and fish. At this point, it was felt that the models contained all the groups to be considered, with the exception of cormorants. A large portion of the biomass in each ecosystem was sequestered in the detritus, macrophytes and

dreissenids (Figure 1). These models had fewer groups than proposed after the project's inaugural workshop (Koops et al. 2004) due to the fact that some groups were combined and the microbial food web (MFW) was dropped from the initial comparisons. Even though early comparisons of the Quinte Ecopath model with and without the MFW suggested that inclusion of the MFW could affect the predictions made by the model, the MFW was dropped from the initial comparisons due to a lack of data on the MFW for Oneida Lake. Instead, it was decided that the Quinte model with the MFW would be used as a separate product to examine the importance of the MFW to Ecopath modelling.

Table 1. Ecosystem groups included in the Bay of Quinte and Oneida Lake Ecopath models at the end of 2003.

Trophic Level	No. Groups	Description
Detritus	3	Pelagic, Sedimented, DOC
1° Producers	4	Phytoplankton, Epiphyton, Periphyton, Macrophytes
Zooplankton	5	Copepods, <i>Cercopagis</i> <sup>1</sup> , Rotifers, Predatory Cladocerans, Herbivorous Zooplankton
Benthos	6	Amphipods/Isopods, Oligochaetes-Chironomids, Gastropods, Bivalves, Dreissenids, Other Benthos
Fish	19	Walleye (Adult & YOY), Yellow Perch (Adult & YOY), White Perch (Adult & YOY), Panfish (Adult & YOY), Alewife, Smallmouth Bass, Lake Sturgeon <sup>2</sup> , Drum, Gizzard Shad, Carp, Gobies <sup>1</sup> , Trout-perch, Other Piscivores, Other Invertivores, Other Planktivores

<sup>1</sup>Only present in the Bay of Quinte model. <sup>2</sup>Only present in Oneida Lake model.

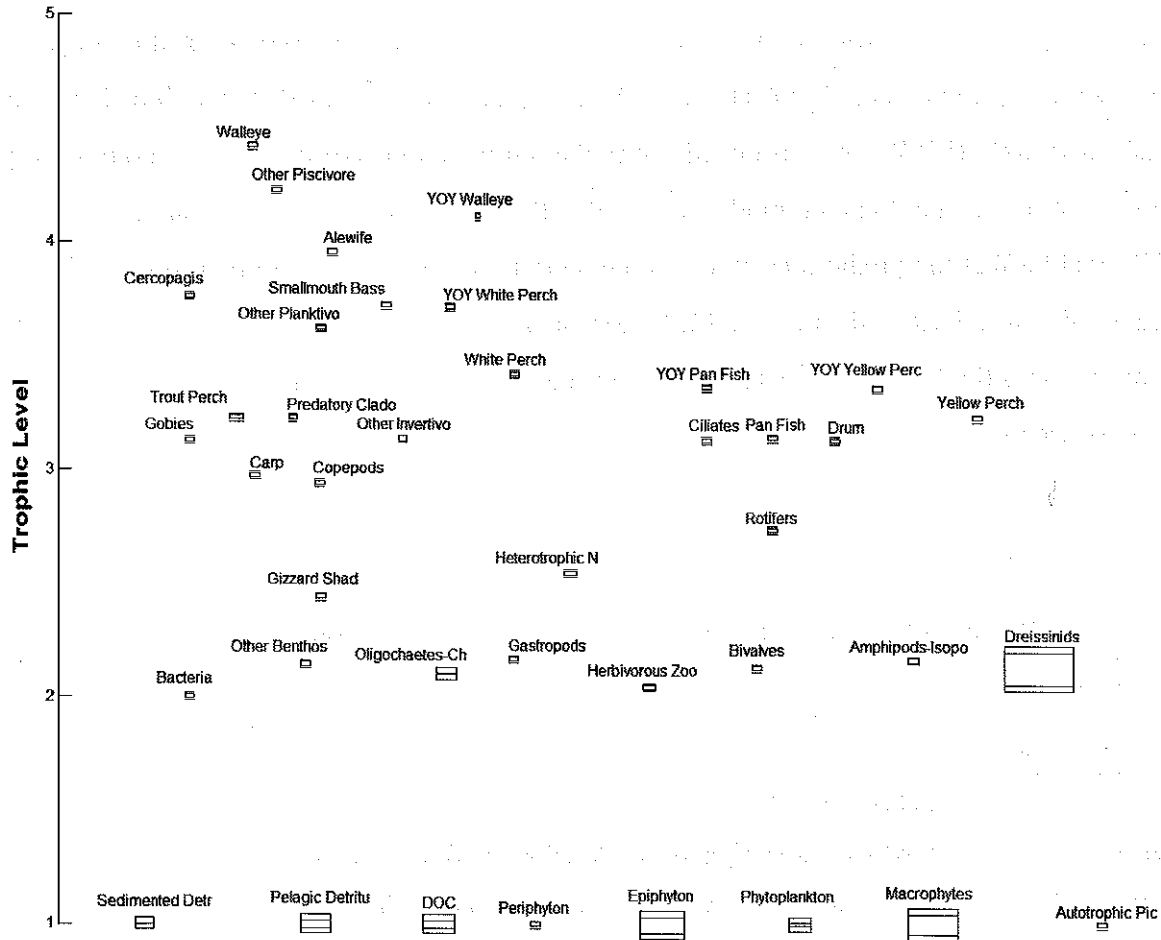


Figure 1. Ecopath model food web for the Bay of Quinte, showing each of the model groups/species (as listed in Table 1). Vertical arrangement is by trophic level, horizontal arrangement is for presentation. Box size is relative to biomass abundance in the upper Bay of Quinte.

## 2004 Goals

The goals for the ecosystem modelling portion of the Quinte-Oneida project for 2004 include:

1. Add cormorants as a top predator in the food web.
2. Presentation at the World Fisheries Congress in Vancouver, BC in May 2004.
3. Finalize Ecopath models for both the Bay of Quinte and Oneida Lake.
4. Identify Ecosim scenarios to explore.

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## POINT SOURCE PHOSPHORUS LOADINGS 1965 TO 2003

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Total phosphorus loads to the Bay of Quinte from six municipal sewage treatment plants (STP) bordering the Bay of Quinte between 1965 and 2003 were derived from routine Ontario Ministry of the Environment (MOE) monitoring data (Table 1). Phosphorus loadings are reported as kilograms per day ( $\text{kg d}^{-1}$ ). Loadings are calculated as the monthly average effluent phosphorus concentration multiplied by the monthly average effluent flow from the STP for the period of record.

In 2003, the estimated total phosphorus loads from STPs bordering the Bay of Quinte were  $22.3 \text{ kg d}^{-1}$  for the year and  $9.3 \text{ kg d}^{-1}$  for the May to October period. Since 1991, low total phosphorus inputs have been maintained by controlling variability in wastewater flow, enhancing phosphorus removal capabilities and expanding treatment capacity. To manage long term phosphorus loading, the MOE advised municipalities that a Bay of Quinte RAP "phosphorus load cap" would be applied to STPs bordering the Bay of Quinte. Initially, the "load cap" was to be calculated as the product of a total phosphorus effluent concentration of  $0.3 \text{ mg L}^{-1}$  and the STP hydraulic capacity for STPs bordering the Bay of Quinte. This "load cap" would be used post 1995 to measure and assess performance. Since 1995, most of the municipal STPs have voluntarily reduced total phosphorus inputs or have had upgrades where the "load cap" has been incorporated into the STP's operating Certificate of Approval. It is also noted that data has been obtained from the 8 Wing Trenton STP for 1998 through to 2003.

Similarly, the MOE has advised municipalities that a Bay of Quinte RAP phosphorus load cap has been applied in the Bay of Quinte watershed in 1995. The watershed "load cap" has been initially established as the product of a total phosphorus effluent concentration of  $0.5 \text{ mg L}^{-1}$  and the STP hydraulic capacity. Most STPs in the watershed have voluntarily reduced total

phosphorus inputs or have had upgrades where the “load cap” has been incorporated into the STP’s operating Certificate of Approval.

Complete bypassing events are not accurately reported in the data as presented. Appreciable bypassing continues to occur at some STPs adding to the phosphorus loading to the Bay of Quinte. Continued efforts are required to control wastewater influent flow variability and reduce bypassing to effectively “cap” phosphorus inputs to the Bay of Quinte.

Table 1. Phosphorus loadings from municipal sewage treatment plants bordering the Bay of Quinte (total P  $\text{kg}\cdot\text{d}^{-1}$ ) from 1965 to 2003.

Period	T	CFB	B	D	N	P	TOTAL
1965-72	53.0	13.0	110.0	2.7	20.0	15.0	214.0
1973-75	47.0	5.9	73.0	2.3	17.0	11.0	156.0
1976-77	43.0	2.1	39.0	2.3	63.0	9.1	158.0
1978-86							
Jan-Dec	7.5	1.9	31.0	0.9	24.0	2.4	68.0
May-Oct	6.3	1.7	25.0	0.7	24.0	1.9	60.0
1987 Jan-Dec	5.9	2.7	16.0	0.6	11.0	2.1	38.0
May-Oct	6.4	2.0	15.0	0.5	6.2	1.8	32.0
1988 Jan-Dec	6.9	4.7	15.0	0.7	9.2	2.2	42.0
May-Oct	6.3	1.7	11.0	0.5	12.4	1.9	34.0
1989 Jan-Dec	6.0	*	13.0	0.7	5.6	1.4	26.7
May-Oct	5.3	*	11.0	0.6	5.9	1.0	23.8
1990 Jan-Dec	5.9	*	14.0	1.0	4.1	1.8	26.8
May-Oct	6.5	*	9.0	0.6	3.8	1.5	21.4
1991 Jan-Dec	6.8	*	9.2	1.0	2.6	1.7	21.3
May-Oct	5.2	*	4.6	0.8	2.3	0.9	13.8
1992 Jan-Dec	5.9	*	12.3	1.4	2.5	1.5	23.6
May-Oct	5.1	*	9.6	0.9	2.3	0.8	18.7

Table 1. Cont'd

Period	T	CFB	B	D	N	P	TOTAL
1993 Jan-Dec	6.1	*	12.1	0.9	3.0	1.0	23.1
May-Oct	4.6	*	10.1	0.3	2.8	0.7	18.5
1994 Jan-Dec	4.2	*	18.5	0.5	2.0	1.3	26.5
May-Oct	3.3	*	12.1	0.4	1.4	0.9	18.1
1995 Jan-Dec	**4.2	*	14.3	0.3	1.5	1.2	21.5
May-Oct	**3.3	*	14.2	0.2	1.1	0.9	19.7
1996 Jan-Dec	3.4	*	18.4	0.4	1.4	1.7	25.3
May-Oct	4.4	*	14.9	0.3	1.2	1.1	21.9
1997 Jan-Dec	4.0	*	16.7	0.5	1.8	1.4	24.3
May-Oct	3.2	*	13.2	0.4	1.4	0.6	18.8
1998 Jan-Dec	2.3	0.7	11.6	0.4	1.5	1.1	16.9
May-Oct	2.3	0.6	11.8	0.4	1.3	0.6	16.4
1999 Jan-Dec	3.3	0.6	6.8	0.7	1.6	1.3	13.6
May-Oct	3.5	0.5	7.0	0.6	1.3	0.8	13.2
2000 Jan-Dec	2.0	0.7	6.1	0.6	1.5	1.5	12.4
May-Oct	2.5	0.8	7.3	0.5	1.4	0.8	13.4
2001 Jan-Dec	1.5	0.5	4.8	0.2	1.3	1.8	10.1
May-Oct	1.4	0.5	3.5	0.1	1.3	1.0	7.8
2002 Jan-Dec	1.7	0.5	7.0	0.9	1.3	1.2	12.6
May-Oct	1.9	0.4	9.2	0.4	1.4	1.2	14.5
2003 Jan-Dec	2.2	0.7	13.0	0.2	4.0	2.2	22.3
May-Oct	2.8	0.8	4.0	0.2	1.0	0.5	9.3

\* CFB Trenton loadings not available.

\*\* No 1995 records available, 1994 loadings substituted to estimate total loading.

T=Trenton, CFB=Canadian Forces Base Trenton, B=Belleveille, D=Deseronto, N=Napanee,

P=Picton

## NUTRIENTS AND PHYTOPLANKTON

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### Sampling and Analyses<sup>3</sup>

Thirteen samplings at each of the four main Bay of Quinte stations (B, N, HB, and C) during the period May 6 to October 22, 2003 were undertaken by personnel of Fisheries and Oceans Canada (DFO) according to methods and at locations previously established by Project Quinte (see e.g. Millard and Burley, 2004 for a map (their Figure 1) and other details). Samples for nutrients and chlorophyll were again analyzed by the Ontario Ministry of the Environment, except for those collected August 13 which were lost in a laboratory accident; some data available for this date from DFO (total phosphorus) were incorporated into the main data set and used in calculations of May-October means and for plotting change over time. In accordance with the enhanced analysis protocol of recent years, all 13 individual phytoplankton samples were analyzed from Stations B, N and C, and for the July through September period (seven samples) for the HB location. In addition, pooled samples resulting from the quantitative combining of aliquots of each of the 13 samples were analyzed for each of the four main Bay of Quinte stations to provide an additional estimate of “average” May-October biovolume (but not used in this report, except for Station HB).

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<sup>3</sup>Staff of the Laboratory Services Branch, Ontario Ministry of the Environment (MOE) in Toronto performed the chemical analyses. Sample allocation for these analyses was provided by the Technical Support Section, Eastern Region, MOE. Most phytoplankton analyses over the 32- year period of Project Quinte were performed by MOE (Lucja Heintsch and Elaine Carney); E.C. has done all such analyses for the past several years with support from Fisheries and Oceans Canada.

## Results and Discussion

### *Total phosphorus and chlorophyll*

There were two strong peaks in total phosphorus (TP) in the upper Bay of Quinte in 2003. These were very well defined at Station N, where concentrations about 20  $\mu\text{g/L}$  during May and early June rose quickly to the first peak of 50  $\mu\text{g/L}$  by mid- July. Concentrations then declined over the next six weeks to a mid-summer low of 34  $\mu\text{g/L}$  on 26 August, but then reached the second peak of 53  $\mu\text{g/L}$  on 23 September (Figure 1a). Although the peaks were less well-defined at Station B, where they were separated by a relatively low value of 27  $\mu\text{g/L}$  on 13 August, overall levels during the entire May to October period were similar to those measured at Station B such that average total phosphorus concentrations at the two locations of 30.8 and 34.1 were determined for stations B and N, respectively.

