Lake Champlain Long-Term Water Quality and Biological Monitoring Program

Summary of Program Activities During 2007

May 23, 2008

Prepared by:

Vermont Department of Environmental Conservation
Water Quality Division
103 South Main St.
Waterbury, VT 05671-0408

and

New York State Department of Environmental Conservation
Region 5
P.O. Box 296
Ray Brook, NY 12977-0296

Submitted to:

Lake Champlain Basin Program
P.O. Box 204
54 West Shore Rd.
Grand Isle, VT 05458

CONTENTS

Purpose of Report

The workplan for the Lake Champlain Long-Term Water Quality and Biological Monitoring Program approved by the Lake Champlain Basin Program specifies the following annual reporting requirements:

An annual report will consist of a summary of the history and purpose of the (program), description of the sampling network, summary of field sampling and analytical methods, parameter listings, and data tables. The purposes of this annual report will be achieved by maintaining an up-to-date Program Description document, graphical presentations of the data, and an interactive database, including statistical summaries, on the project website…… In addition, the quarterly report produced in April each year will provide a summary of program accomplishments for the calendar year just ended, including the number of samples obtained and analyzed at each site by parameter.

The Program Description document, interactive access to the project data, and graphical and statistical summaries of the data are available on the program webpage: http://www.anr.state.vt.us/dec/waterq/lakes/htm/lp_longterm.htm

The purpose of this report is to provide a summary of sampling activities and accomplishments during 2007.

Summary of Sampling Activities During 2007

Table 1 lists the number of sampling visits to each lake and tributary station in relation to the target frequencies specified in the project work plan. Table 2 lists the number of samples collected and analyzed for each monitoring parameter.

The frequency of lake station sampling exceeded workplan targets at all stations during 2007. The frequency of tributary sampling was below the workplan targets. The number of tributary samples obtained each year depends to some extent on the number and timing of high flow events, since sampling is geared toward capturing the highest flow conditions when loading of phosphorus and other materials is greatest. There is little value in obtaining more samples under low or moderate flow conditions simply to meet workplan targets, since low flow data do not contribute significantly to improving the precision of annual loading estimates. However, an effort should be made to sample more tributary high flow events each year whenever possible in order to meet workplan targets.

Table 1. Number of sampling visits during 2007 at each lake and tributary station in comparison with workplan targets.

Lake Station	**Number of Sampling Visits**	**Workplan Target**	**Tributary Station**	**Number of Sampling Visits for All Parameters**	**Number of Sampling Visits for Total Phosphorus**	**Workplan Target**[1]
2	21	12	AUSA01	8	13	14/24
4	21	12	BOUQ01	9	14	14/24
7	15	12	GCHA01	9	14	14/24
9	15	12	LAMO01	11	18	14/24
16	16	12	LAPL01	9	16	14/24
19	15	12	LAUS01	10	15	14/24
21	16	12	LCHA01	10	15	14/24
25	18	12	LEWI01	9	16	14/24
33	15	12	LOTT01	9	16	14/24
34	15	12	METT01	9	13	14/24
36	15	12	MISS01	11	17	14/24
40	16	12	OTTE01	9	16	14/24
46	22	12	PIKE01	9	11	14/24
50	22	12	POUL01	9	13	14/24
51	21	12	PUTN01	9	13	14/24
			ROCK02	10	16	14/24
			SALM01	10	15	14/24
			SARA01	10	15	14/24
			WINO01	12	17	14/24

[1] The project workplan calls for 14 samples per year for all monitoring parameters, including 10 samples at high flow and 4 samples at low flow. Additional sampling for total phosphorus only should occur on 10 other dates under high flow conditions, for a target of 24 samples per year for total phosphorus.

Table 2. Number of samples collected and analyzed for each monitoring parameter during 2007.

Parameter	**Lake**	**Tributaries**	**Total**
TP	396	312	708
DP	397	207	604
Cl	397	220	617
TN	397	200	597
Alkalinity	92	34	126
DO (Winkler)	437	--	437
Chl-a	273	--	273
TSS	--	207	207
Temperature	129	232	361
Conductivity	--	228	228
pH	--	235	235
Secchi depth	264	--	264
Multiprobe depth profiles	134[1]	--	134[1]
Zebra mussel veligers	106	--	106
Zebra mussel settled juveniles	7	--	7
Mysids	54[2]	--	54[2]
Zooplankton	126[2]	--	126[2]
Phytoplankton	146[2]	--	146[2]

[1] The results of 130 profiles were not included in the database due to instrument errors.

[2] Samples are analyzed but results are not yet available on the project website. Zooplankton density data from 1993-2007are available on request. All phytoplankton samples from 2006 and 2007 have been analyzed and the raw cell counts are available on request. However, calculation of biovolumes and incorporation of the results into a database for convenient query have not been accomplished yet due to delays in obtaining the necessary technical support from Vermont ANR Information Technology staff.

Analyses, Presentations, and Reports

Certain analyses of the data were required by the 2007 project workplan. In addition, project personnel prepared special presentations and reports during 2007 from the monitoring program data. These items are listed below and presented in more detail in the Appendices.

Wastewater Phosphorus Discharge Data

The project workplan requires an annual compilation of wastewater phosphorus discharge data for all facilities in the Vermont and New York portions of the Lake Champlain Basin. These data are provided for Vermont in Appendix A and for New York in Appendix B, and are available in computer spreadsheet format on request.

Environmental factors associated with the severity of algae blooms in Missisquoi Bay, Lake Champlain

In 2007, contrary to all expectations, Missisquoi Bay experienced a summer with very few algae blooms. Preliminary investigations into this were presented during the Lake Champlain Research Consortium conference "Our lake, our future" held January 8-9, 2008 in Burlington, Vermont. The extended abstract for this presentation is located in Appendix C.

Missisquoi Bay-Lake Champlain, Zooplankton Crash of 2007

As well as having low algal densities in 2007, Missisquoi Bay also had zooplankton densities significantly lower than any previously noted. Preliminary investigations into this were presented during the Lake Champlain Research Consortium conference "Our lake, our future" held January 8-9, 2008 in Burlington, Vermont. The extended abstract for this presentation is located in Appendix D.

Historical changes in phytoplankton populations and water quality in Missisquoi Bay

As part of the on-going analysis of Lake Champlain phytoplankton, archived samples for key locations are being analyzed. In 2007, the archived samples for Missisquoi Bay were completed and summarized. The final report discussing the results of this investigation is located in Appendix E. It was also presented as a poster during the Lake Champlain Research Consortium conference "Our lake, our future" held January 8-9, 2008 in Burlington, Vermont.

Presentations by project staff on aspects of the Lake Champlain monitoring program

- "A broad view of Lake Champlain – Water quality among the basins"
  LCBP Potvin Lecture Series presentation February 28, 2007
- "Monitoring for Cyanobacteria on Lake Champlain" – poster presented at the annual meeting of the New England Association of Aquatic Biologists March 8, 2007.
- "Environmental implications of increasing chloride levels in Lake Champlain and other Vermont waters"
    - Presentation to the UVM Rubenstein School of Environment and Natural Resources water discussion group February 1, 2007.
    - Presentation of data and participation on panel discussion on chloride in New England waters at the annual meeting of the New England Association of Aquatic Biologists March 8, 2007.
    - Presentation to the U32 High School marine biology class March 28, 2007.
    - Presentation to the UVM Rubenstein School's Ecological Risk Assessment class April 11, 2007.

Evaluation of the effectiveness of SolarBee® water circulation devices in reducing algae blooms in St. Albans Bay, Lake Champlain

SolarBees have been installed in many lakes, ponds, and reservoirs throughout North America, and there is significant interest among lake residents in Vermont in trying the SolarBee devices for control of algae blooms and nuisance aquatic plants. However, there have been relatively few SolarBee installations in lakes as large as St. Albans Bay (7.2 km^2) or Lake Champlain where large-scale wind-driven currents exist that might possibly overwhelm the circulation effects of the SolarBee devices. Their effectiveness in treating small portions of large lakes has not been sufficiently demonstrated. For these reasons, the Vermont Agency of Natural Resources (ANR) conducted water quality monitoring of the SolarBee installation in St. Albans Bay during 2007. The purpose of this monitoring program was to objectively evaluate the effectiveness of SolarBees in reducing algae blooms in the northern portion of the bay. Lake Champlain Monitoring Program staff assisted in the sampling and analysis of the data for this study. A report will be issued during 2008.

Appendix A. Vermont 2007 Wastewater Phosphorus Discharge Data

Vermont Facility	Receiving Lake Segment	Mean Flow (mgd)	Mean TP Conc. (mg/L)	Mean TP Load (mt/yr)	TMDL Wasteload Allocation (mt/yr)
Benson	01 South Lake B	0.012	2.720	0.044	0.122
Castleton	01 South Lake B	0.321	0.225	0.100	0.397
Fair Haven	01 South Lake B	0.200	0.331	0.091	0.414
Poultney	01 South Lake B	0.239	0.186	0.061	0.414
West Pawlet	01 South Lake B	0.015	6.625	0.138	0.276
Orwell	02 South Lake A	0.021	1.523	0.044	0.228
Brandon	04 Otter Creek	0.331	0.297	0.136	0.580
Middlebury	04 Otter Creek	1.016	0.417	0.585	1.823
Otter Valley Union High School	04 Otter Creek	0.003	5.564	0.021	0.173
Pittsford	04 Otter Creek	0.059	2.308	0.188	0.483
Pittsford Fish Hatchery	04 Otter Creek	1.326	0.005	0.008	0.691
Proctor	04 Otter Creek	0.232	2.213	0.708	0.359
Rutland City	04 Otter Creek	4.868	0.225	1.512	5.634
Salisbury Fish Hatchery	04 Otter Creek	0.893	0.077	0.095	0.181
Shoreham	04 Otter Creek	0.010	5.425	0.075	0.242
Vergennes	04 Otter Creek	0.359	0.354	0.175	0.621
Wallingford	04 Otter Creek	0.071	2.850	0.278	0.829
West Rutland	04 Otter Creek	0.191	0.173	0.045	0.364
Barre City	05 Main Lake	2.744	0.167	0.633	3.314
Burlington East	05 Main Lake	0.639	0.325	0.287	0.994
Burlington Electric	05 Main Lake	0.153	0.014	0.003	0.017
Burlington North	05 Main Lake	1.171	0.413	0.668	1.657
Cabot	05 Main Lake	0.025	0.411	0.014	0.041
Essex Junction	05 Main Lake	1.912	0.594	1.569	2.569
IBM	05 Main Lake	3.222	0.225	1.003	5.531
Marshfield	05 Main Lake	0.020	4.975	0.136	0.311
Montpelier	05 Main Lake	1.906	0.421	1.108	3.290
Northfield	05 Main Lake	0.647	0.408	0.365	0.829
Plainfield	05 Main Lake	0.057	3.008	0.237	0.691
Richmond	05 Main Lake	0.088	0.163	0.020	0.184
South Burlington Airport Park.	05 Main Lake	1.426	0.423	0.833	1.906
Stowe	05 Main Lake	0.317	0.300	0.131	0.282
Waterbury	05 Main Lake	0.254	3.975	1.397	0.563
Weed Fish Culture Station	05 Main Lake	7.031	0.023	0.222	0.914
Williamstown	05 Main Lake	0.071	3.158	0.311	1.036
Winooski	05 Main Lake	0.807	0.489	0.545	1.160
Hinesburg	06 Shelburne Bay	0.183	0.308	0.078	0.276
Shelburne #1	06 Shelburne Bay	0.263	0.311	0.113	0.348
Shelburne #2	06 Shelburne Bay	0.331	0.342	0.156	0.497
South Burlington Bart. Bay	06 Shelburne Bay	0.565	0.264	0.206	0.878
Burlington Main	07 Burlington Bay	4.257	0.478	2.807	4.392
Brown Ledge Camp	09 Malletts Bay	0.004	2.530	0.014	0.005
Fairfax	09 Malletts Bay	0.031	4.700	0.202	0.539
Hardwick	09 Malletts Bay	0.231	2.867	0.916	0.410
Jeffersonville	09 Malletts Bay	0.037	7.250	0.366	0.532
Johnson	09 Malletts Bay	0.149	0.485	0.100	0.224
Milton	09 Malletts Bay	0.197	0.709	0.193	0.829
Morrisville	09 Malletts Bay	0.342	0.475	0.224	0.352
Wyeth Nutritional PBM Nutritionals	09 Malletts Bay	0.118	0.155	0.025	0.352
Northwest State Correctional	11 St. Albans Bay	0.029	0.096	0.004	0.028
St. Albans City	11 St. Albans Bay	2.641	0.235	0.857	2.762
Enosburg Falls	12 Missisquoi Bay	0.244	0.454	0.153	0.373
Newport Center	12 Missisquoi Bay	0.021	0.467	0.014	0.006
North Troy	12 Missisquoi Bay	0.080	1.151	0.128	0.760
Richford	12 Missisquoi Bay	0.258	0.375	0.134	0.420
Rock Tenn	12 Missisquoi Bay	0.193	0.439	0.117	1.260
Sheldon Springs	12 Missisquoi Bay	0.020	2.525	0.070	0.373
Swanton	12 Missisquoi Bay	0.508	0.378	0.265	0.746
Troy/Jay	12 Missisquoi Bay	0.040	0.527	0.029	0.221
Alburg	13 Isle LaMotte	0.057	0.019	0.002	0.108
TOTAL		**43.5**		**21.0**	**55.8**