A different pattern was observed in TP at the middle and lower bay stations, where levels at Station HB rose steadily to a single peak on 24 September of 51  $\mu\text{g/L}$  before falling back to 36  $\mu\text{g/L}$  by the last sampling date (Figure 1b). No clear pattern was detected in the TP data from Station C in the lower bay, but the euphotic zone samples from this location were consistently higher than those from the near-bottom, until the fall, when more complete mixing of the water column presumably blurred this distinction (figure 1b).

The 2003 May to October mean TP concentrations of 30.8, 34.1, 30.8, and 11.4  $\mu\text{g/L}$  at Stations B, N, HB, and C, respectively, were only slightly higher than those calculated for the previous year, but were higher than the very low levels seen in the 3-year period 1995-1997 when total phosphorus concentrations in the upper and middle Bay of Quinte were all below the interim RAP objective of 30  $\mu\text{g/L}$  (Figure 2).

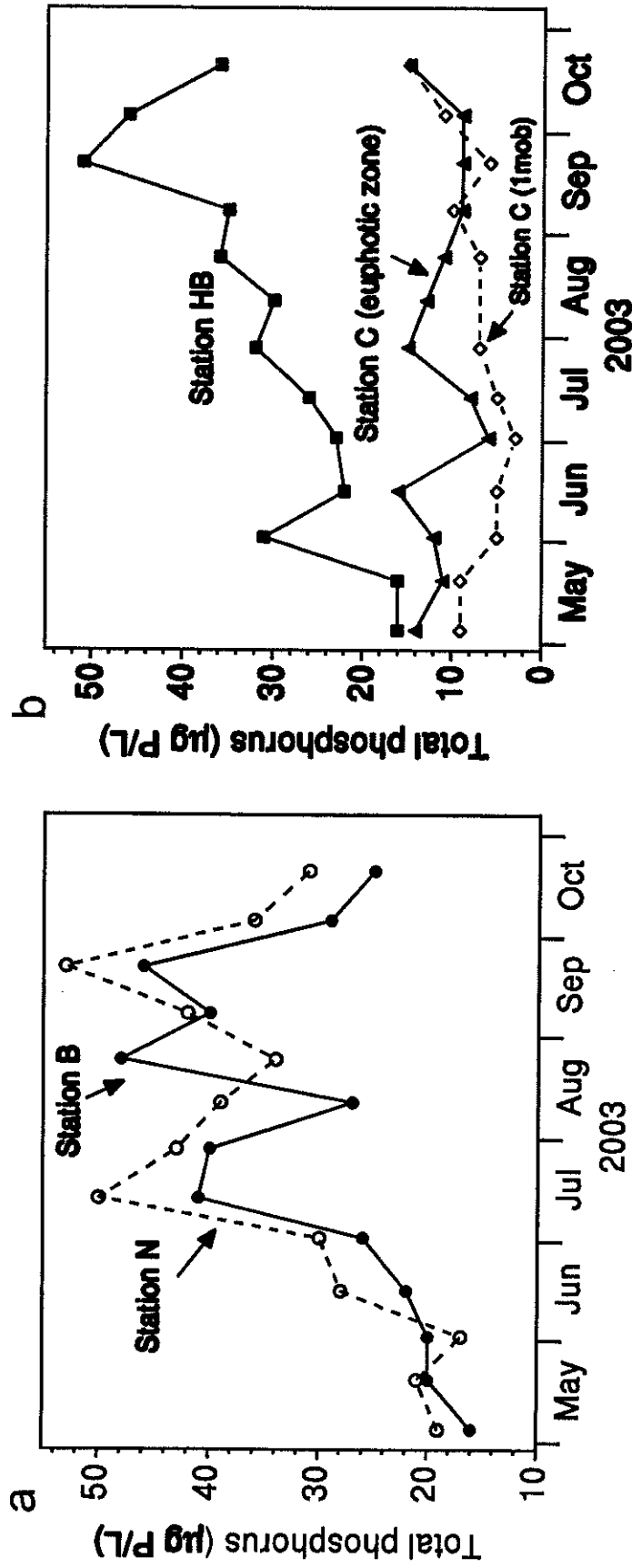


Figure 1. Concentrations of total phosphorus in the upper (a) and middle and lower (b) Bay of Quinte during the May to October period of 2003. All samples were from the euphotic zone, except where "1mob" indicates samples from one metre above bottom.

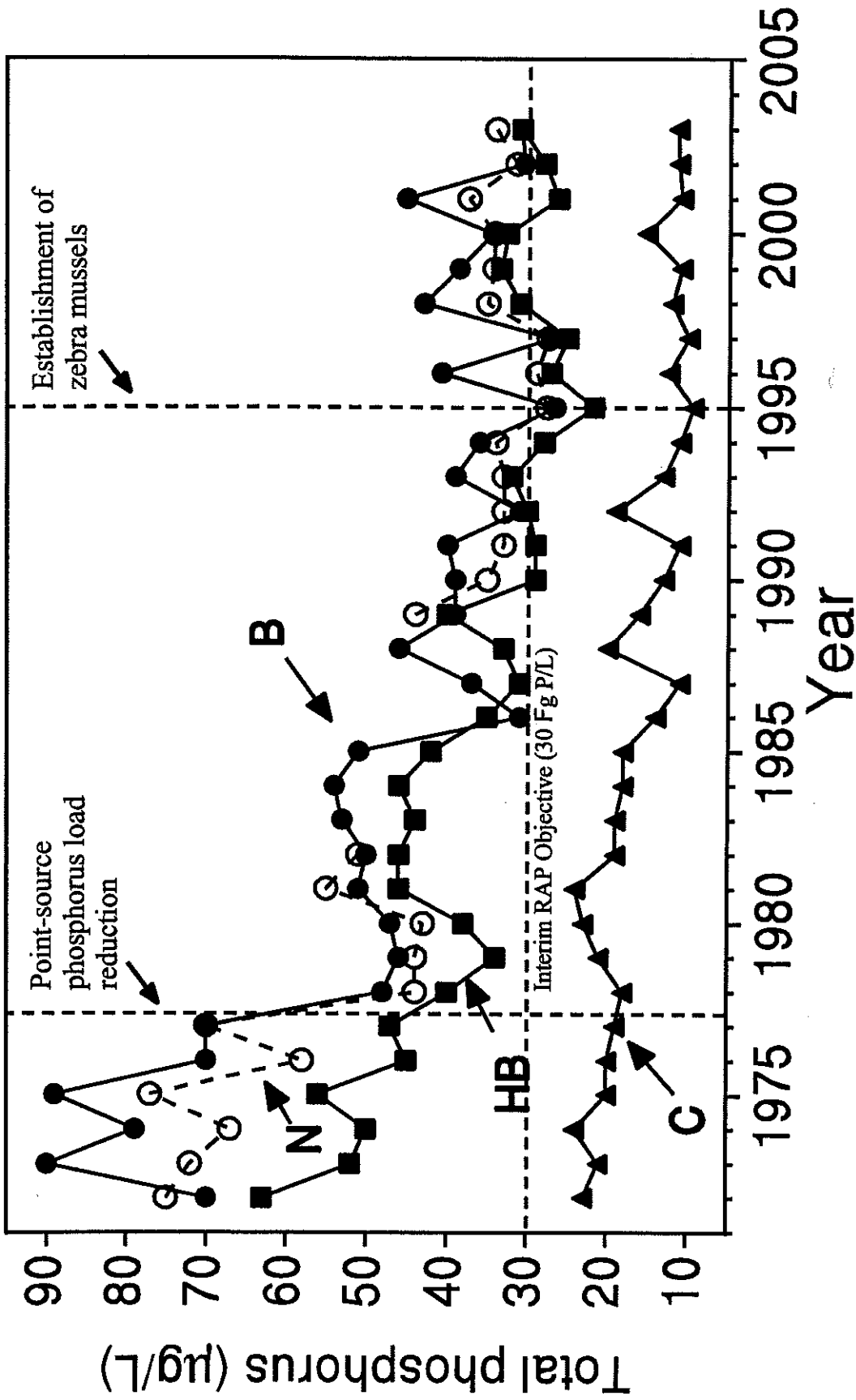


Figure 2. Long term trends in May-October mean total phosphorus concentrations at the four main Bay of Quinte sampling stations, B, N, HB, and C, relative to two major interventions/perturbations indicated by vertical dashed lines. The interim RAP objective of 30 µg/L is also indicated. No data were collected at Station N between 1983 and 1988, inclusive.

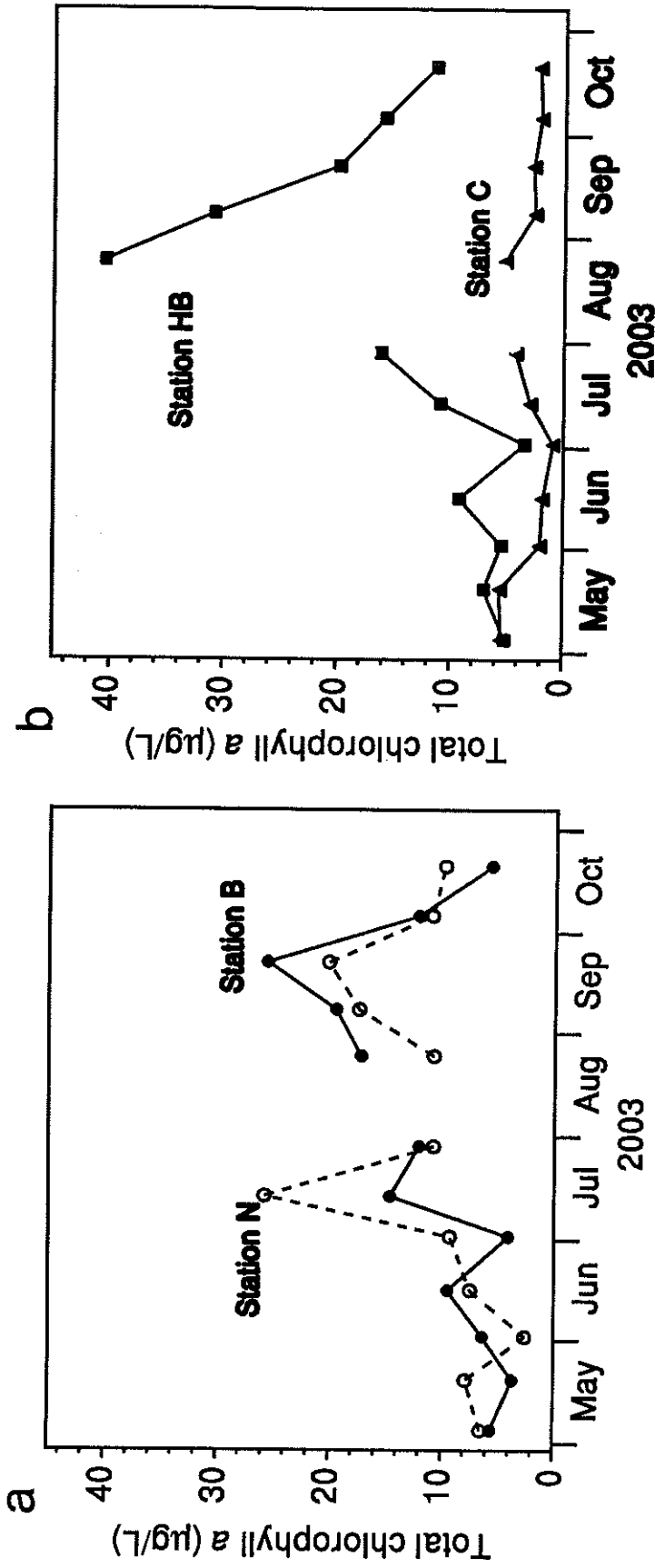


Figure 3. Concentrations of total chlorophyll *a* (uncorrected for phaeopigments) in the upper (a) and middle and lower (b) Bay of Quinte during the May to October period of 2003. All samples were from the euphotic zone. Samples collected 13 August were lost in a laboratory accident.

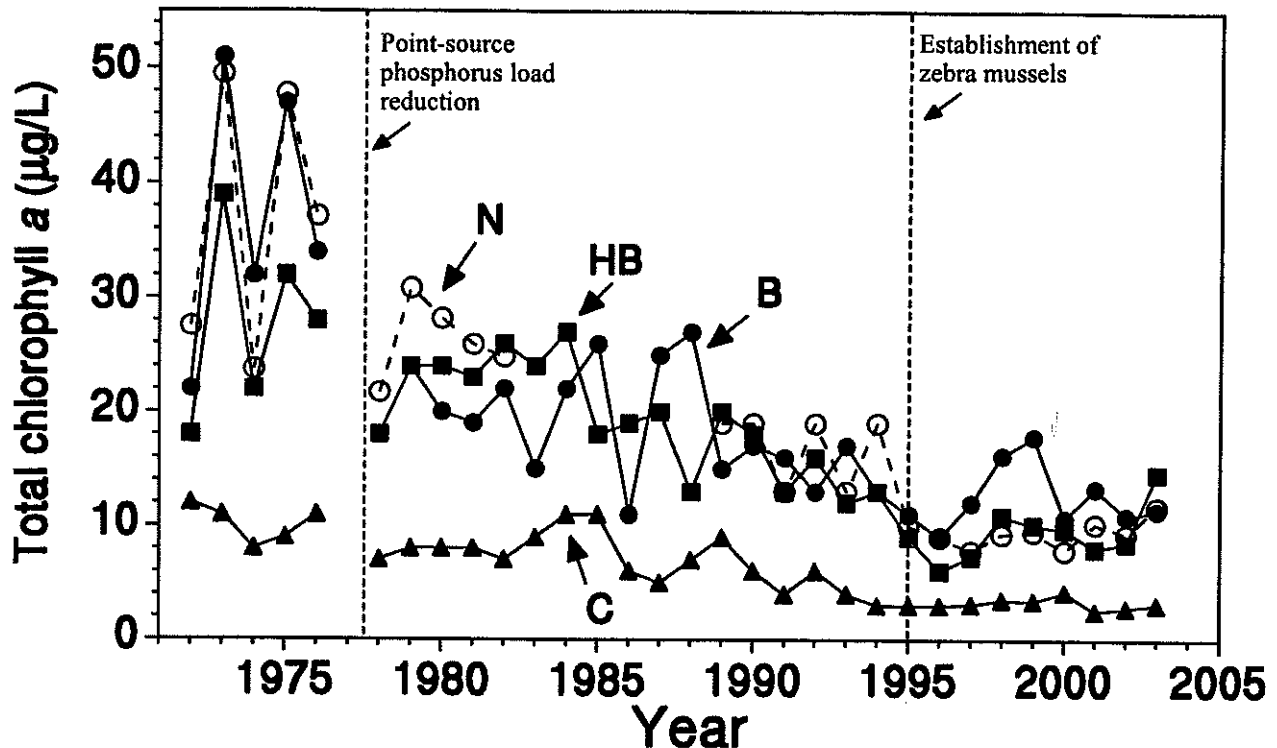


Figure 4. Long term trends in May-October mean total chlorophyll *a* concentrations at the four main Bay of Quinte sampling stations, B, N, HB, and C, relative to two major interventions/perturbations indicated by vertical dashed lines. No data are available for 1977 and for Station N between 1983 and 1988, inclusive. The 2003 means were calculated in the absence of data from the 13 August sampling (laboratory accident).

Notwithstanding the gap in the chlorophyll data in August (samples from 13 August were accidentally destroyed), it would appear that the Station B data revealed a single peak of 25.6 µg/L on 23 September, while Station N showed two peaks - one in mid-July of 25.8 µg/L, and another on 23 September of 20.2 µg/L (Figure 3a). This is consistent with the observed seasonal distribution of TP concentrations at these locations (see above). A single peak in chlorophyll was found in the Station HB data (40.4 µg/L on 26 August); thereafter concentrations declined precipitously to 11.4 µg/L by the third week of October (Figure 3b). In contrast, chlorophyll levels at Station C in the lower bay exceeded 3 µg/L on only four occasions with a maximum of 5.5 µg/L in May (Figure 3b).

Overall long term trends in chlorophyll *a* concentrations in the Bay of Quinte reflect very

well the trends in total phosphorus and phytoplankton (see below). There are however, some noteworthy differences. The 2003 mean concentrations of 11.7 and 14.6  $\mu\text{g/L}$  at the upper and middle bay Stations N, and HB, respectively, were higher than all previous means at these locations since the establishment of zebra mussels in 1995 (Figure 4). The 2003 means at upper bay Station B (11.4  $\mu\text{g/L}$ ) and lower bay Station C (3.1  $\mu\text{g/L}$ ) were little changed from the previous year and lower than those mean values calculated for the late 1990's (Figure 4).

### *Phytoplankton*

Clear multi-year patterns have emerged in total phytoplankton biovolume over the entire 32-year period of Project Quinte. While there have often been marked differences between the May to October mean total phytoplankton biovolume among sampling stations, in general, the major trends over several multi-year time blocks are reflected well at all stations, with the possible exception of lower bay Station C. At Stations B, N and HB, long term trends have shown remarkable concordance. The overall trend at these upper and middle bay stations can be summarized with reference to Figure 5 as follows:

- (i) a six year period (1972-1977) of very high total biovolumes in the 7-16  $\text{mm}^3/\text{L}$  range,
- (ii) a precipitous decline to much lower biovolumes in 1978 (associated with reductions in point-source phosphorus loading); followed by a steady increase between 1979 and 1984,
- (iii) a levelling out to values generally in the 5-10  $\text{mm}^3/\text{L}$  range that persisted between 1985 and 1994,
- (iv) a 3-year period (1995-1997) coinciding with the establishment of dreissenid mussels, during which phytoplankton biovolumes were among the lowest ever recorded during the previous 24 years of the study; these low values were also reflected in the lower bay at Station C,
- (v) a rapid increase to levels observed in 1998 that were similar to those found during the pre-phosphorus control period.
- (vi) an equally precipitous decline after 1998 resulting in the year 2000 values being the lowest biovolumes measured since the beginning of the project (all three upper and

middle bay May- October averages were under  $3 \text{ mm}^3/\text{L}$ ),  
(vii) three additional years of relatively low biovolumes (under  $5 \text{ mm}^3/\text{L}$ ) also characterized by a low degree of difference among the upper and middle bay stations (Figure 5).

Specifically, with reference to the 2003 data, May-October mean biovolumes for Stations B, N, HB and C were 3.49, 2.76, 3.28 and  $0.60 \text{ mm}^3/\text{L}$ , respectively. The early portion of the 2003 sampling period was characterized by low biovolumes until mid-July when biovolume nearly doubled to about  $3 \text{ mm}^3/\text{L}$  at Stations B and N, the two upper bay locations (Figure 6). Station N achieved its peak biovolume ( $8.17 \text{ mm}^3/\text{L}$ ) at the end of July, Station HB, its peak ( $9.0 \text{ mm}^3/\text{L}$ ) near the end of August, and Station B, its peak biovolume of  $6.4 \text{ mm}^3/\text{L}$  in early September (Figure 6). By the third week of October, the upper bay stations had declined to values similar to those found in spring and early summer ( $2.4 \text{ mm}^3/\text{L}$  at Station B and  $1.0 \text{ mm}^3/\text{L}$  at Station N). Station C in the lower bay achieved its peak biovolume of  $1.7 \text{ mm}^3/\text{L}$  on 27 August; none of the four values measured after this date at Station C was above  $0.34 \text{ mm}^3/\text{L}$  (Figure 6).

Compared to the recent past, there was a major shift in the relative composition of blue-green algae (Cyanophyceae or Cyanobacteria) and diatoms (Bacillariophyceae) at the middle bay Station HB in 2003. Blue-green algae at HB in 2003 were about 6x higher in relative abundance than in previous recent years (Figure 7). May-October blue-green representation was 37% for 2003 compared to values of 5.8, 7.0 and 5.0% for the three previous years. This blue-green increase in 2003 was at the expense of the diatoms which represented 80, 78 and 77% of total phytoplankton in 2000, 2001 and 2003 but declined to 50% in 2003 (Figure 7). For compatibility with previous years, the May-October mean at this station was based on the pooled sample, not the individual samples, of which only the July-September samples were analyzed individually. As expected, the representation by blue-green algae for the July-September period was considerably higher (60%) than for the May-October period and diatom representation considerably lower (28%) than for the entire sampling period of May-October owing to the characteristic late summer-fall domination by cyanophytes in the Bay of Quinte (Nicholls et al., 2002).

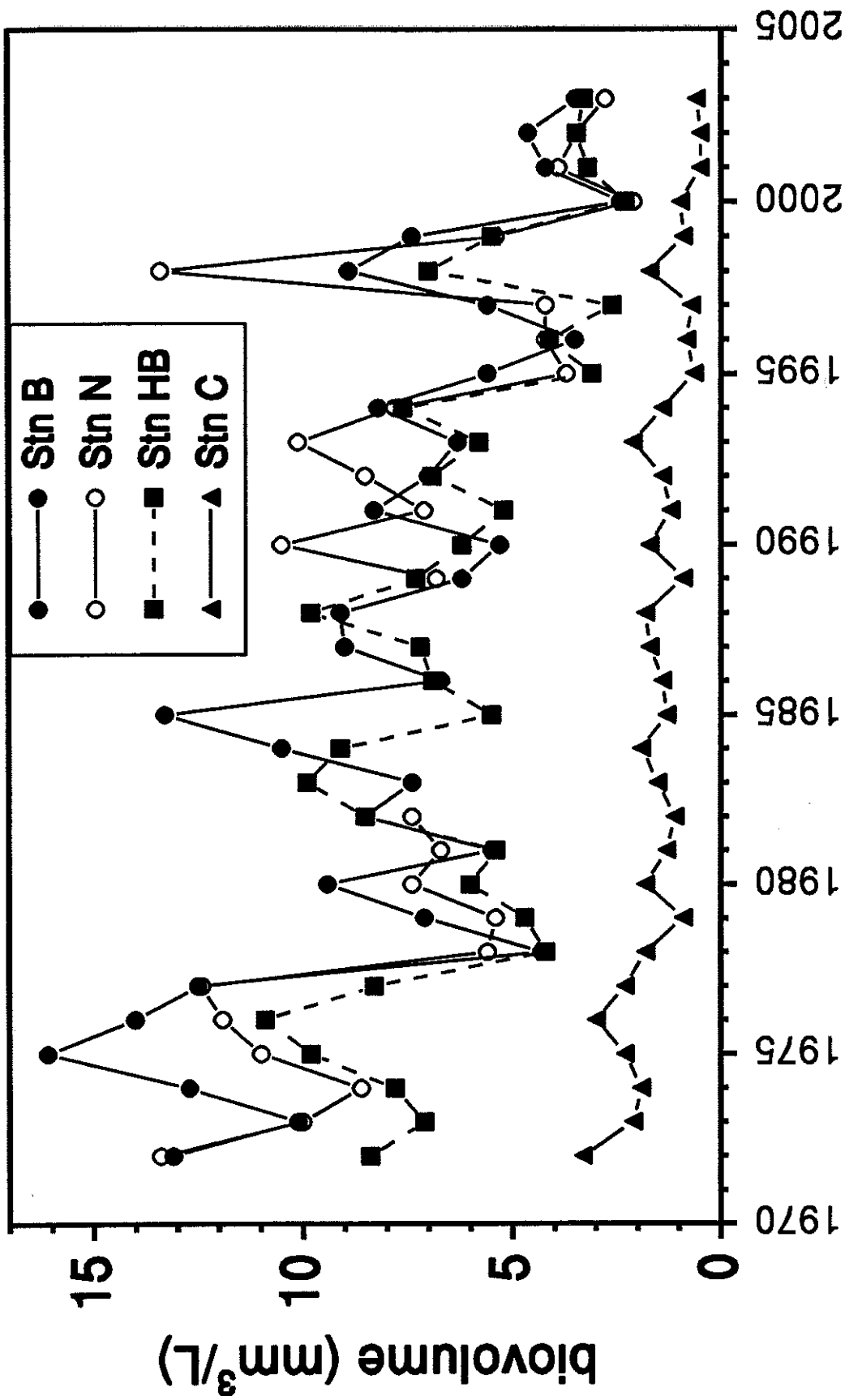


Figure 5. May-October average total phytoplankton biovolume for all years of Project Quinte, 1972-2003 for Stations B, N, HB and C. Values for 2003 were arithmetic means determined on 13 samples for each of Stations B, N and C, but for Station HB were based on the results of analysis of a single composite sample comprised of aliquots from each of the 13 May-October samples collected at Station HB.

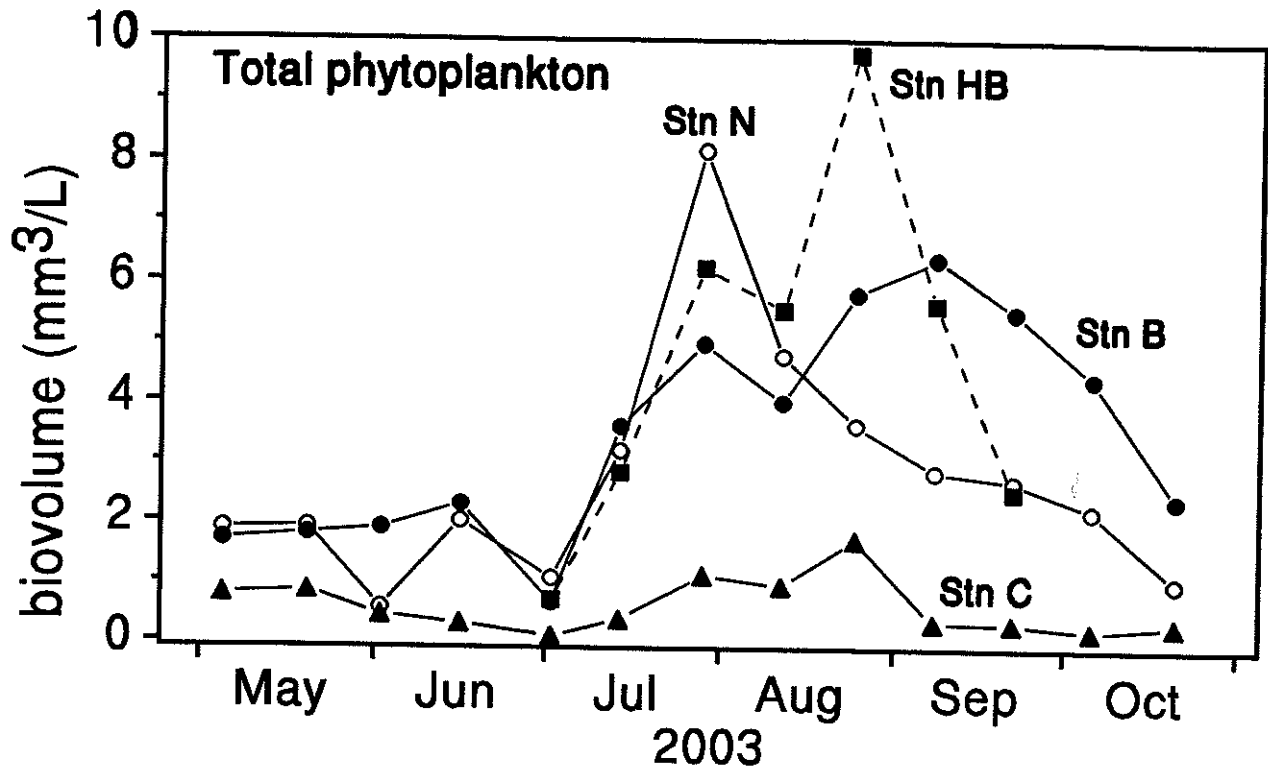


Figure 6. Total phytoplankton biovolume during 2003 at the four main Bay of Quinte stations. Samples from Station HB were analysed for the July-September period only.

Other characteristics of the total phytoplankton composition have remained fairly constant during the most recent four years. Typically, Station C in the lower bay again demonstrated much greater representation by cryptophytes (a highly food-chain functional group) than the upper and middle bay locations with contributions of 22, 26, 31 and 23% during 2000-2003, respectively. As well, the Chrysophyceae were better represented in the lower bay than at the other Bay of Quinte stations with an average contribution of 9.6% at Station C during the past four years compared to an average of 2.2% for the other stations (Figure 7). Other classes of algae (Dinophyceae, Euglenophyceae and Chlorophyceae) have typically made a combined contribution of less than 2% of the total phytoplankton biovolume in recent years at the upper and middle bay stations.