Appendix B. New York 2007 Wastewater Phosphorus Discharge Data

New York Facility	Receiving Lake Segment	Mean Flow (mgd)	Mean TP Conc. (mg/L)	Mean TP Load (mt/yr)	TMDL Wasteload Allocation (mt/yr)
Fort Ann	South Lake B	0.070		0.261	0.220
Granville	South Lake B	0.695	0.279	0.268	0.720
Great Meadows Correctional	South Lake B	0.378	0.583	0.305	0.280
Washington Correctional	South Lake B	0.123	0.245	0.042	0.120
Whitehall	South Lake B	0.480	0.877	0.582	0.600
Crown Point	South Lake A	0.029	3.409	0.136	0.090
International Paper	South Lake A	15.51	0.142	3.034	6.340
Ticonderoga	South Lake A	1.127	1.593	2.478	1.470
Port Henry	Port Henry	0.477	2.001	1.317	0.490
Westport	Port Henry	0.105	2.398	0.348	0.400
Au Sable Forks	Main Lake	0.065	4.025	0.370	0.740
Keeseville	Main Lake	0.325	0.269	0.121	0.330
Lake Placid	Main Lake	1.198	0.981	1.624	2.160
Peru	Main Lake	0.209	1.651	0.476	0.610
Peru/Valcour	Main Lake	0.004	1.964	0.011	0.010
Wadhams	Main Lake	0.007	4.100	0.040	0.040
Willsboro	Main Lake	0.032	3.433	0.150	0.330
Adirondack Fish Hatchery	Cumberland Bay	2.967	0.005	0.021	0.080
Cadyville	Cumberland Bay	0.004	4.914	0.024	0.040
Champlain Park	Cumberland Bay	0.061	3.400	0.285	0.290
Dannemora	Cumberland Bay	0.851	2.440	2.866	3.360
Plattsburgh	Cumberland Bay	5.421	1.325	9.916	10.85
Saranac Lake	Cumberland Bay	1.946	0.528	1.420	2.240
St Armand	Cumberland Bay	0.038	4.317	0.228	0.280
Altona Correctional	Isle LaMotte	0.073	0.530	0.053	0.080
Champlain	Isle LaMotte	0.277	0.406	0.155	0.570
Chazy	Isle LaMotte	0.030	1.486	0.061	0.100
Rouses Point	Isle LaMotte	0.648	2.034	1.820	2.610
Wyeth-Ayerst Chazy	Isle LaMotte	0.044	1.436	0.087	0.070
TOTAL		**31.4**		**28.5**	**35.5**

Appendix C. Environmental factors associated with the severity of algae blooms in Missisquoi Bay, Lake Champlain

Eric Smeltzer[1], Angela Shambaugh[1], Peter Stangel[1], and Fred Dunlap[2]
[1] Vermont Agency of Natural Resources
[2] New York State Department of Environmental Conservation

It was apparent to lake users and researchers that Missisquoi Bay was remarkably free from algae blooms in 2007. The severe summer blooms of cyanobacteria that have been common in most recent years never materialized during 2007.

The availability of long-term water quality and environmental monitoring data provided an opportunity to evaluate factors that might explain annual variations in summer algae conditions in the bay. Water quality data from Missisquoi Bay (Station 50) during the period of 1992-2007 were obtained from the Lake Champlain Long-Term Monitoring Program conducted by Vermont DEC and New York State DEC (2007) through the Lake Champlain Basin Program. Data on river flows and weather variables were obtained from databases maintained by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration.

The analysis tested the following factors that are thought to promote the occurrence of cyanobacteria blooms in lakes in general, or to explain the annual variations in bloom levels in Missisquoi Bay specifically.

- High phosphorus concentrations
- High nitrogen concentrations
- Low nitrogen to phosphorus ratios
- Light limitation caused by high turbidity
- Warm temperatures
- High spring runoff
- High summer runoff
- Selective filter-feeding or nutrient regeneration by zebra mussels
- Grazing by zooplankton

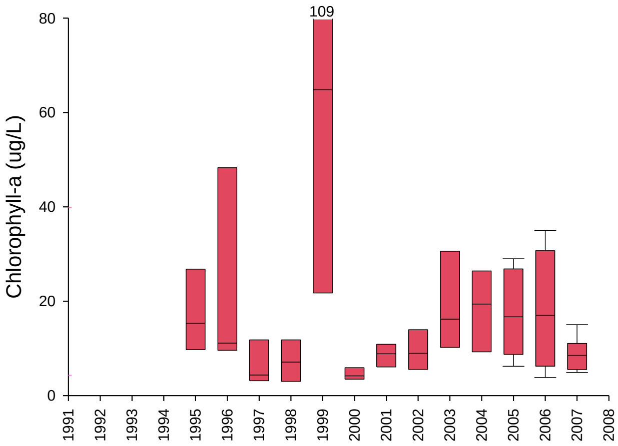


Figure 1. Distributions of July-September CHL values in Missisquoi Bay, 1995-2007. Box plots show 5th, 25th, median, 75th, and 95th percentiles of the CHL sample distributions within each year.

Chlorophyll-a (CHL) was the primary measure of algal abundance used in this analysis. CHL levels were low in Missisquoi Bay during 2007, but not unprecedented (Figure 1). A comparison of phytoplankton data between 2006 and 2007 found that net phytoplankton densities were much lower in 2007 than in 2006, but the seasonal pattern of succession and the dominance by cyanobacteria during late summer were similar both years.

Mean summer total phosphorus (TP) concentrations were near normal for Missisquoi Bay during 2007 in relation to the range of summer means during previous years (Figure 2). There was a significant positive relationship between summer mean CHL and mean TP in Missisquoi Bay indicating that phosphorus is an important controlling factor across the years. However, low phosphorus was not the explanation for the unusually low chlorophyll levels during 2007.

Summer mean total nitrogen (TN) during 2007 was almost the lowest on record for Missisquoi Bay (Figure 3). There was a significant positive relationship between summer mean CHL and TN. Furthermore, the residuals of the CHL-TP regression (Figure 2) were strongly correlated with TN. When TN was low, there was less CHL than would be expected from the TP concentrations present.

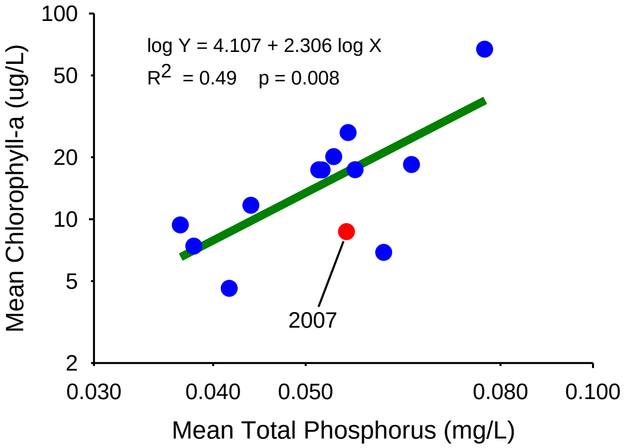


Figure 2. Regression of yearly mean July-September CHL vs. TP in Missisquoi Bay, 1995-2007.

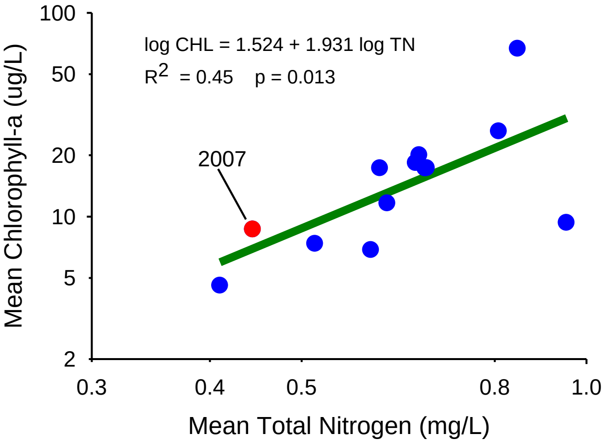


Figure 3. Regression of yearly mean July-September CHL vs. TN in Missisquoi Bay, 1995-2007.

A multiple regression (Equation 1) using TP and TN as independent variables indicated that both nutrients were important in predicting CHL levels. Regression coefficients for both independent variables were statistically significant ($p < 0.01$), and the R^2 value was substantially improved over the R^2 for the regressions using either TP or TN alone (Figures 2 and 3).

$$\log \mathbf{Chl} = 3.89 + 1.90 \log \mathbf{TP} + 1.55 \log \mathbf{TN} \qquad (1)$$
$$R^2 = 0.76$$

July-September TN/TP ratios were among the lowest on record for the bay during 2007, averaging 8.2 by weight. However, TN/TP ratios in Missisquoi Bay were nearly always less than the criterion of 29 below which cyanobacteria are likely to dominate the phytoplankton community in lakes (Smith, 1983). Since low TN/TP ratios should promote even greater cyanobacterial dominance, the low TN/TP ratios observed in Missisquoi Bay during 2007 do not explain the relatively good water quality that year.