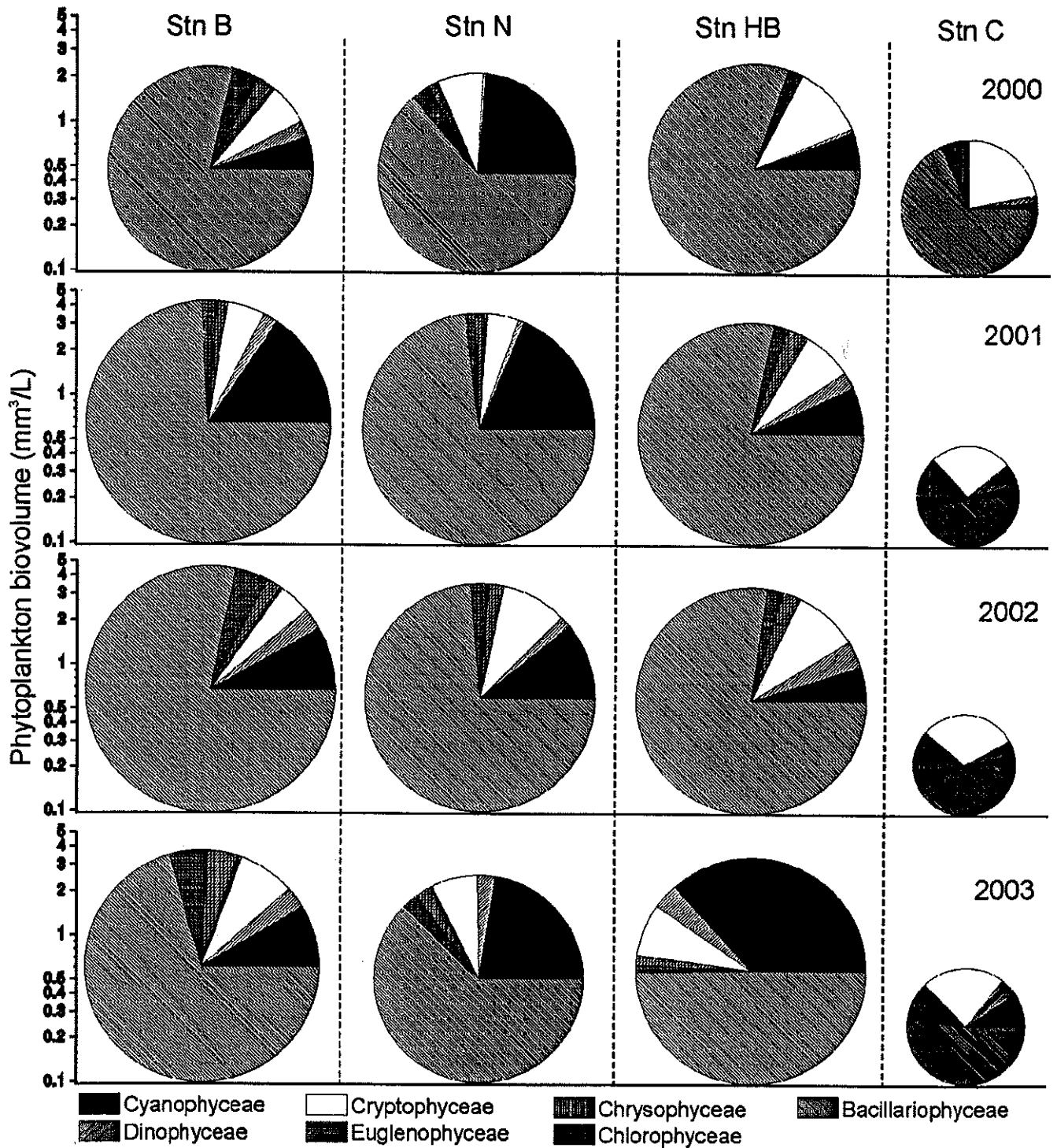


Figure 7. Percentage contributions by the major classes of algae to the total phytoplankton biovolume during the 4-year period, 2000-2003. Additionally, the size of the circles enclosing the class contributions represents the average May-October total phytoplankton biovolume according to the scales indicated on the Y-axis.

Some phytoplankton taxa continued in 2003 to demonstrate a pronounced seasonal distribution with peaks in abundance either in spring and early summer (certain chrysophytes, including the haptophyte *Chrysochromulina parva*, included in the Chrysophyceae for convenience), in mid-summer (the diatom *Aulacoseira*), or in late summer (certain blue-green algae). More specifically, several chrysophytes showed strong peaks in the upper bay in the 21 May samples (Figure 8a). *Chrysochromulina parva*, and species of *Uroglena*, *Mallomonas*, *Chromulina* and *Dinobryon* all contributed to the strong 21 May peak in total chrysophyte biovolume. Populations of these taxa quickly declined to near insignificant levels by the end of June (Figure 8a), but at Station B, a moderate peak was achieved again in the 22 October sample, in which *C. parva*, *Chromulina* and *Codoncladium* [= *Codonosiga* ? - a colourless form, not properly classified as a chrysophyte according to modern concepts of the class (Nicholls and Wujek 2002)] were common.

In spring and early summer the diatom communities of the upper and middle Bay of Quinte were populated by moderately low densities of a small *Stephanodiscus* species, *Aulacoseira* and *Diatoma elongatum*. These populations decreased to near zero by the end of June when the total Bacillariophyceae was a negligible component of the Bay of Quinte phytoplankton (Figure 8b). *Aulacoseira* quickly achieved a large population, especially at Station N where a biovolume of 7.19 mm<sup>3</sup>/L was recorded at the end of July (Figure 8b), and significant but smaller biovolumes of 5.17 and 4.17 mm<sup>3</sup>/L, respectively, were measured at Station HB, and, two weeks later, at Station B (Figure 8b). These high densities were maintained well into the fall at Station B, but had declined significantly at Station N, where, for example, the *Aulacoseira* biovolume in the 7 October sample was only 1.17 mm<sup>3</sup>/L.

Blue-green algae at Station HB dominated the phytoplankton samples on three consecutive sampling dates in August and September of 2003. The maximum biovolume of 8.03 mm<sup>3</sup>/L measured in the 26 August sample was comprised largely by *Anabaena* (mainly *A. crassa*) at 5.35 mm<sup>3</sup>/L and *Gloeotrichia* at 1.27 mm<sup>3</sup>/L. This was well in excess of the peak

recorded for Station N in the 13 August sample when the same two taxa contributed 0.64 and 0.75  $\text{mm}^3/\text{L}$ , respectively, to the total (Figure 8c). Somewhat lower levels of blue-greens were found at Station B. The early September "peak" was comprised mainly of *Anabaena* (0.38  $\text{mm}^3/\text{L}$ ) and *Aphanizomenon* (0.13  $\text{mm}^3/\text{L}$ ).

Aside from Station B where the cryptomonads *Cryptomonas* (0.83  $\text{mm}^3/\text{L}$ ) and *Rhodomonas* (0.20  $\text{mm}^3/\text{L}$ ) contributed to an early July peak (Figure 8d), the Cryptophyceae demonstrated no clear seasonal tendencies - ignoring, of course, the winter period, which was not sampled.

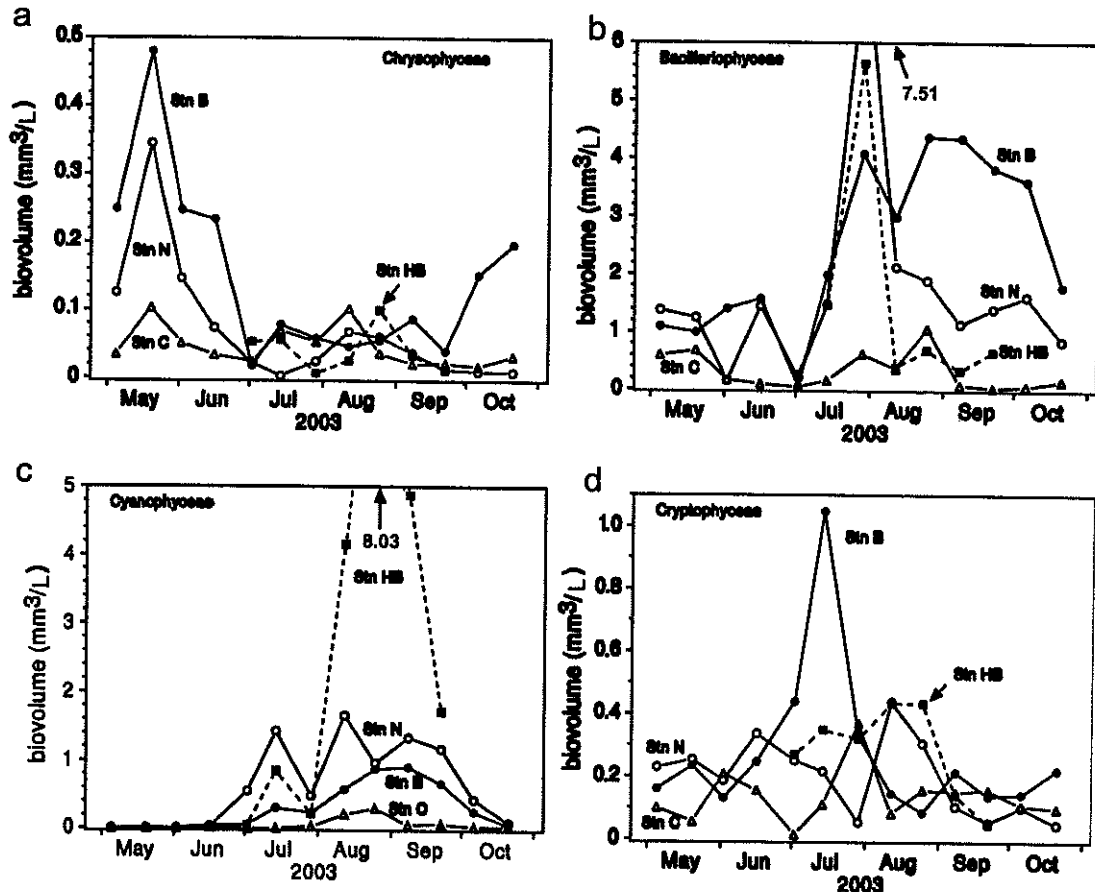


Figure 8. Changes in the biovolumes of four algal classes (a) Chrysophyceae, (b) Bacillariophyceae, (c) Cyanophyceae (or Cyanobacteria) and (d) Cryptophyceae at the four main Bay of Quinte sampling stations in 2003. Note that samples from the Hay Bay (HB) location were analyzed for the July-September period only.

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# PHOTOSYNTHESIS, CHLOROPHYLL *A*, AND LIGHT EXTINCTION

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## Nutrients and Lower Trophic Level Sampling Cruises 2003

The 2003 field season was carried out aboard the 24-foot Hourston launch, the Willet. It was operated by scientific personnel from Fisheries and Oceans Canada (Burlington). Thirteen cruises were conducted on alternate weeks starting in early May and ending in late October. Stations Belleville (B), Napanee (N), Hay Bay (HB), Glenora (GL) and Conway (C) were visited on every cruise (Fig. 1). The majority of the sampling was carried out by Jocelyn Gerlofsma, Silvina Carou and Heather Niblock. Assistance was provided by Bud Timmins and Sara Booth. All participants were staff of the Great Lakes Laboratory for Fisheries and Aquatic Sciences in Burlington.

Physical measurements such as station depth, mixing depth, secchi disc depth and light extinction (400-700 nm -  $\epsilon_{\text{par}}$ ) were measured. Using a Hydrolab minisonde 4a, depth profiles of temperature, dissolved oxygen, pH, were obtained at each station. Samples for nutrients, phyto- and zooplankton biomass and species composition, chlorophyll *a* (Chl) and seston were collected. Photosynthesis vs. light experiments were conducted in an incubator using the  $^{14}\text{C}$ -uptake technique to obtain photosynthetic parameters required as input for programs that compute depth and time-integrated photosynthetic rates. Seasonal (May 1-Oct 31) areal ( $\text{g C}\cdot\text{m}^{-2}$ ) and volumetric ( $\text{g C}\cdot\text{m}^{-3}$ ) rates of phytoplankton photosynthesis have been calculated. Photosynthesis experiments, chlorophyll and seston filtration as well as nutrient processing were conducted at the Ontario Ministry of Natural Resources, Glenora Fisheries Research Station.

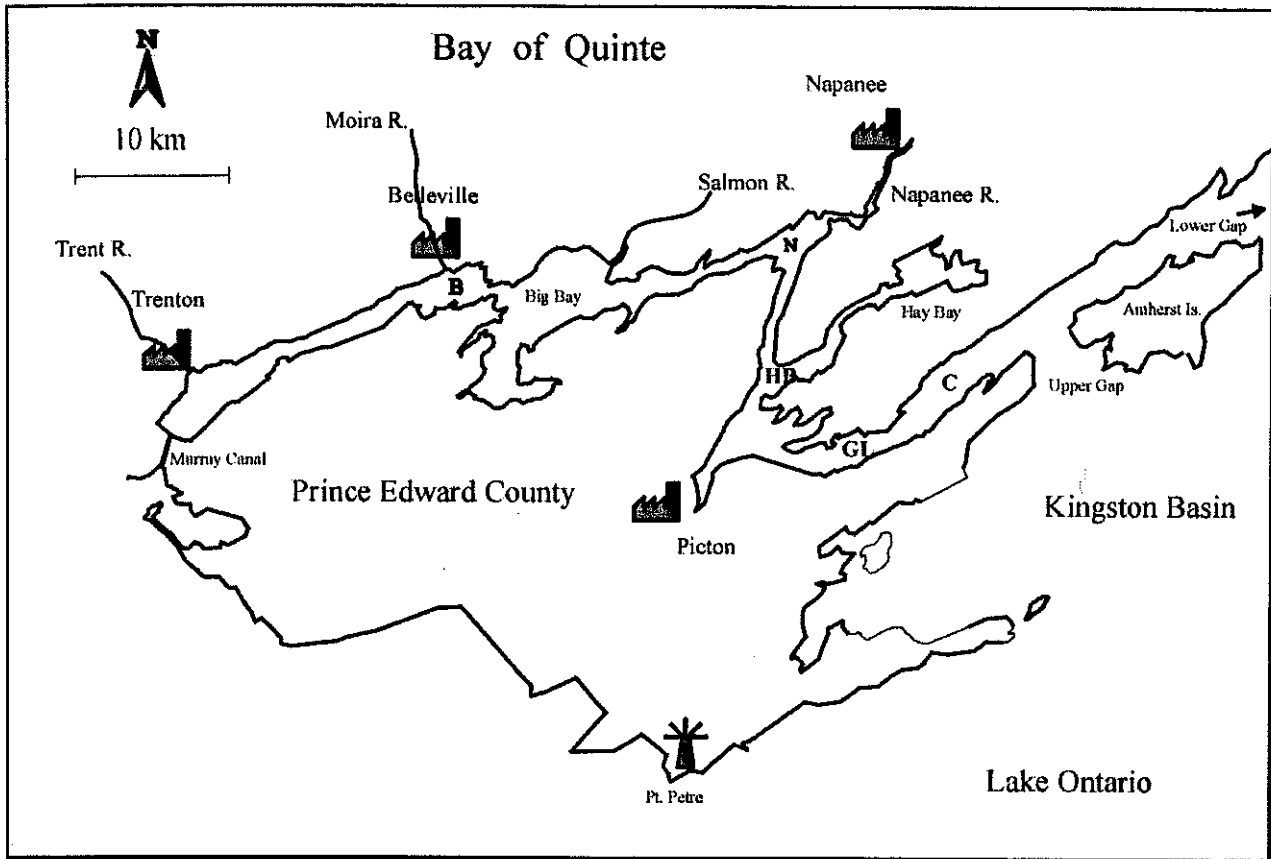


Figure 1. Project Quinte sampling stations, B, N, HB, GL, C.

### Chlorophyll *a*

Reduced phytoplankton biomass due to zebra mussel grazing, using seasonal mean chlorophyll *a* (Chl) as an index, was first observed in 1995 (Table 1). Averaging the seasonal means indicates a decrease of Chl concentrations between a third to one half across all stations post zebra mussel introduction. With few exceptions, station Napanee (N) had consistently higher chlorophyll levels than Belleville (B) prior to 1994. This trend reversed from 1995 to 2002. The chlorophyll seasonal means post zebra mussel introduction at both stations N and HB (Hay Bay) declined to levels typical of the lower bay prior to zebra mussel colonization station Conway (C) (1977-1994).

Table 1. Seasonal means and maximum chlorophyll *a* concentrations ( $\text{mg m}^{-3}$ ) at stations B, N, HB and C from 1977-2003.

Year	B		N		HB		C	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
1977	39.3	88.2	42.1	118.1	32.0	55.0	6.0	8.9
1978	20.9	48.4	29.0	71.1	23.8	51.8	6.2	13.2
1979	27.8	53.5	30.5	72.9	26.6	65.6	8.1	18.5
1980	21.7	48.8	29.3	50.9	28.4	48.5	10.1	17.7
1981	22.2	44.9	29.1	69.2	25.2	44.8	8.8	14.2
1982	21.8	47.8	26.8	45.3	24.7	73.3	6.1	9.9
1983	20.0	48.2	na	na	24.1	60.9	8.9	23.9
1984	32.4	74.7	na	na	37.1	65.4	8.6	27.3
1985	31.8	54.0	na	na	28.3	48.2	8.8	19.3
1986	13.9	26.7	na	na	24.9	43.5	8.0	13.9
1987	33.1	72.6	na	na	25.0	52.9	7.4	17.9
1988	30.4	62.3	na	na	22.3	50.0	6.4	9.3
1989	21.5	43.8	31.3	69.5	29.7	71.1	7.2	12.7
1990	24.5	51.1	25.0	50.5	21.2	42.3	7.1	12.0
1991	26.0	46.6	25.9	44.1	17.1	44.2	5.8	12.4
1992	20.7	43.6	28.4	69.1	22.8	46.0	6.4	11.5
1993	20.3	45.1	23.0	50.3	20.3	41.2	6.8	14.6
1994	25.8	58.8	25.9	57.1	22.2	48.3	5.5	10.9
<b>Post P Control Means</b>	<b>24.4</b>	<b>51.2</b>	<b>27.7</b>	<b>59.1</b>	<b>24.9</b>	<b>52.8</b>	<b>7.4</b>	<b>15.2</b>
1995	16.2	36.2	12.8	28.3	10.5	20.3	4.7	12.1
1996	9.5	38.2	8.9	26.5	8.5	24.2	3.2	9.4
1997	10.4	21.0	8.8	21.6	7.8	18.5	2.9	5.6
1998	16.7	44.4	10.5	22.0	12.0	24.3	4.0	14.8
1999	14.0	32.4	7.4	14.3	7.8	16.7	2.8	5.4

Table 1. Cont'd.

2000	11.5	21.7	8.0	22.1	9.3	18.8	3.7	6.9
2001	15.2	39.2	11.4	20.2	9.8	19.6	3.3	5.4
2002	12.2	26.9	10.0	22.6	10.1	18.5	3.2	5.4
2003	13.0	28.3	12.7	27.0	16.6	44.5	3.1	5.3
<b>1995-2003 Means</b>	<b>13.2</b>	<b>32.0</b>	<b>10.1</b>	<b>22.7</b>	<b>10.3</b>	<b>22.8</b>	<b>3.4</b>	<b>7.8</b>

\* Chlorophyll analysis was done with GF/C filters ground in 90% acetone with concentrations uncorrected for phaeopigments. In previous reports the values were corrected for phaeopigments. Data using this method are not available prior to 1977. 1977 values are the only Pre-control data available using this method. See Nicholls for 1972-1976 chlorophyll data.

na - data not available 1983-1988.

The coefficient of variation about seasonal means pre and post zebra mussels is similar for all stations except HB which has increased considerably. The higher mean in 2003 of 16.6 mg m<sup>-3</sup> contributed to the higher variability. This is the highest mean observed at all stations post zebra mussel invasion with the exception of B in 1998. At N the increase in the 2003 versus 2002 Chl seasonal mean is not as considerable as that seen at HB but is still the highest recorded at this station since 1995. The Chl seasonal mean at B and N in 2003 are very close, a similarity not observed between these stations since 1994.

Chlorophyll levels at station C in the lower bay have shown a similar impact in all years since 1995 with levels varying between 3-5 mg m<sup>-3</sup>. The seasonal means post zebra mussels are typically half of pre invasion levels. The seasonal means from 2001-2003 have stayed been very similar close (3.1-3.3 mg m<sup>-3</sup>). Station C chlorophyll values in 2003 had the lowest coefficient of variation of all of the study sites.

The dramatic impact that zebra mussels have had on Chl since 1995 is very apparent if the grand mean of seasonal means since 1995 is compared to the post P control mean (1978-94). Mean Chl for these periods show declines of about 60% at stations N and HB and 50% at stations B and C.

A long-term, mean seasonal chlorophyll trend line was determined for the post phosphorus control period and before zebra mussels colonized the bay (1978-94) by calculating the mean across years for sequential two-week time periods throughout the season. Confidence limits for this line are high because of high inter-annual variability in driving variables such as climate, food-chain structure and phosphorus concentration (Nicholls and Hurley 1989). For clarity, only the most recent years have been graphed in comparison to the 1978-1994 trends (Figure 2).

With few exceptions the Chl levels are below the long-term seasonal trend lines throughout the season at all stations. Two of these exceptions are in 2003 at stations N (mid-July) and HB (Aug 26). Despite the peak ( $26.3 \text{ mg m}^{-3}$ ) observed at N in the summer 2003, the overall trend is similar to that observed in 2001 and 2002. At Hay Bay however, the 2003 mid-August to early September chlorophyll values are the highest observed since 1994. The values peak at the end of August at  $44.5 \text{ mg m}^{-3}$ . The lowest inter-annual variability from 2000 to 2003 is observed at station Conway. Although concentrations still tend to be higher during the summer months in the upper bay, the massive summer peaks in concentration are no longer present (with the exception of B 2001 peak).

### **Light Extinction**

Secchi disk transparency and vertical light extinction (extinction coefficient) are inversely related. Transparency increases (extinction coefficients decrease) from upper to lower bay, but the upper to lower bay gradient is less dramatic in post phosphorus versus pre phosphorus control years (Table 2). Prior to phosphorus control, Chl levels contributed significantly to light extinction coefficients (Millard 1986). Presently Chl levels are low enough that background light extinction due to dissolved colouring and abiotic particulate matter may be more significant than Chl in light attenuation, even in the upper bay.

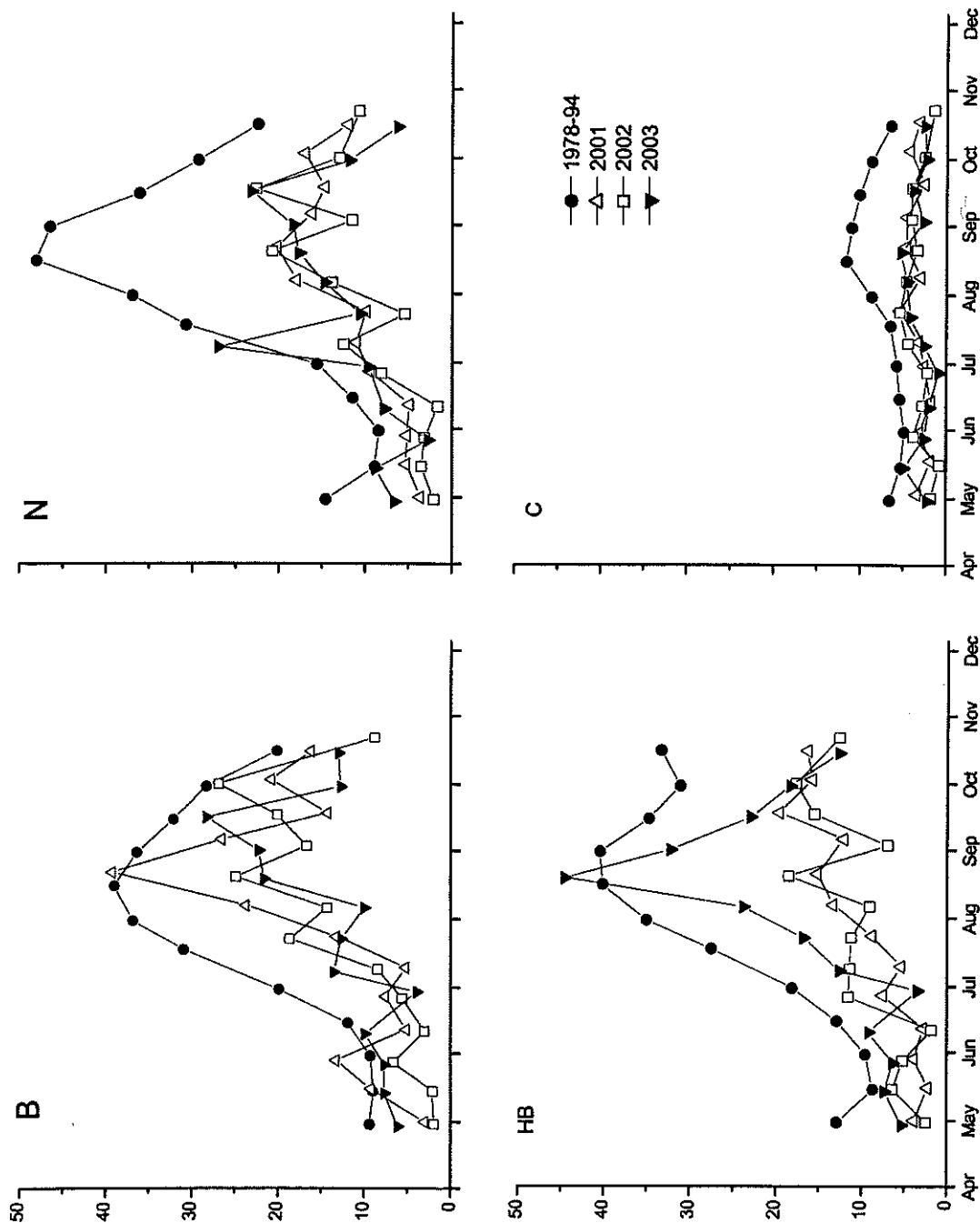


Figure 2. Seasonal trends in chlorophyll a in the upper, middle and lower Bay of Quinte from 2000-2003 with comparison to the long-term seasonal trend line for the post-phosphorus control, pre-zebra mussel period (1978-94).

Annual variability in Chl at the levels now observed may consequently not be reflected in light extinction. Zebra mussels can also reduce light extinction (increase transparency) by grazing directly on tripton. The lower grand mean of all post zebra mussel seasonal means compared to the grand mean of all post P control seasonal means shows the significant impact of zebra mussels on water clarity in the entire Bay of Quinte.

The seasonal mean light extinction at stations B (0.83) and C (0.32) decreased considerably from 2002 to 2003. These values are the lowest observed for B and C over the duration of the study. Comparing grand seasonal means, trends in light extinction at station N reflect a higher grazing impact compared to station B. However, the mean decrease in extinction from 2002 to 2003 is higher for B (17%) than for N (8%). Light extinction has decreased (22%) from 2000 to 2003 at station C. the greatest decrease in light extinction coefficient observed for all stations during this time frame.

Extinction coefficients at HB are still lower than at station N with a seasonal mean of 0.77  $m^{-1}$  in 2003 and show a 38% decrease in light extinction following zebra mussel invasion.

Secchi disk measurements are not as sensitive to changes in water transparency as extinction coefficients because of the non-linear linear relationship between these parameters. From 1995-2000 station N had greater Secchi disk depths compared to B. This is the same pattern noted for Chl and light extinction, suggesting a greater impact at station N by zebra mussel grazing than at B (Table 3). However, the difference between the two stations has been less evident since 2001.

At station HB the seasonal mean Secchi disc values have declined from 2001-2003. The 2003 value of 2.0m is the lowest recorded for this station in the post zebra mussel time period. The lower bay Secchi disc seasonal mean average has remained the same from 2001-2003 (6.0m). This value is almost double the grand seasonal mean average (3.3m) of the pre zebra mussel time period.

Table 2. Seasonal means and maxima for the vertical light extinction coefficient ( $m^{-1}$ ) at stations B, HB, C from 1972-2003.

Year	B		HB		C	
	Mean	Max	Mean	Max	Mean	Max
1972	1.63	2.56	1.42	2.00	0.64	1.10
1973	1.83	2.71	1.36	2.00	0.64	0.89
1974	2.02	3.18	1.43	2.63	0.72	1.03
1975	1.96	3.07	1.44	2.05	0.68	0.99
1976	1.99	3.18	1.56	2.09	0.61	0.94
1977	1.82	3.07	1.39	2.22	0.53	0.76
<b>Pre P Control Means</b>	<b>1.88</b>	<b>2.96</b>	<b>1.43</b>	<b>2.17</b>	<b>0.64</b>	<b>0.95</b>
1978	1.44	2.19	1.27	1.84	0.53	0.96
1979	1.52	2.97	1.37	2.71	0.63	0.94
1980	1.47	2.25	1.38	1.81	0.66	0.83
1981	1.39	1.92	1.33	2.30	0.60	0.87
1982	1.45	2.30	1.28	2.56	0.55	0.75
1983	1.33	1.84	1.27	1.75	0.55	0.86
1984	1.50	2.42	1.45	2.70	0.55	1.03
1985	1.86	2.56	1.27	1.83	0.54	0.74
1986	1.18	1.33	1.12	1.53	0.54	0.79
1987	1.48	2.27	1.29	2.06	0.56	0.84
1988	1.74	2.35	1.21	1.78	0.60	0.91
1989	1.48	2.23	1.29	1.88	0.56	1.09
1990	1.46	2.14	1.05	1.48	0.54	0.67
1991	1.43	2.12	1.07	1.45	0.47	0.60
1992	1.22	1.95	1.13	1.68	0.47	0.81
1993	1.42	2.44	1.07	1.54	0.49	0.86
1994	1.46	2.33	1.11	1.74	0.42	0.67
<b>Post P Control Means</b>	<b>1.45</b>	<b>2.19</b>	<b>1.19</b>	<b>1.84</b>	<b>0.53</b>	<b>0.82</b>

Table 2. Cont'd.