A regression relationship between July-September mean Secchi disk depth and mean CHL was used to assess the amount of non-algal light-attenuating materials (e.g., turbidity from inorganic particles or detritus, dissolved organic coloring compounds) in the water column. A negative residual from the regression would suggest greater light attenuation than would be predicted from the CHL concentrations. The data gave no such indication of greater than normal non-algal light attenuation during 2007.

There was a significant positive relationship between July-September mean CHL in Missisquoi Bay and summer mean air temperature recorded at Burlington, VT. However, summer air temperatures were near normal during 2007 compared with conditions during the other years monitored, so cool weather did not account for the relative absence of algae blooms in the bay during 2007. No relationship was found between summer CHL and summer water temperatures in Missisquoi Bay.

There was a significant negative relationship between early spring (March-May) mean flows in the Missisquoi River and July-September mean CHL. This is surprising and counter to the hypothesis that heavy spring runoff stimulates algae blooms by loading the bay with nutrients for the coming growing season. March-May runoff was high during 2007 due to heavy snowmelt, and the low CHL levels in 2007 were consistent with this unexplained relationship.

Late spring (May-June) runoff was slightly lower than normal during 2007. This is the period when much of the manure and fertilizers are applied to fields. However, there was no relationship between May-June flows and summer CHL across the years. July-August runoff was slightly lower than normal during 2007, but there was no relationship between summer runoff and July-September mean CHL.

Zebra mussel adults are not monitored quantitatively in Lake Champlain, but veliger (larval) densities provide an indication of population trends. Veliger densities have been increasing slowly in Missisquoi Bay in recent years, but densities in 2007 were not higher than in the immediately preceding years. Veliger densities in Missisquoi Bay remain extremely low ($< 500/m^3$) compared with levels found elsewhere in Lake Champlain ($> 20{,}000/m^3$), so it is not likely that zebra mussels are having much impact on the food web in Missisquoi Bay.

July-September mean crustacean zooplankton densities were nearly the lowest on record during 2007 (Dunlap, Mihuc, and Pershyn, 2008). There was a significant positive relationship between July-September mean CHL and summer mean crustacean zooplankton densities in Missisquoi Bay across the years. The low zooplankton densities during 2007 suggest that the zooplankton were limited by the amount of their phytoplankton food source that year (i.e., bottom-up food web control), rather than top-down control of algae populations by grazing.

In conclusion, most of the hypotheses listed above for why algae levels were so low in Missisquoi Bay during 2007 appear to be ruled out by this analysis. Low TN concentration is the most likely explanation. The fact that TN seems to have its own independent effect on algae levels in the bay on a year-to-year basis suggests that algae blooms in the bay could be reduced by controlling nitrogen sources where they occur separately from phosphorus sources.

We have not examined the quantities or seasonal patterns of nitrogen loading to the bay to determine whether inputs were, in fact, lower during 2007. It will be important to determine whether the lower TN concentrations in the bay were the result of lower external inputs, or changes in internal processes such as nitrogen fixation by cyanobacteria. The forms of nitrogen present may be a factor as well in determining cause and effect.

We are not the first to discover the importance of nitrogen in Lake Champlain. Levine *et al.* (1997) found that both phosphorus and nitrogen exerted an influence on the abundance and species composition of phytoplankton in the lake. Similar to our findings for Missisquoi Bay, but working with a multiple lake data set, Downing *et al.* (2001) found that the risk of cyanobacteria blooms was strongly correlated with both TP and TN, and less with the TN/TP ratio. Other factors beyond those analyzed here (e.g., forms of inorganic nitrogen present) may also influence the occurrence of cyanobacteria in lakes (Hyenstrand *et al.*, 1998).

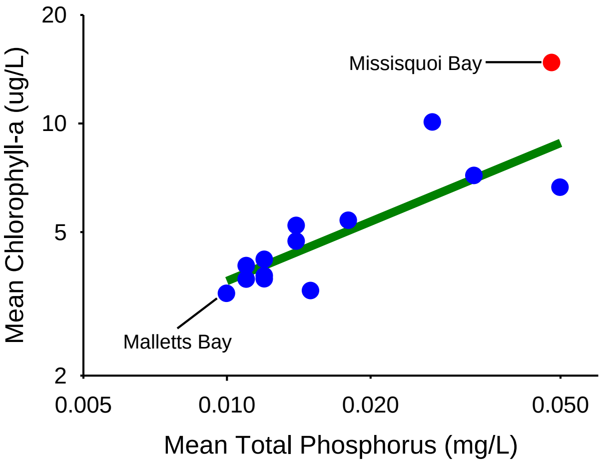


Figure 4. Relationship between long-term mean July-September CHL and TP at 14 stations in Lake Champlain monitored during 1995-2007.

These findings do not suggest that phosphorus reduction is any less important as a lake management priority in Missisquoi Bay and Lake Champlain. High phosphorus levels remain the basic reason why severe algae blooms are much more prevalent in Missisquoi Bay than in other areas of the lake such as Malletts Bay, for example, where phosphorus concentrations are much lower (Figure 4). However, when better understood, the significant role of nitrogen may suggest some additional management tools (i.e., reducing nitrogen inputs) that could be developed to improve water quality conditions in Missisquoi Bay.

References

Downing, J.A., S.B. Watson, and E. McCauley. 2001. Predicting Cyanobacteria dominance in lakes. Can. J. Fish. Aquat. Sci. 58:1905-1908.

Dunlap, F., T. Mihuc, and C. Pershyn. Missisquoi Bay zooplankton: The crash of 2007. This conference.

Hyanstrand, P., P. Blomqvist, and A. Pettersson. 1998. Factors determining cyanobacterial success in aquatic systems – a literature review. Arch. Hydrobiol. Spec. Issues. Advanc. Limnol. 51:41-62.

Levine, S.N., A.d. Shambaugh, S. Pomeroy, and M. Braner. 1997. Phosphorus, nitrogen, and silica as controls on phytoplankton biomass and species composition in Lake Champlain (USA-Canada). J. Great Lakes Res. 23:131-148.

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science. 221:669-671.

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation. 2006. Lake Champlain Long-term Water Quality and Biological Monitoring Program. Program Description. Waterbury, VT and Ray Brook, NY. http://www.anr.state.vt.us/dec/waterq/lakes/docs/lp_lclongtermdescription.pdf

Appendix D. Missisquoi Bay-Lake Champlain: Zooplankton Crash of 2007

Fred Dunlap[1], Tim Mihuc[2], Carrianne Pershyn[2]
[1]New York State Department of Environmental Conservation
[2]Lake Champlain Research Institute, SUNY Plattsburgh

During the summer of 2007, lake monitoring crews noted a distinct difference in the water clarity of Missisquoi Bay as opposed to more recent years of monitoring. The water column was remarkably free of the dense plankton blooms that have come to be associated with summer conditions in the Bay. In addition to the visual observations of the bay itself, field crews noted, that vertical net tows for zooplankton had little to no visible matter in them. This was particularly evident during the second half of the summer.

Zooplankton collection has been part of the Lake Champlain Long-Term Water Quality and Biological Monitoring project supported by the Lake Champlain Basin Program and conducted jointly by the New York State Department of Environmental Conservation and the Vermont Agency of Natural Resources. This project has been on-going since the early 1990s. Zooplankton samples have been consistently collected with a 153 µm mesh net having a 30 cm diameter mouth opening. Collection method has been by vertical net tows of the entire water column beginning just above the sediments with a retrieval rate of approximately 0.8 m/sec. Samples are preserved with a buffered 10% formalin solution to a final concentration of approximately 5%. Analyses are conducted at the Lake Champlain Research Institute located at the State University at Plattsburgh. Analyses consist of taxonomic identification to the lowest taxon possible along and a raw count of individuals. Raw counts are then converted to densities (number per cubic meter).

Analyses of the zooplankton samples revealed a sharp drop in total zooplankton densities and number of species observed between the first half of the summer and the second half. In particular, August samples showed dramatic declines over the long-term averages for species richness, species eveness, and simpson's diversity index which is a relatively simple measure of diversity using richness and relative abundance (figure 1). During August 2007, species richness, eveness and diversity had the lowest average values ever observed over the course of this monitoring project. Also, the lowest individual sample values for the three indices were observed during August 2007. A single sample richness of 4 (against a long-term average of ~17) and single sample eveness and diversity values of less than 0.2 out of a possible 1.0 were observed during August.

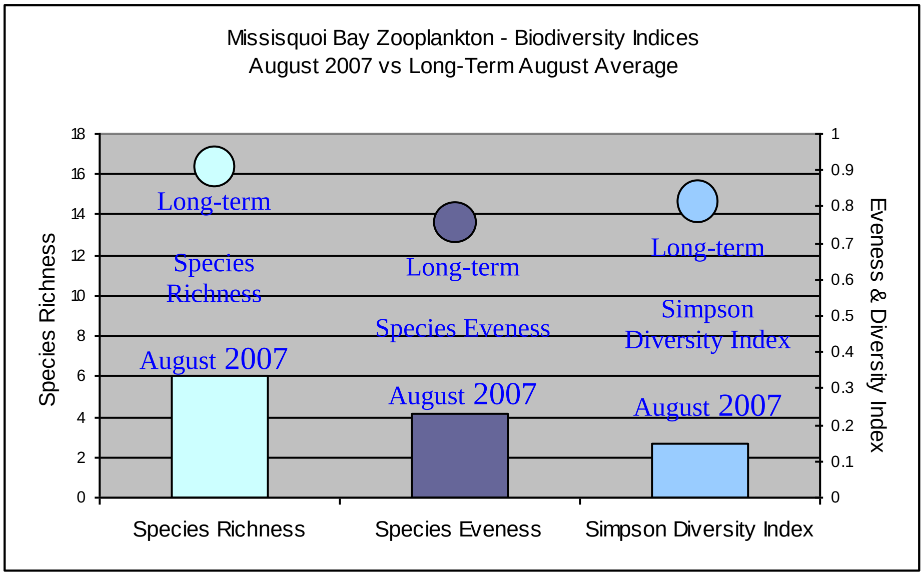
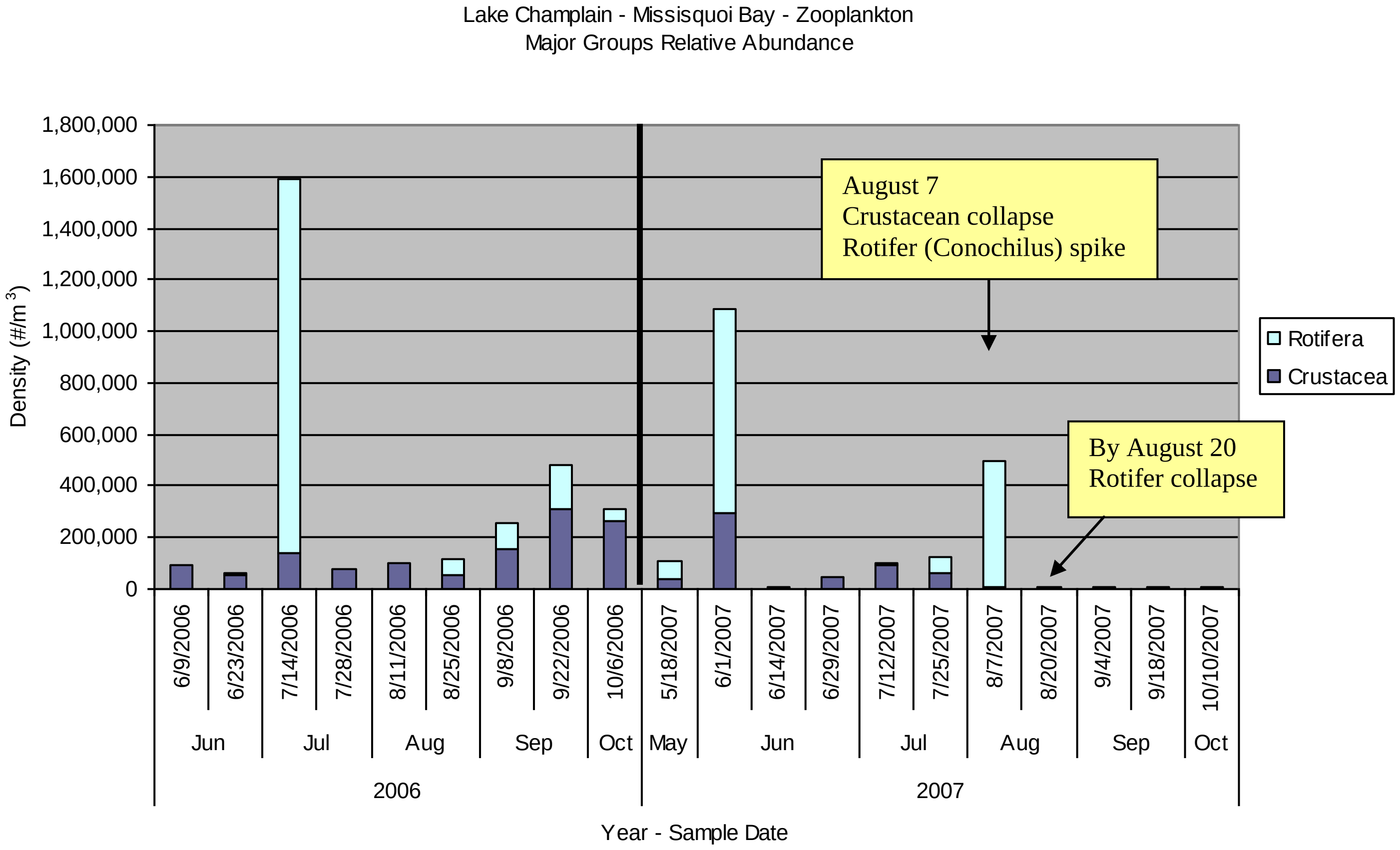


Figure 1. Simple biodiversity indices for zooplankton in Missisquoi Bay - August 2007 vs August long-term average

The shift in taxonomic composition and total densities was also very evident as the season progressed from July into August and when compared to observations of 2006 (figure 2). Early season patterns in both years were similar as populations increased which then declined and were again followed by re-building. This pattern appears to be fairly typical in Lake Champlain and is thought to be associated with seasonal transitions in populations linked to changing food supplies and warming water temperatures. The early season spikes in rotifer populations in both 2006 and 2007 were, however, more extreme than in prior years. The primary difference in 2007 came in early August as rotifers spiked at the same time that the crustacean population collapsed. This was followed within 2 weeks by the collapse of the rotifer population. Neither crustaceans nor rotifers rebounded over the remainder of the summer.


Lake Champlain - Missisquoi Bay - Zooplankton
Major Groups Relative Abundance

August 7
Crustacean collapse
Rotifer (Conochilus) spike

By August 20
Rotifer collapse

In looking at the crustaceans and rotifers separately, some general observations may be made. The early season pattern for crustaceans was generally typical, although, similarly to the total zooplankton densities, the early June crustacean density was considerably higher than the long-term average. Over the course of the summer, crustacean densities varied more so than when compared to 2006 (figure 3). In 2007, crustacean populations did not recover after the August 7 collapse. Crustacean composition in 2007 was relatively consistent with long-term compositions. Generally, Cladocerans dominated with members of the families Bosminidae, Daphniidae, and Sididae being the most commonly occurring taxa. Rotifer densities varied even more considerably than the crustaceans. This, also, is not unusual as rotifer densities have fluctuated considerably within years, as well as, across years. Initial early spikes in rotifer densities were followed by periods of decline before again rebounding. In 2007, following a mid-summer re-bound, the rotifer population collapsed in mid-August and did not recover (figure 4). Peaks in rotifer populations in both 2006 and 2007 were the highest since 1996. Additionally, 2006 and 2007 rotifer taxa were very much dominated by *Conochilus spp.* as compared to 1996 when there was a fairly balanced mix of taxa, and while Conochilids were present, they were not dominant.

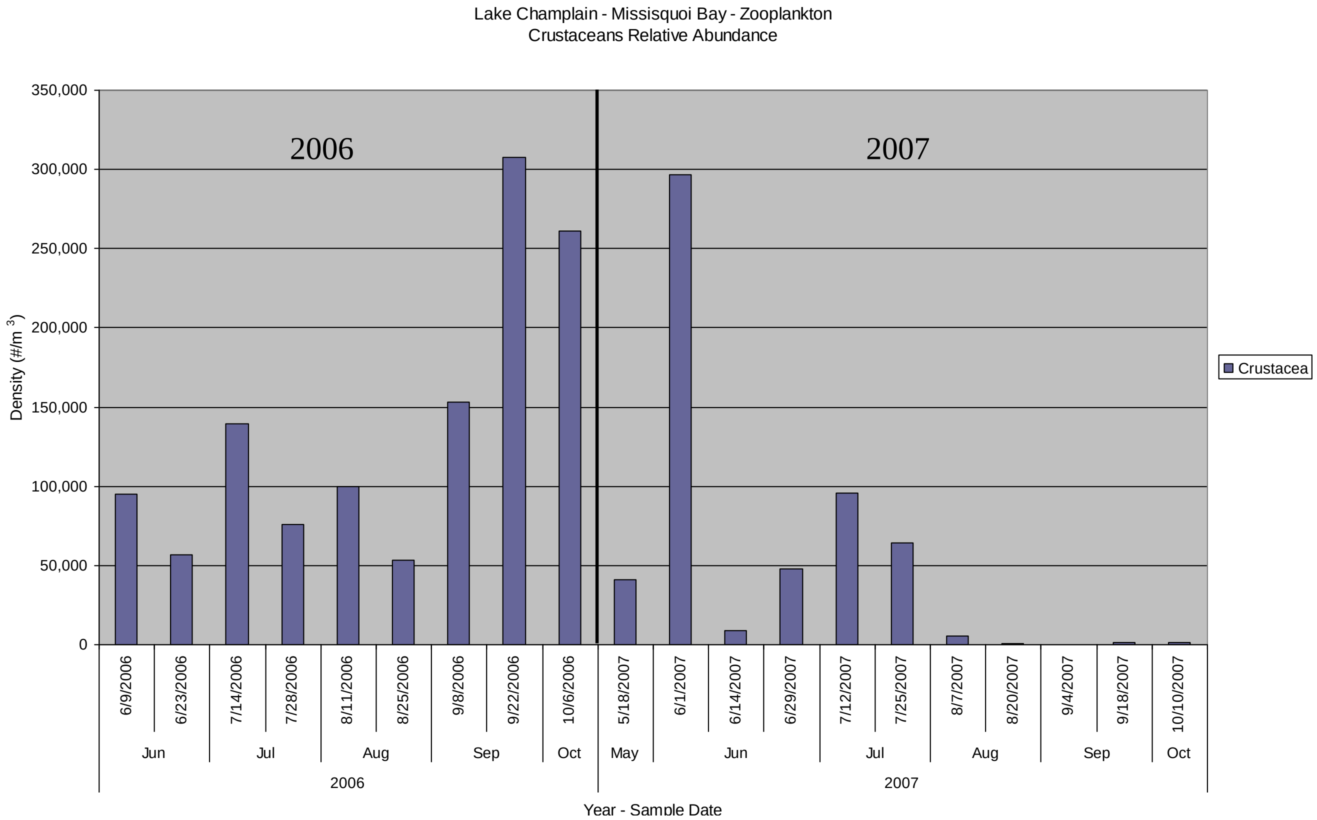


Figure 3. Comparison of Crustacean densities in Missisquoi Bay in 2006 and 2007

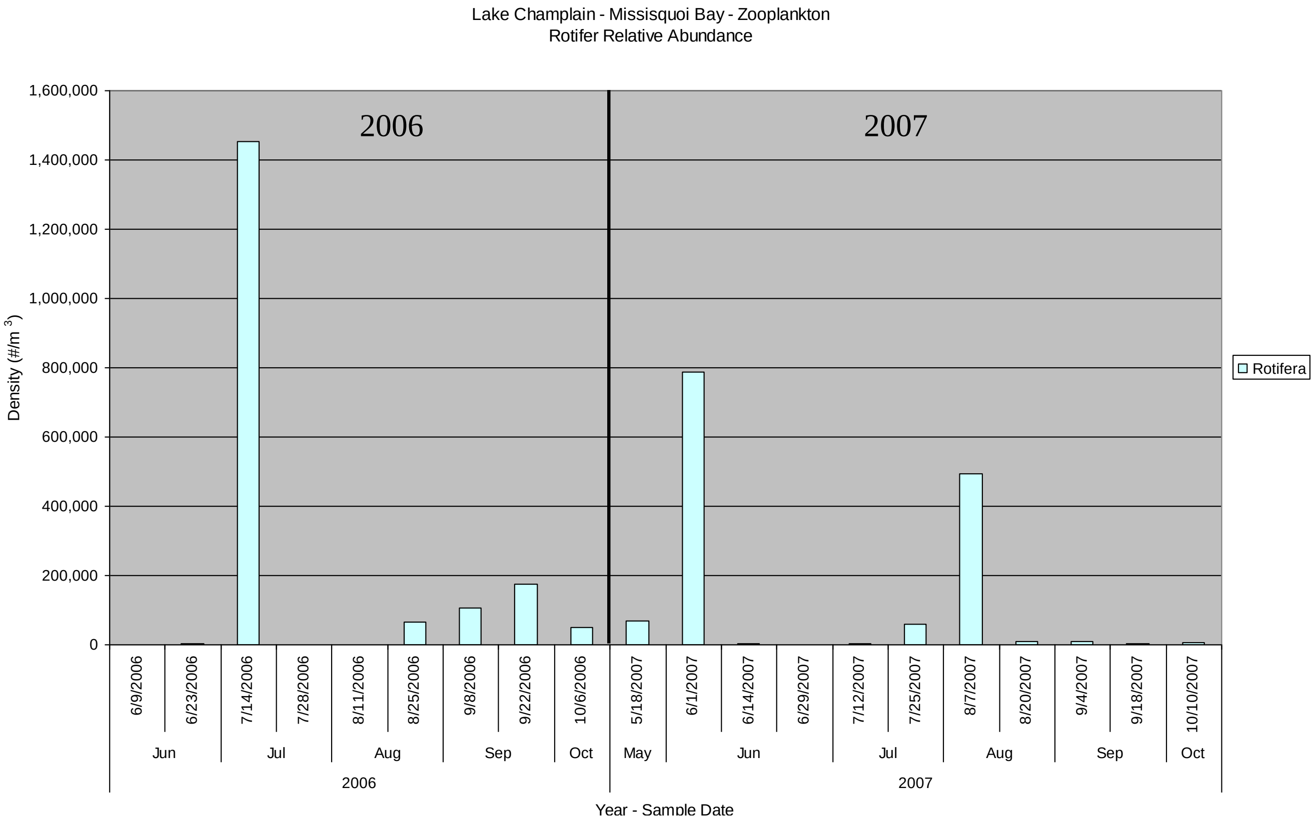


Figure 4. Comparison of Rotifer densities in Missisquoi Bay in 2006 and 2007

Summary

- Zooplankton densities exhibited a sharp decline in 2007, particularly from early August on.
- In August 2007, the lowest biodiversity indices (richness, eveness, simpson diversity) were observed since the early 1990s.
- During August/September, the lowest total zooplankton densities were observed since the early 1990s.
- Crustacean densities collapsed in the first week of August concurrent with a rotifer spike
- Rotifer densities collapsed shortly after
- Crustacean taxonomic composition remained relatively consistent with long-term composition, although at much lower densities
- Rotifer taxonomic composition has shown a marked shift to favor the genus, *Conochilus* as compared to earlier years
- Rotifer densities (particularly *Conochilus)* have exhibited very high peaks in densities over the last 2 years. Each time, substantial declines in all zooplankton (rotifers and crustaceans) are observed immediately afterward.