Year	B		HB		C	
	Mean	Max	Mean	Max	Mean	Max
1995	1.21	1.84	0.81	1.20	0.39	0.63
1996	1.10	1.71	0.83	1.27	0.40	0.67
1997	1.03	1.34	0.71	1.17	0.36	0.51
1998	1.31	2.82	0.82	1.47	0.38	1.08
1999	1.16	1.83	0.84	1.46	0.34	0.54
2000	0.89	1.16	0.76	1.04	0.38	0.55
2001	1.06	1.63	0.66	1.30	0.34	0.58
2002	1.00	1.64	0.72	0.94	0.41	0.50
2003	0.83	1.04	0.77	1.41	0.32	0.42
<b>1995-2003 Mean.</b>	<b>1.07</b>	<b>1.67</b>	<b>0.77</b>	<b>1.25</b>	<b>0.37</b>	<b>0.61</b>

Table 3. Seasonal means and maximum secchi disc depths (m) at stations B, N, HB and C from before (1991-1994) and after zebra mussel invasion (1995-2003).

Year	B		N		HB		C	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
1990	1.3	1.8	1.2	1.8	1.6	2.5	2.9	3.5
1991	1.3	2.0	1.4	2.5	1.6	2.4	3.2	4.5
1992	1.3	1.8	1.2	1.8	1.5	2.3	3.1	4.5
1993	1.3	2.0	1.3	2.0	1.7	2.5	3.4	4.3
1994	1.3	2.0	1.3	2.3	1.6	2.0	4.0	5.0
<b>Mean 1990-1994</b>	<b>1.3</b>	<b>1.9</b>	<b>1.3</b>	<b>2.1</b>	<b>1.6</b>	<b>2.3</b>	<b>3.3</b>	<b>4.4</b>
1995	1.4	2.3	1.5	2.3	1.9	3.3	3.5	5.0
1996	1.9	2.5	2.4	4.0	2.5	3.5	4.9	7.0
1997	2.1	3.0	2.5	3.3	3.0	4.3	6.1	9.0
1998	1.8	4.2	2.1	4.0	2.4	4.2	5.8	9.5
1999	1.6	3.2	1.9	2.8	2.1	2.8	5.5	7.0
2000	1.8	2.8	2.4	4.5	2.4	3.8	5.3	8.3
2001	1.9	4.0	1.8	2.5	2.6	3.8	6.0	10.0
2002	2.1	3.3	2.2	3.5	2.3	3.3	6.0	10.3
2003	1.9	2.3	1.8	3.3	2.0	3.8	6.0	8.0
<b>Mean 1995-2003</b>	<b>1.8</b>	<b>3.1</b>	<b>2.1</b>	<b>3.4</b>	<b>2.4</b>	<b>3.6</b>	<b>5.5</b>	<b>8.2</b>

### Photosynthetic Parameters

Areal rates of phytoplankton photosynthesis (PP) integrate the effects of light extinction, biomass (Chl), and the photosynthetic parameters  $P_m^B$  and  $\alpha^B$  over the euphotic zone.  $P_m^B$  is an index of the maximum photosynthetic capacity of the phytoplankton community because it is measured at light levels that are optimal for photosynthesis.  $\alpha^B$  measures the photosynthetic efficiency of the phytoplankton community at sub-optimal light levels and determines photosynthetic rates at deeper parts of the water column. Both parameters are normalized on biomass as denoted by the superscript B.

Seasonal mean  $P_m^B$  remained high in 2003 at station B (6.54 mg C mg Chl<sup>-1</sup> h<sup>-1</sup>) and similar to the 2002 seasonal mean of 6.69 C mg Chl<sup>-1</sup> h<sup>-1</sup> at this station. With the exception of 1999 these values are the highest observed in the post zebra mussel time period. The post zebra mussel  $P_m^B$  grand means at stations B, N and HB are approximately 20% higher than the pre zebra mussel  $P_m^B$  grand means (Table 4, Figure 3). Seasonal mean  $P_m^B$  at B, N and HB in all years post invasion have been higher than the pre-invasion means with only two exceptions (B 1995 and HB 1997). Napanee's 2003 seasonal mean  $P_m^B$  of 5.59 was a decrease from 2002. Notably the seasonal mean  $P_m^B$  at HB in 2003 was 16% lower than in 2002, a reversal of the increase observed from 2001 to 2002 at this station. The  $P_m^B$  pre and post zebra mussel invasion grand seasonal means for both lower bay stations (GL, C) show only a minimal difference. Despite this there was a 15% increase observed in the  $P_m^B$  seasonal mean at C in 2003 compared to 2002.

The field year 1999 stands out as having anomalously high  $\alpha^B$  values. Pre and post zebra mussel invasion grand seasonal mean  $\alpha^B$ 's were compared excluding 1999 data. This exclusion results in little difference between upper bay stations but increases are still observed at stations HB (6%) and C (5%). Most seasonal means at all stations have tended to be between 4.25 to 5.50 mg C mg Chl<sup>-1</sup> E<sup>-1</sup> m<sup>-2</sup> with the mean for the period just prior to zebra mussel invasion (1990-94) also falling in this range. Seasonal mean  $\alpha^B$  in 2003 at stations GL (5.34) and C (6.11) were the highest values recorded for  $\alpha^B$  (post zebra mussel invasion) with the exception of 1999.

Increasing temperatures are associated with higher  $\alpha^B$ 's (need a reference for this type of statement). In 2003 temperature explained 26% of the variance in  $\alpha^B$  at B, which has higher mixed depth temperatures. At C in 2003 20% of the variance in  $\alpha^B$  was due to temperature. Other variables such as mixing depth have a greater impact at C.

Table 4. Comparison of seasonal means for the light-saturated rate of photosynthesis  $P_{opt}$  ( $\text{mg C m}^{-3} \text{ h}^{-1}$ ), the photosynthetic parameters,  $P_m^B$  ( $\text{mg C mg Chl}^{-1} \text{ h}^{-1}$ ) and  $\alpha^B$  ( $\text{mg C mg Chl}^{-1} \text{ E}^{-1} \text{ m}^{-2}$ ), chlorophyll ( $\mu\text{g L}^{-1}$ ), and light extinction-  $\epsilon_{par}$  ( $\text{m}^{-1}$ ) before (1990-94) and after zebra mussel invasion (1995-02). Number of observations = n.

Stations	$P_{opt}$	$P_m^B$	Chl	$\alpha^B$	$\epsilon_{par}$	n
<b>B</b>						
<b>Mean 1990-1994</b>	<b>107</b>	<b>4.58</b>	<b>23.4</b>	<b>4.95</b>	<b>1.40</b>	<b>65</b>
1995	78	4.59	16.2	4.59	1.21	13
1996	49	5.13	9.1	4.51	0.83	13
1997	64	5.54	10.4	6.40	1.03	13
1998	82	4.67	16.7	4.88	1.31	13
1999	116	7.33	14.0	7.21	1.16	13
2000	72	5.64	11.4	4.25	0.89	13
2001	87	5.10	15.2	4.75	1.06	13
2002	91	6.69	12.2	5.51	1.00	13
2003	88	6.54	13.0	5.19	0.83	13
<b>Mean 1995-2003</b>	<b>81</b>	<b>5.69</b>	<b>13.1</b>	<b>5.25</b>	<b>1.03</b>	<b>13</b>
<b>N</b>						
<b>Mean 1990-1994</b>	<b>118</b>	<b>4.54</b>	<b>25.5</b>	<b>4.77</b>	<b>1.43</b>	<b>65</b>
1995	66	5.01	12.8	4.73	1.00	13
1996	50	5.23	8.9	4.25	0.59	13
1997	48	5.15	8.8	4.70	0.84	13
1998	63	5.66	10.5	5.46	0.98	13
1999	52	6.69	7.40	6.48	0.94	13
2000	49	6.06	8.0	4.49	0.83	13
2001	75	5.96	11.4	4.83	0.93	13
2002	71	6.26	10.0	5.30	0.90	13
2003	69	5.59	12.7	5.33	0.82	13
<b>Mean 1995-2003</b>	<b>60</b>	<b>5.73</b>	<b>10.1</b>	<b>5.06</b>	<b>0.87</b>	<b>13</b>
<b>HB</b>						
<b>Mean 1990-1994</b>	<b>90</b>	<b>4.10</b>	<b>20.9</b>	<b>4.77</b>	<b>1.10</b>	<b>64</b>
1995	46	4.31	10.5	4.68	0.81	13
1996	41	4.68	8.5	4.99	0.48	13
1997	34	4.05	7.8	5.96	0.71	13
1998	57	4.42	12.0	4.85	0.82	13
1999	59	7.27	7.8	6.86	0.84	13
2000	69	5.78	9.3	4.64	0.76	13
2001	48	4.75	9.8	4.10	0.78	13
2002	67	6.14	10.1	6.02	0.72	13
2003	80	5.13	16.6	5.47	0.77	13
<b>Mean 1995-2003</b>	<b>56</b>	<b>5.17</b>	<b>10.3</b>	<b>5.29</b>	<b>0.74</b>	<b>13</b>

Table 4. Cont'd.

Stations	$P_{opt}$	$P_m^B$	Chl	$\alpha^B$	$\epsilon_{par}$	n
GL						
<b>Mean 1992-1993</b>	<b>48</b>	<b>3.81</b>	<b>11.8</b>	<b>4.61</b>	<b>0.69</b>	<b>26</b>
1996	25	4.07	7.4	4.60	0.57	13
1997	12	2.68	4.1	4.85	0.45	13
1998	22	3.39	6.6	4.87	0.47	13
1999	22	5.49	4.2	6.90	0.46	13
2000	26	3.80	6.2	3.64	0.51	13
2001	17	3.80	4.7	3.96	0.40	13
2002	22	3.99	5.2	4.25	0.51	13
2003	23	4.05	5.9	5.34	0.44	13
<b>Mean 1996-2003</b>	<b>21.1</b>	<b>3.91</b>	<b>5.5</b>	<b>4.80</b>	<b>0.48</b>	<b>13</b>
C						
<b>Mean 1990-1994</b>	<b>25</b>	<b>3.78</b>	<b>6.3</b>	<b>4.62</b>	<b>0.48</b>	<b>64</b>
1995	18	3.58	4.7	4.46	0.39	13
1996	13	3.97	3.2	4.83	0.23	13
1997	7	2.43	2.9	4.25	0.36	13
1998	11	3.68	4.0	5.17	0.38	13
1999	10	3.65	2.8	6.46	0.34	13
2000	14	3.77	3.7	4.68	0.38	13
2001	12	3.60	3.3	4.50	0.37	13
2002	13	4.10	3.2	4.78	0.41	13
2003	16	4.84	3.1	6.11	0.32	13
<b>Mean 1995-2003</b>	<b>12</b>	<b>3.74</b>	<b>3.4</b>	<b>5.03</b>	<b>0.35</b>	<b>13</b>

### Seasonal Photosynthesis

Annual and inter-annual variability in seasonal areal phytoplankton photosynthesis (SAPP) are not primarily influenced by solar irradiance. The primary variables are Chl,  $\epsilon_{par}$ ,  $P_m^B$  and  $\alpha^B$  (see Millard in 2002 report, Millard et al., 1996). Incident irradiance is an important factor contributing to variability in PP over shorter time scales of days to a week.

SAPP calculated using empirical solar irradiance as a percentage of the rates calculated with theoretical cloudless solar irradiance has shown a slight increase (3-4%) throughout the bay following zebra mussel invasion (Table 5). However the value at station B in the upper bay in 2003 was typical of pre-zebra mussel values. This increase in photosynthetic efficiency by the phytoplankton community may be linked to the trend toward higher values for photosynthetic parameters in recent years.

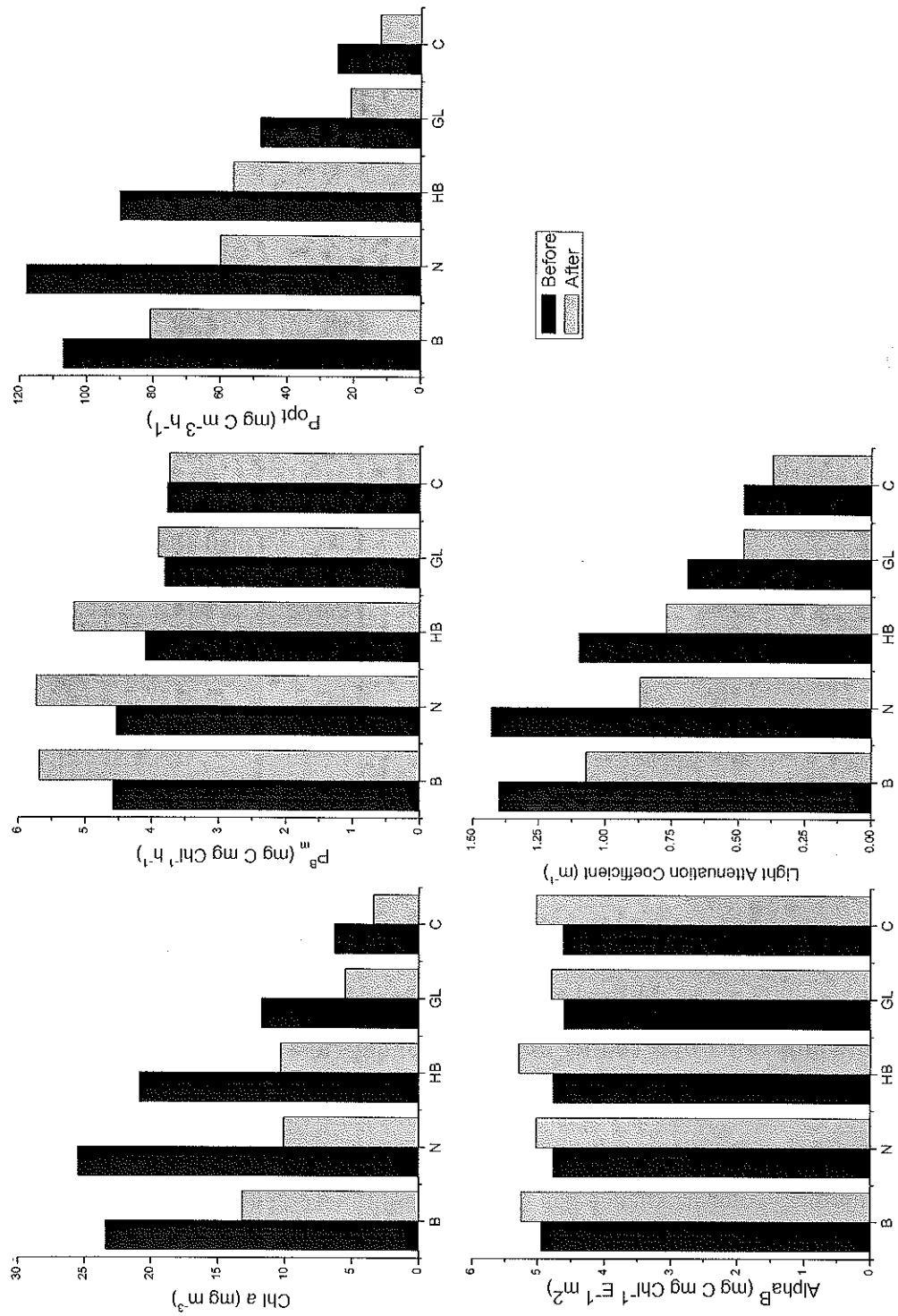


Figure. 3. Grand mean of seasonal means for chlorophyll a, photosynthetic parameters,  $P_{opt}$  and light attenuation before 1990-94 and after (1195-2003) zebra mussel colonization.