There are several thoughts regarding the cause or causes for the zooplankton collapse observed in 2007. The leading theory is one associated with the plankton food web and a “bottom up” control whereby zooplankton densities were regulated by a limited phytoplankton food supply (Smeltzer, et al, 2008). Also being considered are possibilities that high early season zooplankton densities may have overgrazed a limited food supply, thus altering the food web structure for the remainder of the summer. The collapse first of the crustacean population in early August followed by the rotifers may suggest cropping off by alewife which would specifically target the larger crustaceans. Anecdotal information suggests alewife may have been in considerable abundance for the first time in 2007. There remain many factors to examine before a definitive conclusion may be reached explaining the zooplankton collapse during the 2007 season. We have not yet performed direct comparisons with phytoplankton data collected over the same period. Analyzing these two datasets together to look for variations in both composition and timings of emergence, dominance and declines in both communities may shed some light on the lower food web interactions. Discussions still need to take place with fisheries scientists regarding alewife populations and the timing of spawning and hatching and subsequent foraging in Lake Champlain. There may well be other environmental factors that contributed to the zooplankton decline that have yet to be factored in.

References

Balcer, M.D., N. Korda and S. Dodson. 1984. Zooplankton of the Great Lakes. A guide to the identification and ecology of the common crustacean species, 174 p. University of Wisconsin Press.

Carling, K.J., I. Ater, M. Pellam, A. Bouchard, T. Mihuc. 2004. A Guide to the Zooplankton of Lake Champlain, Plattsburgh State University

Smeltzer, E., A. Shambaugh, P. Stangel, F. Dunlap. Environmental Factors Associated with the Severity of Algae Blooms in Missisquoi Bay, Lake Champlain. Lake Champlain Research Conference, January 2008

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation. 2007. Long-Term Water Quality and Biological Monitoring Project for Lake Champlain, Quality Assurance Project Plan. LCBP Grand Isle, VT.

Appendix E. Historical changes in phytoplankton populations and water quality in Missisquoi Bay

Angela Shambaugh
Vermont Agency of Natural Resources

Introduction

Missisquoi Bay has long been identified as one of the Lake Champlain segments most in need of water quality improvement. Phosphorus concentrations, averaging 45 µg/L from 2001 – 2005, are among the highest in the Basin (LCBP 2006). Currently, water quality in the bay is perceived as having reached an all time low, with cyanobacterial blooms occurring at levels not experienced in the past. Here we use the available phytoplankton data to evaluate changes that have occurred in Missisquoi Bay since long-term monitoring supported by the Lake Champlain Basin Program began in 1992, and examine whether phytoplankton populations may have changed during this time period.

Materials and Methods

The Lake Champlain Long-Term Water Quality and Biological Monitoring Program (LTMP) has monitored water quality and phytoplankton at a single mid-bay station, off Shad Island, in Missisquoi Bay on a bi-weekly basis during the ice-free months since its inception in 1992. An extensive continuous record of basic water quality data exists as a result. These data and descriptions of the methods used for collection and analysis are available on the program's webpage (http://www.anr.state.vt.us/dec/waterq /lakes/htm/lp_longterm.htm).

Whole-water phytoplankton samples were collected through 2003, after which samples have been filtered through a plankton net. However, whole-water phytoplankton analyses were not completed for a variety of reasons, and samples have been in long-term storage. Archived samples from Missisquoi Bay were analyzed for phytoplankton composition after the overall condition of the samples was evaluated. Any that showed signs of fungal growth, insufficient preservative or cell degradation were not analyzed quantitatively. Acceptable samples were analyzed using Utermohl settling chambers and an inverted microscope at 200x. Phytoplankton were identified to the lowest feasible taxonomic level and the number of cells and natural units recorded. Data were log-transformed and evaluated for differences using one way ANOVA, linear regression, or t-tests utilizing a SIGMAPLOT 2004 software package.

Additional water quality data were obtained from the Vermont Lay Monitoring Program, which has coordinated volunteer lake monitoring efforts around the state since 1979. Water quality analyses for both programs were conducted by the DEC Environmental Laboratory. Data for Missisquoi Bay (Secchi depth, grab samples for chlorophyll) were collected from 1981 through 2005 by a family of dedicated volunteers as part of the Vermont Lay Monitoring program (http://www.anr.state.vt.us/dec/waterq/lakes/htm/lp_volunteer.htm). Correspondence and other information relating to monitoring and water quality in Missisquoi Bay were obtained from DEC Water Quality Division files.

Results

Phytoplankton

There were 55 archived whole-water phytoplankton samples from Missisquoi Bay considered acceptable for quantitative analysis. These represented samples collected from September 1992 through October 2003 (Figure 1). There was large variation in the number of samples available annually, with some years poorly represented, and statistical analyses often lacked the power needed to identify differences.

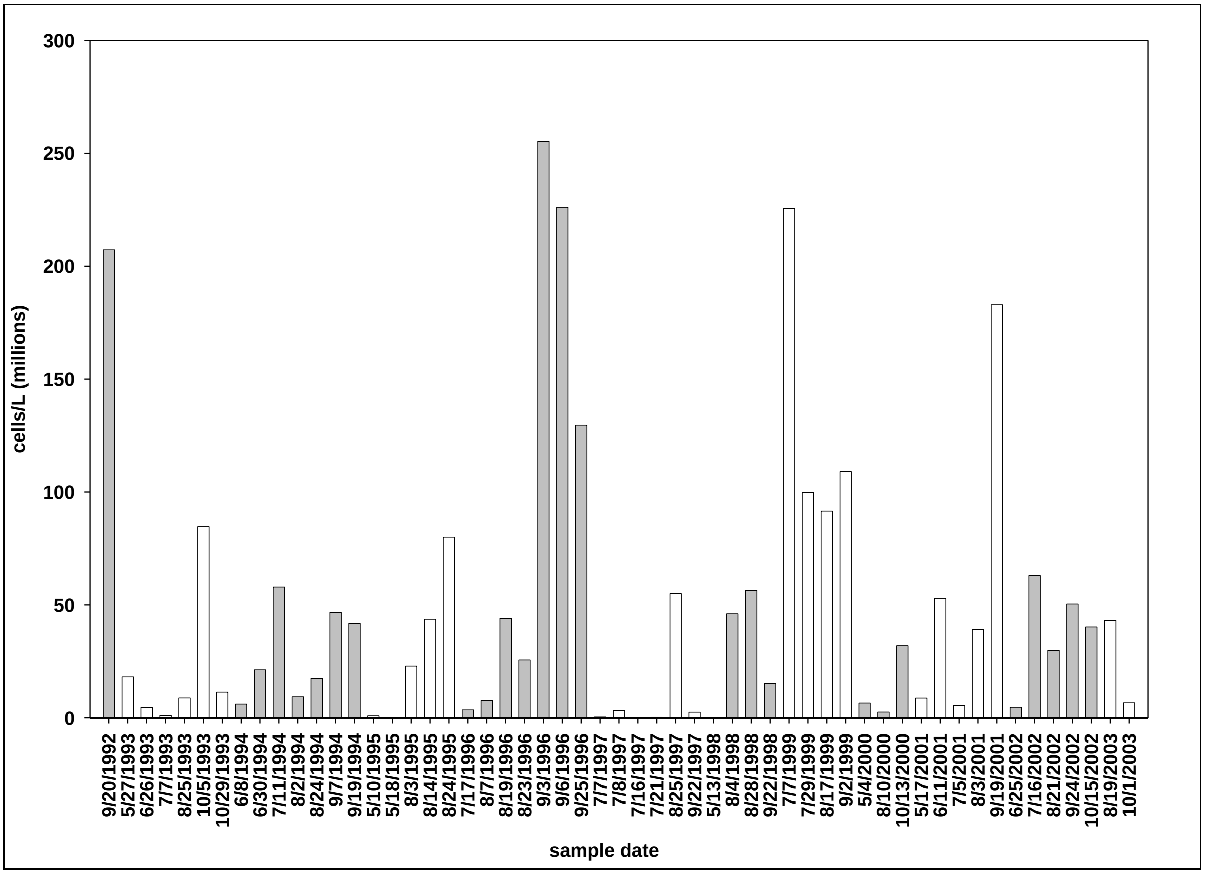


Figure 1. Phytoplankton densities in available historical samples from Missisquoi Bay station 50, 1992 – 2003. The color scheme serves only to distinguish sample years from one another. N=55. Data represent integrated whole-water collections made over twice the Secchi depth.

Differences were detectable in total cell densities among years (one way ANOVA, $p = 0.031$), with densities in 1999 higher than 1997 (Holms-Sidak multiple comparison procedure). To investigate the possibility that phytoplankton densities in recent years have been higher than in the past, paired t-tests were used to compare mean cell densities in 2001 and 2002 (the most recent years with multiple sampling dates) to other years. Compared in this fashion, mean phytoplankton densities in 1997 were significantly lower than those in 2001 and 2002 ($p = 0.027$ and 0.020, respectively) while those in 1999 were significantly higher than densities in 2002 ($p = 0.034$). Otherwise, no differences were detectable (Figure 2).

Cyanobacteria were the most abundant cells in the available samples (Figure 3). Cryptophyte flagellates, chrysophytes (diatoms) and chlorophytes (green algae) were often the primary phytoplankton present in May and June while cyanobacteria dominated in July, August and September.

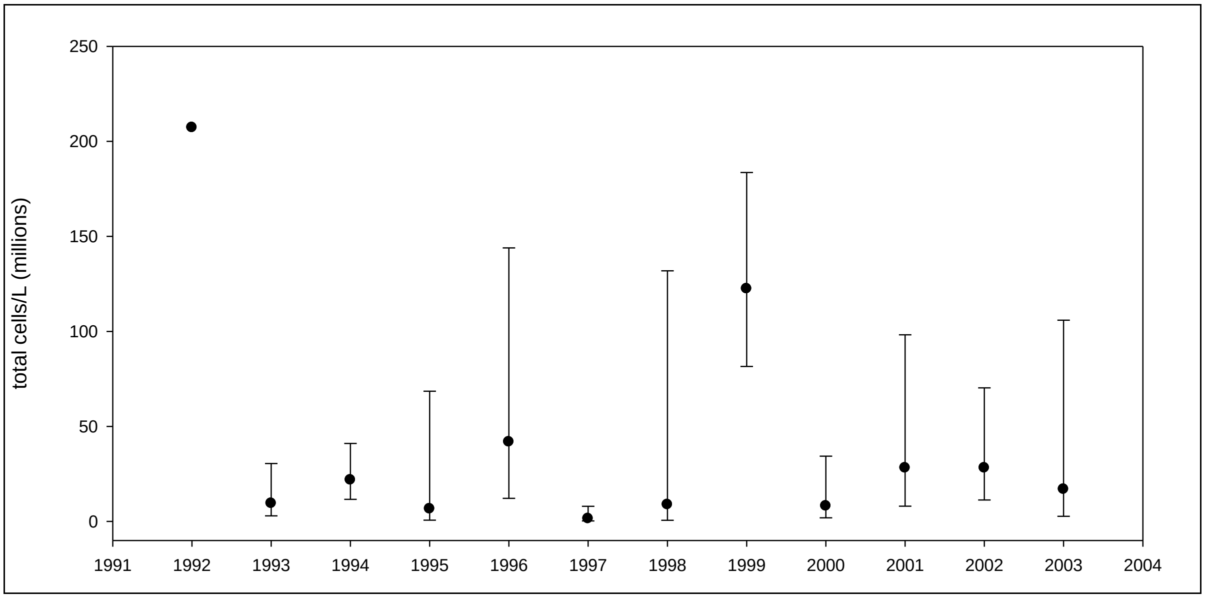


Figure 2. Annual total density of phytoplankton at Missisquoi Bay station 50. Points represent the annual geometric mean. Bars represent the 95% confidence interval. Data represent integrated whole water collections made over twice the Secchi depth.

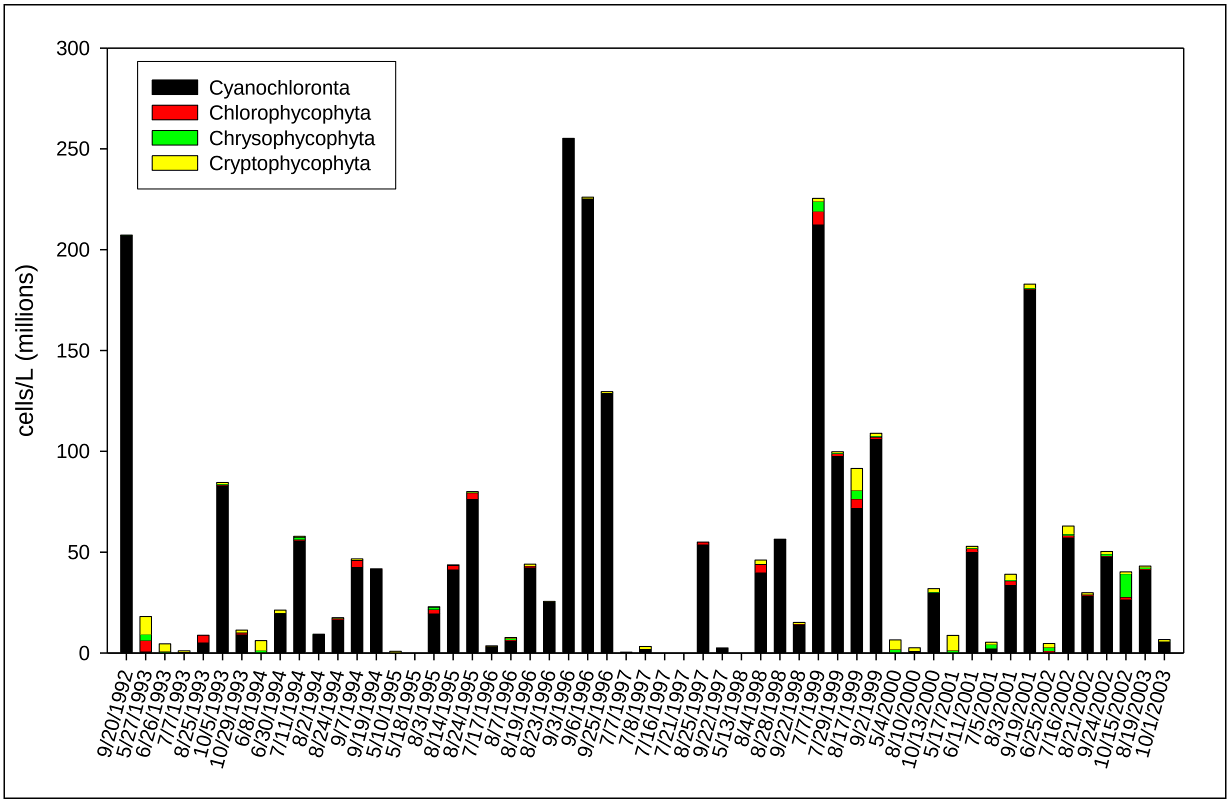


Figure 3. Phytoplankton composition (cells/L, in millions) at Missisquoi Bay station 50, July through September 1992 – 2003. Data represent integrated whole water collections made over twice the Secchi depth. N = 55.

No differences were detected in total cyanobacteria densities across all years (Kruskal-Wallis one way ANOVA on ranks, p = 0.149). Comparisons made using paired t-tests of mean cyanobacteria densities during July, August and September (when they are most prevalent) found little evidence that 2001 and 2002 densities were higher than previous years (Figure 4). Mean

Cyanobacteria densities during these months in 1999 were significantly higher than the same period during 2002 ($p = 0.03$) while those in 1997 were significantly lower than in 2002 ($p<0.03$). Otherwise, no differences were detectable.

Though the limited number of available samples made it difficult to detect statistically significant differences, the data do indicate that several periods of elevated cyanobacteria cell densities have occurred since monitoring began. In particular, high densities occurred in September 1992, September 1996, July 1999, and September 2001 (Figures 1 and 3).

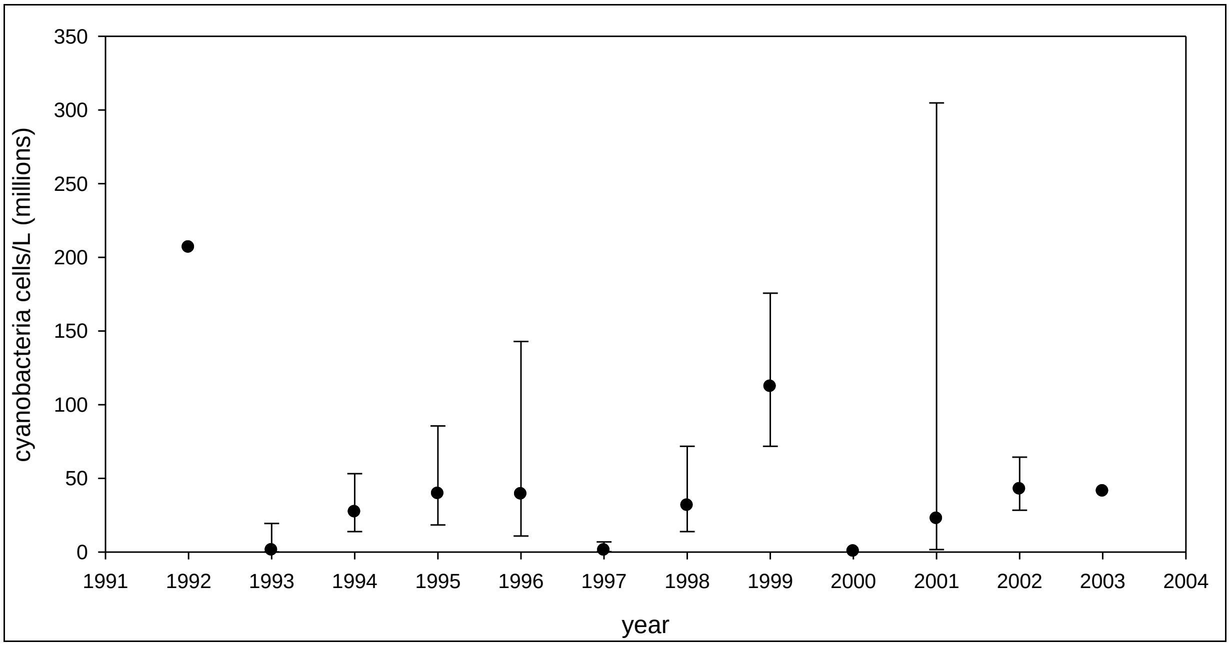


Figure 4. Annual total density of cyanobacteria cells at Missisquoi Bay station 50, July through September. Points represent the annual geometric mean. Bars represent the 95% confidence interval. Data represent integrated whole water collections made over twice the Secchi depth.

In addition to degrading water quality and aesthetics, cyanobacteria are potentially toxic. This has been of particular concern on Lake Champlain since 1999, when several dogs died after swimming in or drinking lake water. Three groups of potentially toxic cyanobacteria were present in Missisquoi Bay – *Aphanizomenon*, *Microcystis* and *Anabaena* (Figure 5). *Aphanizomenon* appears to have been more common in the bay prior to 1997, and represented the dominant cyanobacteria taxa during September 1992, late summer 1994 and late summer 1996. *Microcystis* has been present in the bay since 1992, but has represented a larger fraction of the community after 1998. *Anabaena*, also present since 1992, was most abundant between 1995 and 1999.

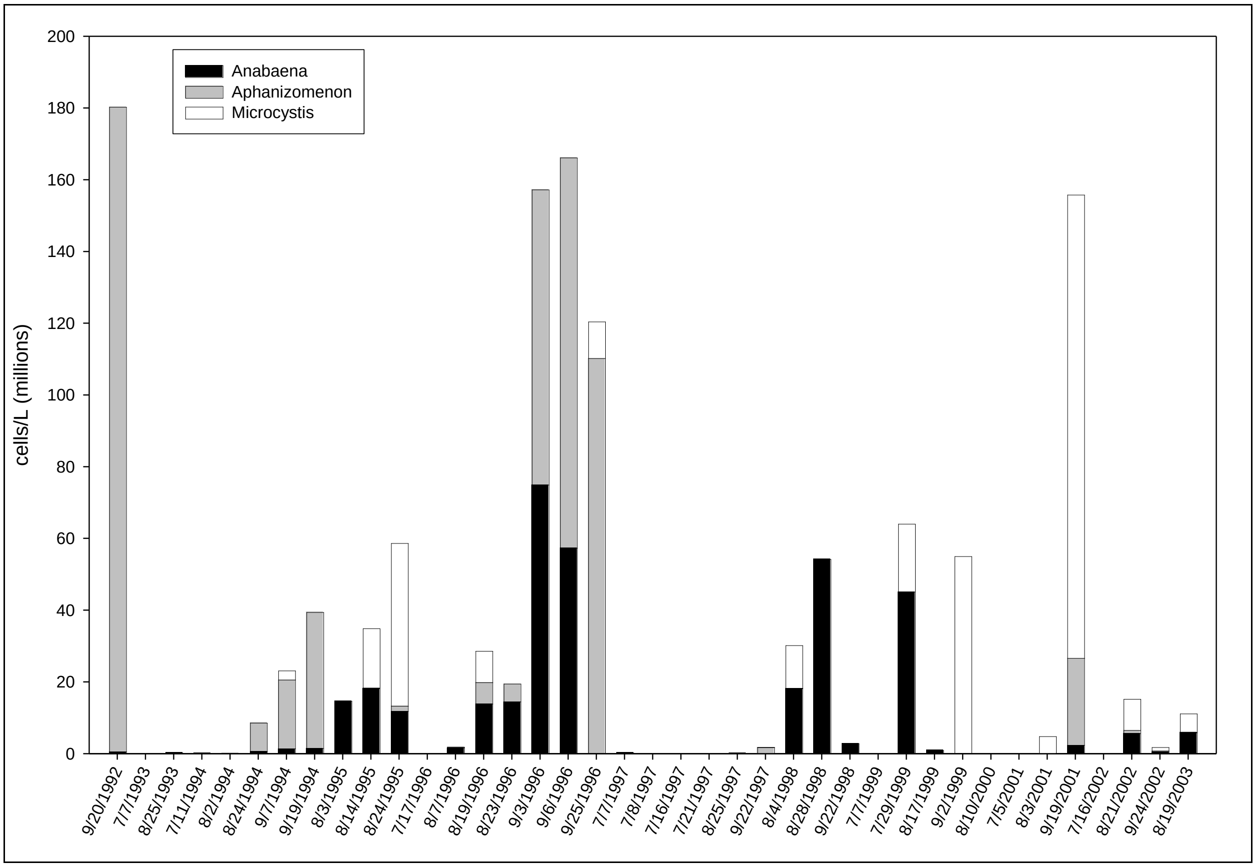


Figure 5. Potentially toxic cyanobacteria (cells/L, in millions) at Missisquoi Bay station 50, July through September 1992 – 2003. Data represent integrated whole water collections made over twice the Secchi depth.