From 2002 to 2003 SAPP increased 14% at B (289 g C·m<sup>-2</sup>), 27% at N and 21% at HB. In the lower bay SAPP increased at both GL (28%) and C (34%) in 2003. With the exception of B in 1999, SAPP in 2003 at B and HB was the highest values recorded at these stations in both the pre and post zebra mussel time frames. SAPP at GL in 2003 was the highest value recorded in the post zebra mussel time frame at this location.

Despite recent increases observed in SAPP, increased transparency and phytoplankton adaptations such as increases in  $P_m^B$  and  $\alpha^B$ , the mean SAPP has declined throughout the bay during the post zebra mussel invasion period compared to pre-invasion means. The most notable decline in SAPP has been at N and GL where SAPP has declined 25% and 32% respectively.

## Discussion

The 2003 field year yielded interesting observations. Although still lower than pre zebra mussel levels, chlorophyll seasonal concentrations at N and HB have consistently increased since 1999. In recent years, transparency has declined in the middle bay in parallel with increasing chlorophyll concentrations. The decline in light extinction at Conway in 2003 despite consistent chlorophyll levels suggests that variability in non-algal sources of light extinction are responsible.

$P_m^B$  increases with temperature and changes in phytoplankton species composition to communities dominated by small fast growing species. Seasonal adaptation by phytoplankton to mean water column light intensities can influence  $\alpha^B$ . Seasonal mean  $P_m^B$  has increased in the upper and middle bay stations in the post zebra mussel time period. The mixed depth temperature means from 1994-2003 do not indicate a temperature increase to associate with higher  $P_m^B$ 's. However, this increase is coupled with the dramatic decline in chlorophyll levels at these stations post zebra mussel invasion suggesting a link between these trends and zebra mussel colonization.

Table 5. Seasonal<sup>†</sup> areal phytoplankton photosynthesis ( $\text{g C}\cdot\text{m}^{-2}$ ) in the Bay of Quinte 1988-2002.

Location	Year	Empirical Irradiance	Cloudless Irradiance	% of Cloudless <sup>‡</sup>
<b>Trenton-T</b>	1991	302	381	79
	1992	239	317	76
	1991-1992	271	349	78
<b>Belleville-B</b>	1988	160	204	78
	1989	238	302	79
	1990	234	311	75
	1991	309	385	80
	1992	267	354	75
	1993	197	264	75
	1994	247	336	74
	<b>1989-1994</b>	<b>249</b>	<b>325</b>	<b>76</b>
	1995	209	268	78
	1996	120	160	75
	1997	211	260	81
	1998	152	189	80
	1999	293	362	81
	2000	224	287	78
	2001	219	270	81
	2002	248	312	80
2003	289	386	75	
<b>1995-2003</b>	<b>218</b>	<b>277</b>	<b>79</b>	
<b>Napanee-N</b>	1990	234	312	75
	1991	283	350	81
	1992	294	385	76
	1993	239	325	74

Table 5. Cont'd.

Location	Year	Empirical Irradiance	Cloudless Irradiance	% of Cloudless‡
<i>Napanee cont'd</i>	1994	254	349	73
	<b>1990-1994</b>	<b>261</b>	<b>344</b>	<b>76</b>
	1995	210	271	78
	1996	133	178	75
	1997	181	225	80
	1998	194	241	81
	1999	183	221	83
	2000	157	201	78
	2001	215	266	81
	2002	207	260	80
	2003	283	369	77
	<b>1995-2003</b>	<b>196</b>	<b>248</b>	<b>79</b>
<b>Hay Bay-HB</b>	1988	153	197	78
	1989	319	405	79
	1990	276	369	75
	1991	282	349	81
	1992	303	402	76
	1993	245	336	73
	1994	245	328	75
	<b>1989-1994</b>	<b>278</b>	<b>365</b>	<b>77</b>
	1995	186	240	78
	1996	158	204	77
	1997	164	201	82
	1998	222	275	81
	1999	242	297	81

Table 5. Cont'd.

Location	Year	Empirical Irradiance	Cloudless Irradiance	% of Cloudless‡
<i>Hay Bay Cont'd</i>	2000	203	259	78
	2001	204	255	80
	2002	282	358	79
	2003	359	469	77
	<b>1995-2003</b>	<b>224</b>	<b>284</b>	<b>79</b>
<b>Glenora-GL</b>	1992	245	324	76
	1993	230	308	75
	<b>1992-93</b>	<b>238</b>	<b>316</b>	<b>76</b>
	1996	147	194	76
	1997	107	131	82
	1998	187	229	82
	1999	202	244	83
	2000	148	191	78
	2001	155	189	82
	2002	146	181	81
	2003	203	265	77
	<b>1996-2003</b>	<b>162</b>	<b>203</b>	<b>80</b>
<b>Conway-C</b>	1988	113	144	78
	1989	169	213	79
	1990	157	206	76
	1991	186	234	79
	1992	210	277	76
	1993	190	252	75
	1994	173	236	73

Table 5. Cont'd.

<i>Location</i>	Year	Empirical Irradiance	Cloudless Irradiance	% of Cloudless <sup>‡</sup>
<i>Conway Cont'd</i>	<b>1989-1994</b>	<b>181</b>	<b>236</b>	<b>76</b>
	1995	165	212	78
	1996	123	161	76
	1997	85	104	82
	1998	167	201	83
	1999	146	176	83
	2000	134	170	79
	2001	147	181	81
	2002	124	154	81
	2003	188	245	77
	<b>1995-2003</b>	<b>142</b>	<b>178</b>	<b>80</b>

<sup>†</sup> Areal photosynthesis calculated for a standardized season length for all years of May 1 to Oct 31.

<sup>‡</sup> Seasonal areal photosynthesis calculated with empirical irradiance measured at Pt. Petre as a percentage of values calculated with theoretical cloudless irradiance at latitude 44°N.

1988 values were unexplainably low and were excluded from means for the pre zebra mussel period. See Millard et al. 1996.

In contrast to this trend the 2003 data at N and HB reveal a decrease in  $P_m^B$  in this field year as well as a decrease in  $\alpha^B$  at HB. This is coupled with considerable increases in SAPP at all stations in 2003. SAPP at B (except 1999) and HB are the highest means recorded in the post phosphorous control time frame of the study. These results indicate a possible shift in the response of the phytoplankton community to zebra mussel presence in the upper and middle bay. The increases observed at C for alpha,  $P_m^B$  and transparency indicates a potentially increasing impact of zebra mussels in the lower bay.

The changes in photosynthetic parameters may be a compensatory response of the phytoplankton community that maximizes production under the pressures of high grazing rates

by mussels. Despite the increases in SAPP in 2003, grand seasonal phytoplankton photosynthesis means show a marked decline throughout the bay since zebra mussel invasion. Research by Nicholls (see summary in 1999-00 report) indicates an alteration in species composition in the Bay of Quinte in response to zebra mussel colonization. The most notable change appears to be an increase in biomass of larger species that are thought to have lower photosynthesis to biomass ratios (lower  $P_m^B$ ). Further data analysis is needed to determine if the shifts observed in 2003 are indicative of species changes in the phytoplankton community. Data from previous years suggests that phytoplankton community structure is not the sole determinant for  $P_m^B$  values. The gradient to lower values of this parameter from upper to lower bay has always been the result of the temperature gradient.

Monitoring efforts must be maintained in order to properly evaluate ecosystem effects of invasive species such as the zebra mussel on the Bay of Quinte. This system has a long history of research and monitoring programs covering from water quality to fisheries. More recent study efforts include the development of an ecosystem model. All of these aspects combine to provide a continuum of data which is uniquely poised to provide great insight into the ecosystem impacts of invasive species in the Bay of Quinte and similar ecosystems throughout the Great Lakes.

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## ZOOPLANKTON IN THE BAY OF QUINTE

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The zooplankton community in the Bay of Quinte is dynamic. It changes in structure down the length of the Bay from the shallow, eutrophic habitat in the upper bay, represented by the station at Belleville (B), through mesotrophic conditions in the section near Hay Bay (HB), to a meso-oligotrophic environment in the mouth of the bay at Conway (C). Station depth increases from 5 m at B, to 11 m at HB and 32 m at C, which means that thermal stratification occurs through out the summer at C, sporadically at HB and not at B. Zooplankton community structure and productivity is controlled not only by the physical environment but also by the type and quantity of available food, which is determined by nutrient conditions, the structure of the fish community which is the primary source of mortality in this system, and the introduction of new species which either compete for food or alter predation on or within the zooplankton community. Monitoring of zooplankton in the Bay of Quinte tracks species composition, size structure, abundance, biomass and productivity in an effort to understand the response of the community to changes in the controlling factors and assess its 'health' as a component of the ecosystem. This report presents data from the 2003 field year in the context of previous data.

### **Methods**

Zooplankton samples were collected at the three primary monitoring stations, B, HB, and C. Zooplankton were also collected at Napanee (N), a 5 m deep station located at the eastern end of the upper bay. Samples were collected on alternate weeks from the beginning of May until the end of October. As in previous years, discrete samples were collected through the water column with a 41 L Schindler-Patalas trap fitted with 64- $\mu$ m mesh. Three depths were sampled at B (1 m, 2 m and 3 m), three at N (1 m, 2 m and 3 m), five at HB (1 m, 2 m, 3 m, 6 m and 9 m), and eight at C (1 m, 3 m, 5 m, 8 m, 10 m, 15 m, 20 m and 25 m). A single composite sample was constructed for each station-date by combining 50% of the sample from each depth. In addition,

4 m samples were collected at both B and N and analyzed separately. At each station, the 4 m discrete depth samples were compared statistically to the 1-3 m composite samples using paired t-tests in Systat V11.

A minimum of 400 individual zooplankters and all loose eggs within a subsample aliquot were enumerated from each sample. The exotic predatory cladoceran *Cercopagis pengoi*, which was first seen in eastern Lake Ontario in 1998 (MacIsaac et al. 1999), was found at Belleville and Conway in 1999, and at all three stations in 2000. Each of the discrete depth samples was filtered through a 400- $\mu\text{m}$  mesh, and all of the *C. pengoi* and *Leptodora kindtii* were enumerated. *Cercopagis* was not subsampled because individuals have a tendency to form clumps within the samples when their caudal spines becoming entangled. *Leptodora* is generally rare but an important species to follow because it is a large predatory cladoceran vulnerable to fish predation. Veliger larvae were not counted in the zooplankton samples until 1995. Dreissenids were first found in the upper bay in 1995 and therefore veligers were not likely present in the plankton until that year. However dreissenids were abundant in the eastern basin of Lake Ontario in 1991, and veligers may have occasionally been present in the plankton at Conway before 1995.

Seasonally-weighted mean (SWM) abundance, biomass and production were calculated over the sampling season: May 1 to Oct. 31. Size was not originally measured. The requirements of a project examining the biomass size spectra of zooplankton communities provided the opportunity to go back and estimate the size structure of all the Quinte samples over the June 1 to Oct 6 period. Therefore, present and future estimates of cladoceran mean length were (will be) calculated over this period. Biomass was calculated by multiplying the abundance estimates by mean species dry weights determined by Watson and Wilson for the Great Lakes, as has been done historically. Production was estimated by the egg-ratio method of Paloheimo (1974) as described in Cooley *et al.* (1986). When a species' seasonally-weighted, mean biomass was  $<50 \text{ mg}\cdot\text{m}^{-2}$ , production was estimated using P/B relationships as described in Johannsson *et al.* (2000). However in several cases, the egg-ratio production estimate was zero or close to zero, so the P/B production estimate was used despite a SWM biomass  $>50 \text{ mg}\cdot\text{m}^{-2}$ . It appears that P/B values estimated from the literature relationships overestimate production in

the Bay of Quinte. Therefore, the Quinte P/B production estimates were corrected based on comparisons of P/B and egg ratio production values from Bay of Quinte between 1995 and 1999. These equations were updated in 2005 as follows:

*Cladocerans:*

$$\text{Belleville: } \ln(\text{egg-ratio prod.}) = -0.301 + 1.026 \ln(\text{P/B prod.})$$

$$N = 19; r^2 = 0.89$$

$$\text{Hay Bay: } \ln(\text{egg-ratio prod.}) = -0.480 + 1.023 \ln(\text{P/B prod.})$$

$$N = 23; r^2 = 0.83$$

$$\text{Conway: } \ln(\text{egg-ratio prod.}) = -0.955 + 1.030 \ln(\text{P/B prod.})$$

$$N = 20; r^2 = 0.80$$

*Cyclopoids: (all stations)*

$$\ln(\text{egg-ratio prod.}) = -0.696 + 1.010 \ln(\text{P/B prod.})$$

$$N = 10; r^2 = 0.93$$

The Belleville cladoceran equation was used to correct the Napanee data.