Water Quality

Chlorophyll and Secchi data can provide additional insight into historical phytoplankton populations. The LTMP data for these parameters are more extensive than the historical phytoplankton data for the years 1992 – 2003 and additional data are available for Missisquoi Bay through the Vermont Lay Monitoring Program (LMP), coordinated by the Vermont Water Quality Division. LMP station 20 corresponds very closely with LTMP station 50 and was monitored each summer by a single family of volunteers between 1981 and 2005 for chlorophyll and Secchi depth (Figure 6). Chlorophyll grab samples were collected near the surface. This method differs from the LTMP, which collects integrated chlorophyll samples over twice the Secchi depth. Analyses of log-transformed data were limited to the summer months of July, August and September when both programs were active.

ANOVA analysis of LTMP chlorophyll for 1992 – 2006 identified significant differences among years (Figure 7, $p<0.001$). 1999 had higher mean chlorophyll than most other years, though 1996 values were not different from those in 1999 (Holm-Sidak multiple comparison procedure). No trend was identified by linear regression ($p=0.848$). Removal of the unusual years 1999 and 1996 from the regression analysis did not affect the results ($p=0.291$). Regression analysis of summer Secchi values also did not detect any significant trends (Figure 8, $p = 0.358$).

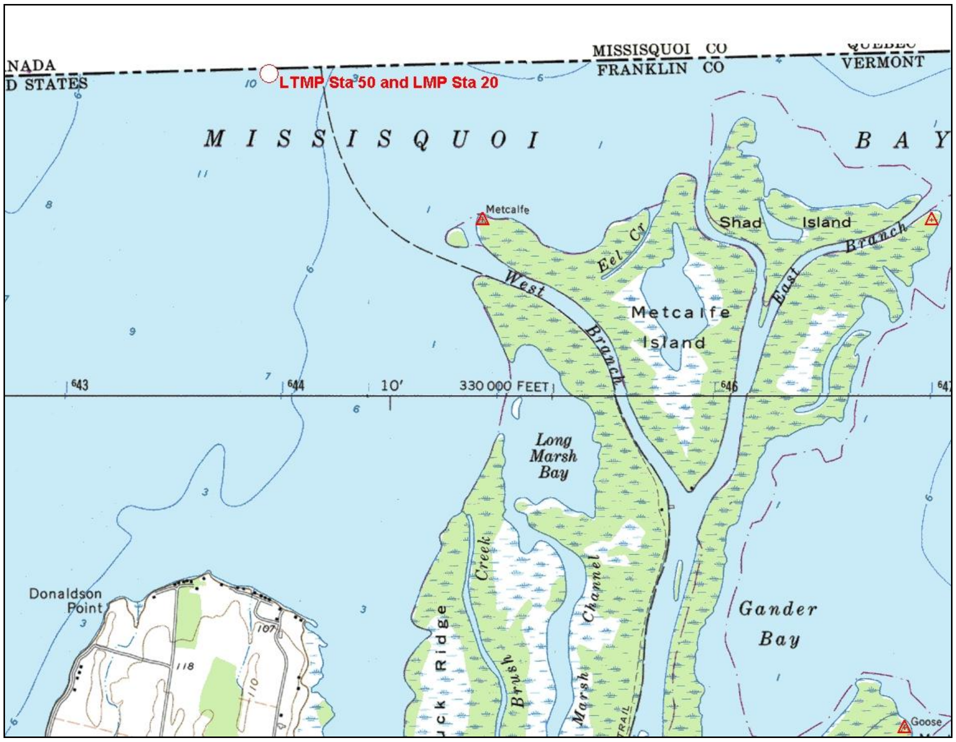


Figure 6. Location of LTMP station 50 and LMP station 20 in Missisquoi Bay.

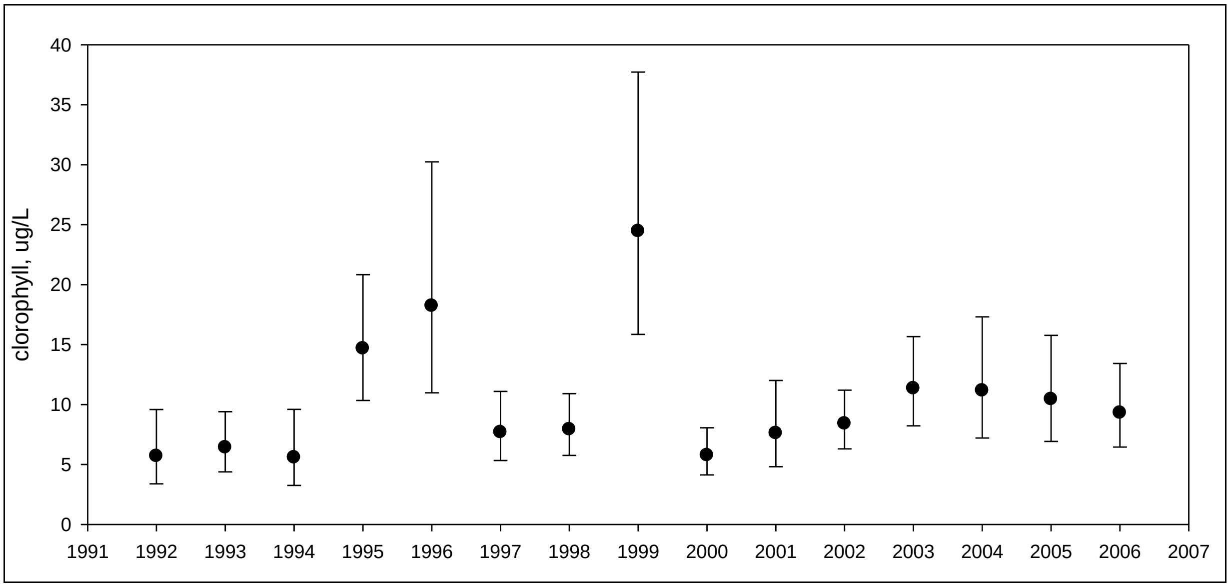


Figure 7. LTMP chlorophyll concentrations (µg/L) at station 50 during July, August, September. Data represent integrated collections over twice the Secchi depth and are presented as geometric means. Bars represent the 95% confidence interval.

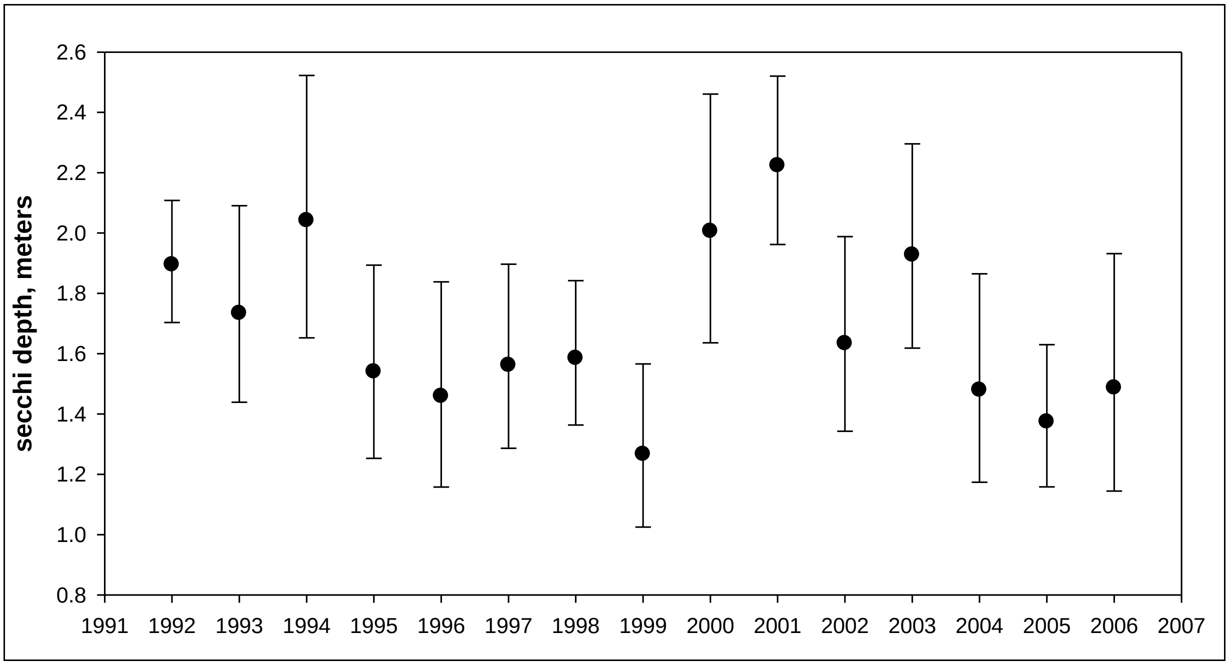


Figure 8. LTMP Secchi depths (meters) at station 50 during July, August, September. Data are presented as geometric means. Bars represent the 95% confidence interval.

Regression analyses on LMP log-transformed data showed statistically significant ($p<0.001$) increasing concentrations of chlorophyll and decreasing Secchi depth in the bay between 1981 and 2005 (Figures 9 and 10).

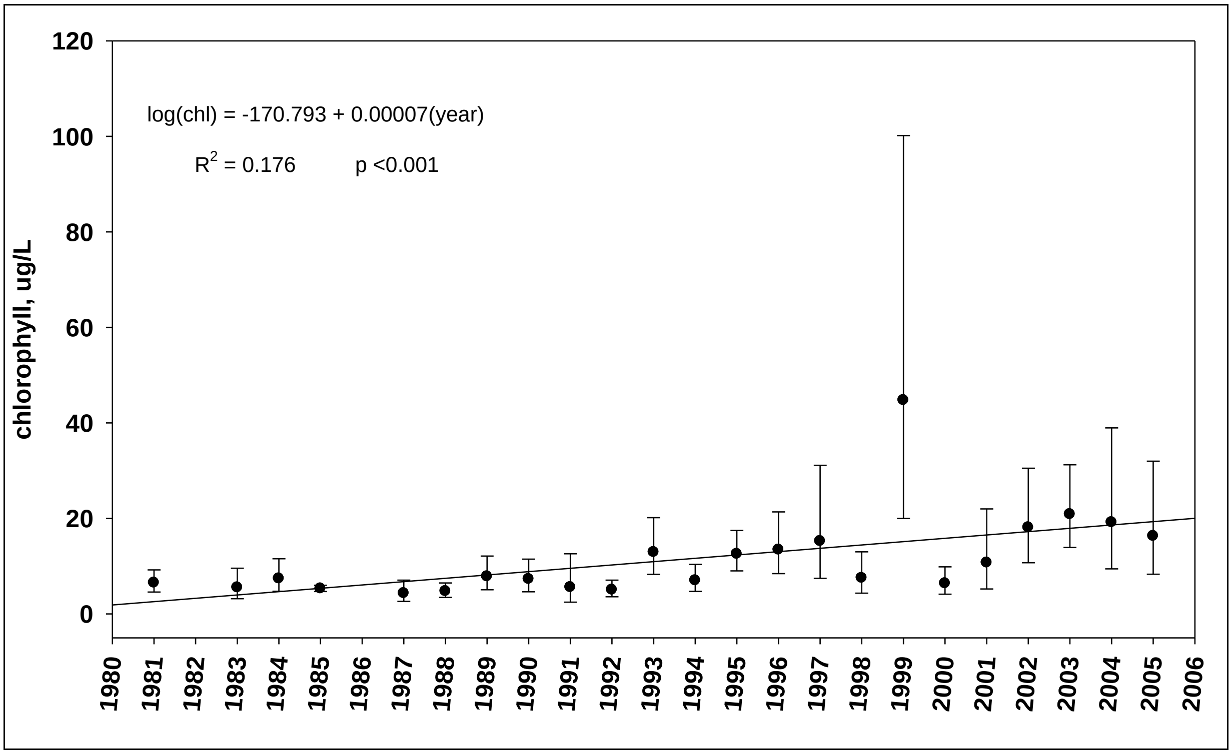


Figure 9. LMP chlorophyll (µg/L at station 20 during July, August, September. Data are presented as geometric means. Bars represent the 95% confidence interval.

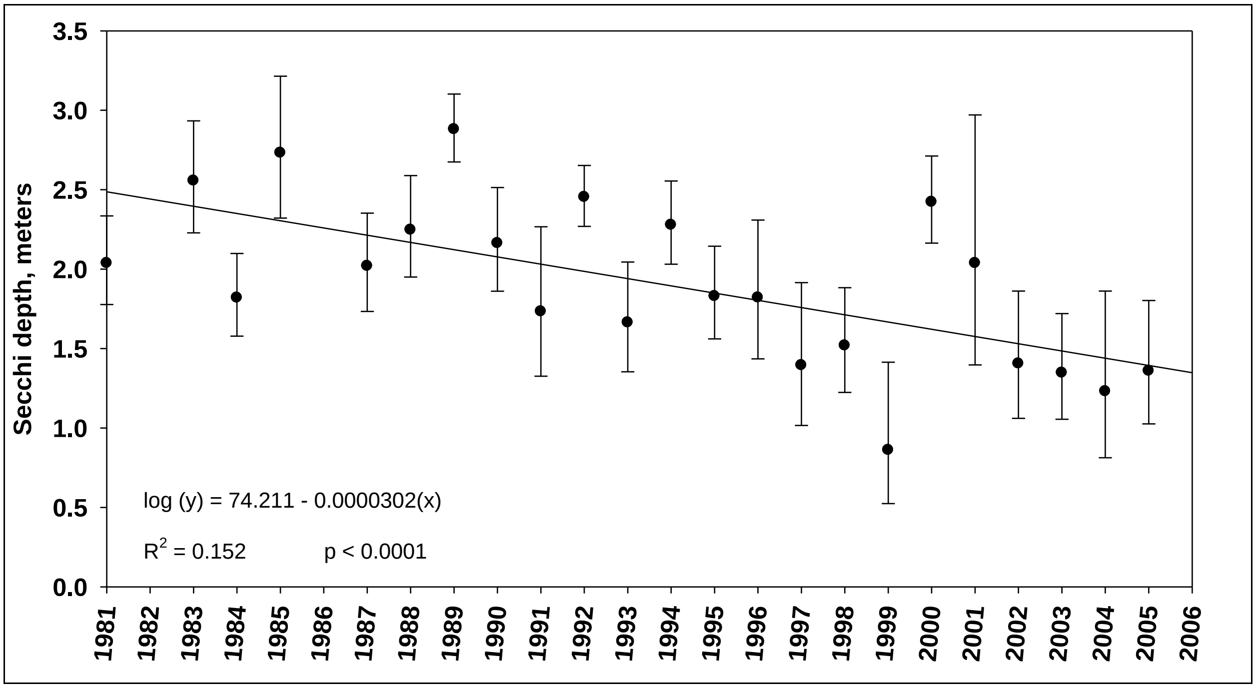


Figure 10. LMP Secchi depths (meters) at station 20 during July, August, September. Data are presented as geometric means. Bars represent the 95% confidence interval.

Discussion

There are few historical data on phytoplankton in Missisquoi Bay. Myer and Gruendling (1979) noted that samples from July and August 1929 had an abundant cyanobacterium (*Aphanothece*) and diatoms. Diatoms were identified as the most important group present in the late 1970s and the authors concluded at this time that the "most striking difference between Missisquoi Bay and other regions of the lake is the lack of significant populations of blue-green algae," though there were indications that some cyanobacteria did reach "moderate population densities." Analyses conducted on the Missisquoi River by the Vermont Water Quality Division in 1974 and 1975 documented the presence of *Microcystis* spp. (V. Garrison, personal communication). Environment Canada documented the occurrence of a heavy and extensive algal bloom during most of July 1981, dominated primarily by *Aphanizomenon* though *Microcystis* was co-dominant in some locations (V. Garrison, personal communication).

Phytoplankton data reported by Brown *et al.* (1991, 1992) and Shambaugh *et al.* (1999) for Missisquoi Bay in the early 1990s also documented several cyanobacterial taxa including *Anabaena*, *Aphanizomenon* and *Microcystis* though differences in collection and analytical methodology do not allow for direct comparison of their data with the LTMP data. The most abundant algae as identified by Brown *et al.*, as natural units/L, were small cryptophyte flagellates. Cyanobacteria were present in the bay during the late summer collections (July/August and September/October), and Missisquoi Bay typically had the highest phytoplankton densities of the 23 stations sampled lake wide during the two years of the study.

Cyanobacteria have dominated the phytoplankton since monitoring by the LTMP began in 1992. Small flagellates, green algae and diatoms were present in the whole-water samples, but cyanobacteria were the most abundant organisms encountered. Three genera of potentially toxic cyanobacteria frequently occurred in the bay during the summer months – *Anabaena,* *Aphanizomenon*, and *Microcystis*. There appeared to be shifts in occurrences of these genera, with *Aphanizomenon* dominant prior to 1996, *Anabaena* abundant from 1995 through 1999, and *Microcystis* predominant 1999 through 2003. After whole-water monitoring ended in 2003 (replaced by net-filtered samples), *Microcystis* continued to be dominant through 2005, while *Aphanizomenon* and *Anabaena* were also abundant (Watzin *et al*. 2006). *Aphanizomenon* was especially abundant during late 2006 (Shambaugh, unpublished data; Watzin *et al.* 2007).

Analysis of available LTMP phytoplankton samples found no statistically significant increase in algal densities between 1992 and 2003. Algal densities in 1999 were higher than any other year, while densities in 1997 were lower. Heavy rain during spring 1997 led to extensive flooding and high water in the Missisquoi and Pike river basins. Lower than normal algal densities may not be unusual after such extreme weather. In contrast, the summer of 1999 was hot, dry and calm. Many of the LTMP stations had higher than usual concentrations of chlorophyll that year, so the unusually high observations in Missisquoi Bay reflected, in part, a regional phenomenon (http://www.anr.state.vt.us/dec/waterq/lakes/docs/lcmonitoring/lp_lc-chlorophyll.pdf). Evaluation of chlorophyll as a possible indicator of changes occurring in the algal population also identified 1997 and 1999 as unusual years, but found no significant trend in the eleven years of monitoring data. Isolation and analysis of summer data (July, August and September), when cyanobacteria are most likely to be abundant, did not change the results. The data do suggest that chlorophyll has been increasing in the bay since 1992, however, the change was not statistically significant. There was also no statistically discernible downward trend in Secchi depth.

The LMP data represent another decade of data for the monitoring station in Missisquoi Bay. With this additional perspective, statistically significant increases in chlorophyll and corresponding decreases in Secchi depth were detected. Taken together, the two data sets suggest that changes which culminated in the current water quality in Missisquoi Bay began in the early 1990s, and that the Bay now has higher chlorophyll and poorer water clarity than occurred in the 1980s.

Conclusions

The very few historical documents available confirm that cyanobacteria were present in the late 1970s and at least occasionally reaching bloom proportions by the 1980s. Though the archived historical phytoplankton samples captured several bloom events for the period 1992 - 2003, statistical analysis could not demonstrate a significant increase in phytoplankton densities during this time. Chlorophyll and Secchi data also showed no significant trends. The additional historical perspective provided by the Lay Monitoring Program (LMP) data indicates that algal populations, measured by chlorophyll concentration and water clarity, were significantly lower during the 1980s than in more recent years.

Literature Cited

Brown, E., A. Duchovnay, A. Shambaugh, A. Williams, and A. McIntosh. 1992. 1991 Lake Champlain Biomonitoring Program. Report issued by the Vermont Water Resources and Lakes Studies Center. School of Natural Resources, University of Vermont. 54 pp.

Brown, E., A. Duchovnay, A. Shambaugh, A. Williams, and A. McIntosh. 1993. 1992 Lake Champlain Biomonitoring Program. Report issued by the Vermont Water Resources and Lakes Studies Center. School of Natural Resources, University of Vermont. 61 pp.

Lake Champlain Basin Program. 2006. Progress 2006 – a 15th Anniversary Report about Lake Champlain's Restoration

Myer, G.E. and G.K. Gruendling. 1979. Limnology of Lake Champlain. Lake Champlain Basin Study, New England River Basins Commission. Burlington, Vermont.

Shambaugh, A., A. Duchovnay, and A. McIntosh. 1999. A survey of Lake Champlain's plankton. In " Lake Champlain in Transition: from research toward restoration". Water Science and Application Volume 1: 323 – 340.

Watzin, M.C., S. Fuller, M. Kreider, S. Couture, M. Levine, and G.L. Boyer. 2006. Monitoring and evaluation of cyanobacteria in Lake Champlain, Summer 2005. Technical Report No. 53. Lake Champlain Basin Program.

Watzin, M.C., S. Fuller, M. Rogalus, M. Levine, S. Couture, K. Crawford, and C. May. 2007. Monitoring and evaluation of cyanobacteria in Lake Champlain, Summer 2006. Technical Report Number 55. Lake Champlain Basin Program.