## Results

### *Belleville*

With the exception of 2001 when seasonally-weighted mean (SWM) biomass reached over  $500 \mu\text{g.L}^{-1}$ , biomass in the upper bay during the 1992-2003 period was lower than that observed in the 1980s (Figure 1). There have been sporadic years of exceptionally low biomass: 1992, 1997, and 2000. Both 1992 and 2000 were cold years, which may explain some of the decrease. SWM biomass averaged  $206 \mu\text{g.L}^{-1}$  in 2003, which was slightly higher than the 2002 value of  $170 \mu\text{g.L}^{-1}$ .

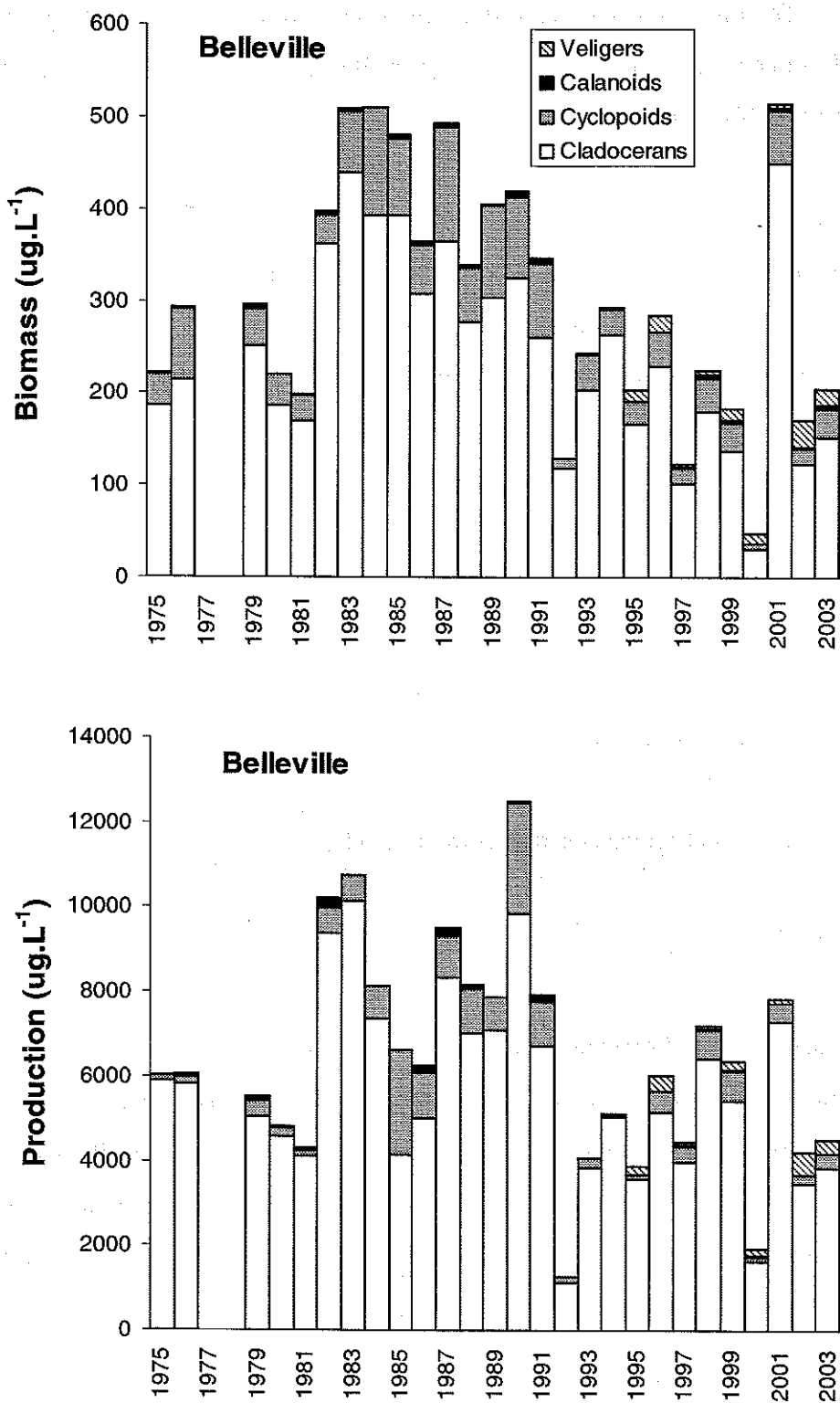


Figure 1. Trends in volumetric seasonally-weighted mean dry biomass and seasonal production at Belleville.

Table 1. Seasonal mean abundances of major zooplankton species at Station B (nos.m<sup>-3</sup>), 1975-2003.

Species	1975	1976	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
<i>Bos</i>	5006	61713	2469	3666	26373	32848	125122	90673	26764	19829	26724	22793	11299	19315
<i>Eubos</i>	48732	29155	49471	51067	41015	103837	59667	58274	90417	72121	70351	47818	60133	60050
<i>D. ret</i>	12632	10742	22971	10350	13535	28695	32717	27919	17335	22262	17866	3678	8778	6312
<i>D.g.m.</i>	285	14	416	3471	646	4927	1866	838	7006	2162	6115	11168	12208	13185
<i>Cerio</i>	490	5750	844	648	2355	3555	6575	13288	10706	11363	9424	1242	645	2573
<i>Chy</i>	41206	54664	43466	20367	11670	36805	46441	64978	56434	22974	51566	50943	28395	46525
<i>Diaph</i>	3270	2122	2268	2317	1243	1160	4262	1929	630	1095	5449	917	1295	572
<i>Lepto</i>	351	381	157	113	51	169	215	74	0	80	274	0	44	41
<i>Diac</i>	24	140	83	57	157	59	63	232	209	174	180	301	111	510
<i>Vern</i>	1518	1134	396	541	468	1142	1546	753	6988	1512	1463	2176	4192	2292
<i>Tropo</i>	55	1710	1885	592	153	275	2011	7856	1951	415	5175	143	553	289
<i>Meso</i>	185	241	582	688	190	1387	1262	1155	1767	705	1644	1338	1945	5161
<b>Species</b>	<b>1991</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	
<i>Bos</i>	7087	10966	8418	10167	15506	22353	13707	15058	7682	24624	25704	40343	10135	
<i>Eubos</i>	60005	16718	47555	46325	13769	21018	22321	44748	31078	1677	42439	7547	28793	
<i>D. ret</i>	9967	4949	7478	13440	2168	11934	6252	21172	8839	1583	5518	4795	3627	
<i>D.g.m.</i>	5961	4575	5347	6417	8943	8961	5607	4340	4885	178	32192	689	6601	
<i>Cerio</i>	2098	1014	1731	457	1925	2218	818	1911	2699	6632	2210	16884	6291	
<i>Chy</i>	52620	10602	19716	52786	9150	15003	715	13861	15980	705	6559	2490	5050	
<i>Diaph</i>	1776	352	1976	3648	913	1526	2384	3456	2070	433	2317	981	1553	
<i>Lepto</i>	103	0	82	146	24	34	112	8	93	6	71	39	48	
<i>Cerco</i>									11	18	1	0	0	
<i>Diac</i>	165	101	855	144	255	142	82	16	4	19	36	32	26	
<i>Vern</i>	971	52	147	85	425	963	753	334	217	51	396	81	97	
<i>Tropo</i>	1757	285	423	57	222	299	522	780	2004	403	2765	653	2269	
<i>Meso</i>	1557	215	277	801	421	808	909	2921	1727	56	2386	200	601	
<i>Veligers</i>					22631	45536	23729	15752	20683	33313	5844	34518	22110	

\*Other species seen in 1997-2003: *Alona* sp., *Ceriodaphnia quadrata*, *Holopedium gibberum*, *Polyphemus pediculus*, *Pleuroxus* sp., *Scaphaloberis kingi*, *Eucyclops agilis*, *Eurytemora affini*, *Leptodiaptomus sicilis*, *L. ashlandi*, *L. siciloides*, *Skistodiaptomus oregonensis*

Table 2. Abbreviations of the species names in the abundance tables.

Scientific Name	Abbreviated Name
<i>Bosmina longirostris</i>	<i>Bos</i>
<i>Eubosmina coregoni</i>	<i>Eubos</i>
<i>Daphnia retrocurva</i>	<i>D. ret</i>
<i>Daphnia galeata mendotae</i>	<i>D.g.m.</i>
<i>Ceriodaphnia lacustris</i>	<i>Cerio</i>
<i>Chydorus sphaericus</i>	<i>Chy</i>
<i>Diaphanosoma birgei</i>	<i>Diaph</i>
<i>Leptodora kindtii</i>	<i>Lepto</i>
<i>Cercopagis pengoi</i>	<i>Cerco</i>
<i>Diacyclops thomasi</i>	<i>Diac</i>
<i>Cyclops vernalis</i>	<i>Vern</i>
<i>Tropocyclops extensus</i>	<i>Tropo</i>
<i>Mesocyclops edax</i>	<i>Meso</i>
<i>Dreissena veligers</i>	<i>Veligers</i>

Since the early 1990s, Belleville has been dominated by small and medium cladocerans (*Bosmina*, *Eubosmina* and *Ceriodaphnia*) and fewer copepods (Tables 1, 2). In 2003, the slightly larger *Eubosmina* displaced *Bosmina* as the dominant taxon. With the exception of 2001, abundance of the large cladoceran *Daphnia galeata mendotae* has remained relatively low. Its numbers were particularly low in 2000 and 2002. Another large cladoceran, the predatory *Leptodora kindtii*, has remained uncommon in the last decade. *Cercopagis pengoi* is rare in the upper bay and none have been observed at Belleville since 2001.

Biomass in the Bay of Quinte shows strong seasonal patterns, which is influenced by water temperature, phytoplankton abundance and fish predation. Zooplankton biomass was very low at Belleville throughout the spring of 2003, and peaked dramatically in early July due to a sudden increase in both *D. galeata mendotae* and *Eubosmina* (Figure 2). This bloom was short-lived, as numbers of both groups began declining by mid-July. By mid-August, there were few *Daphnia*, and the biomass of the remaining groups remained relatively stable until early October.

Mean cladoceran length, which is an indicator of fish predation pressure, has fluctuated widely in the last five years (Figure 3). Cladocera averaged 0.471 mm at Belleville in 2003, which is similar to the sizes observed in the 1990s.

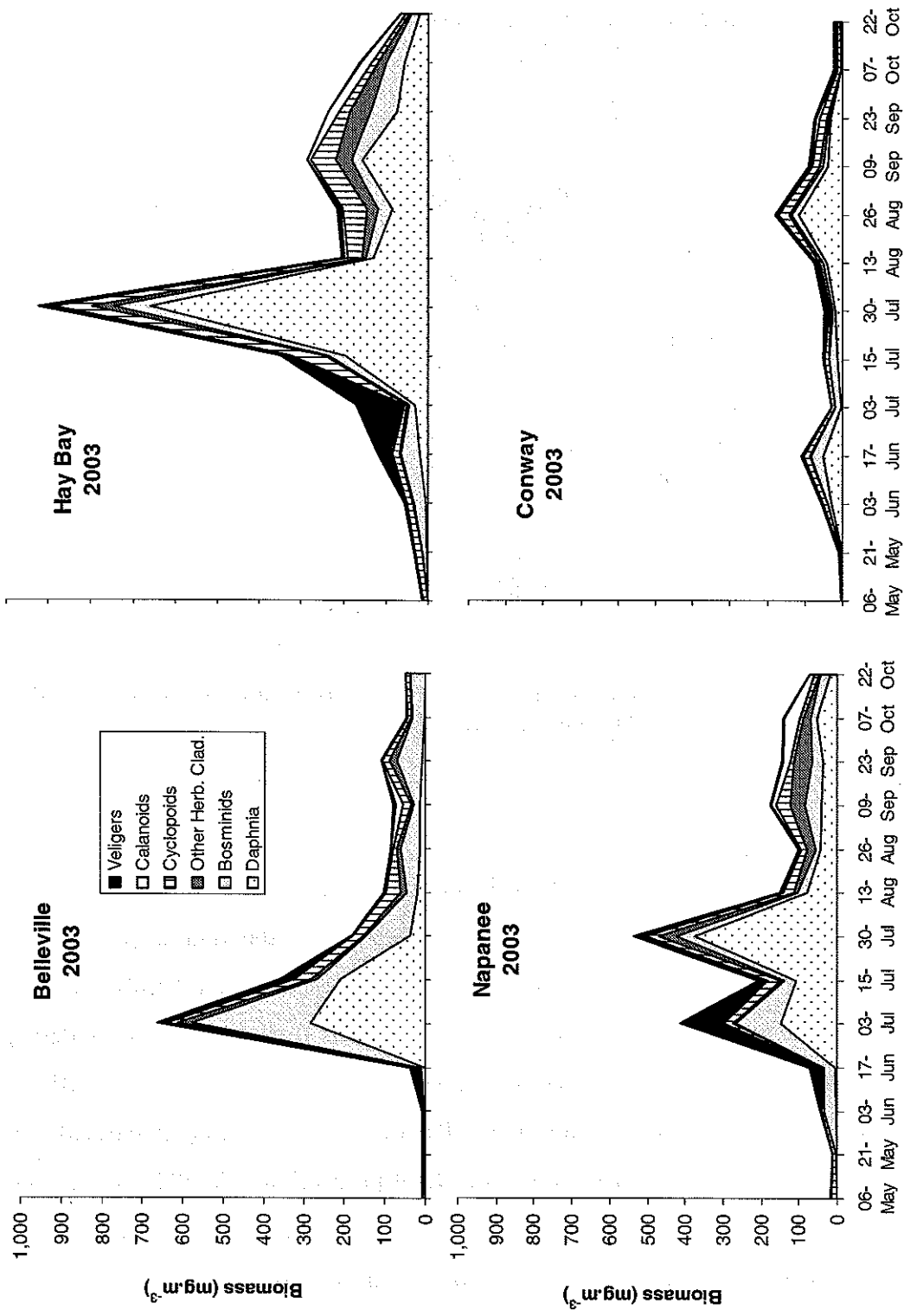


Figure 2. May to October 2003 seasonal trends in volumetric dry biomass (based on measured weights) at Belleville, Napanee, Hay Bay and Conway in the Bay of Quinte. Bosminids include *Eubosmina* and *Bosmina*, and *Daphnia* includes *D. galeata mendotae* and *D. retrocurva*. "Other Herb. Clad." represents the remaining herbivorous cladocerans.