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Developing a Cooperative Monitoring Strategy for Lake Ontario: 2008 Intensive Year and Long-Term Sampling Design

International Joint Commission Council of Great Lakes Research Managers

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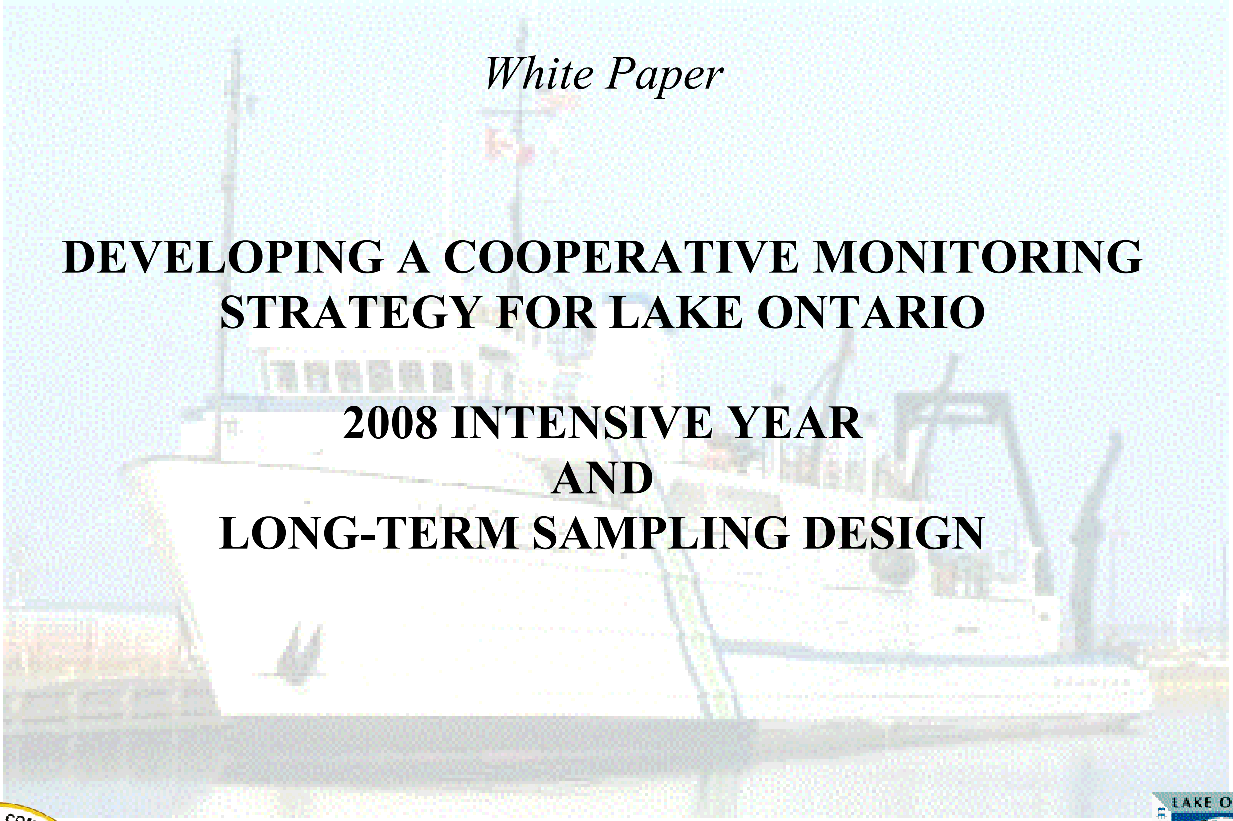


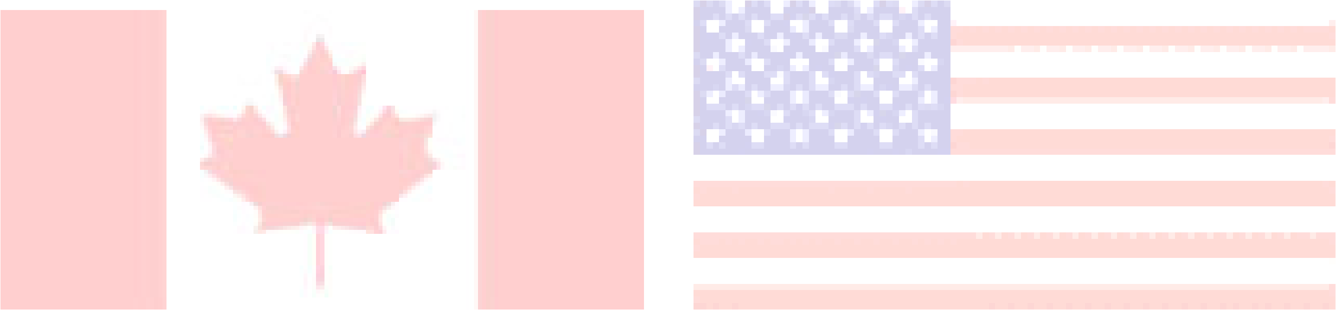
White Paper

DEVELOPING A COOPERATIVE MONITORING STRATEGY FOR LAKE ONTARIO

2008 INTENSIVE YEAR
AND
LONG-TERM SAMPLING DESIGN

in preparation
for the

Lake Ontario 2008 Intensive Sampling Year Workshop
Kingston, Ontario
October 23 – 24, 2006



Preface

Physical, chemical, and biological stressors have caused profound changes in the Lake Ontario ecosystem and its fish community during the last three decades. In the offshore, cultural eutrophication has been reversed and water quality has improved, but the resulting oligotrophication coupled with invasive species impacts has lowered the carrying capacity of offshore fisheries. Cultural eutrophication remains a problem in the coastal zone possibly exacerbated by altered nutrient cycling related to invasive species. Lake Ontario will likely experience additional ecosystem stress from invasive species, habitat alteration, new contaminants and increasing human populations, particularly in the western basin.

These on-going disruptions in Lake Ontario's ecosystem, coupled with declines in funding available for monitoring programs, poses a threat to our ability to understand and manage these changes. The U.S. – Canada Lake Ontario Lakewide Management Plan (LaMP) and its partner the Great Lakes Fishery Commission's Lake Ontario Lake Committee (LOC) have responded by promoting collaborative monitoring approaches recognizing that the scale of multi-trophic level monitoring needed to fully characterize the status of the ecosystem is beyond the resources available to any one organization. The LaMP and LOC began by bringing together a wide range of government and university experts in 2003 to carry out the binational Lake Ontario Lower Aquatic Food Web Assessment project (LOLA), the first lakewide assessment performed since dreissenid mussels had become established.

A fall 2005 workshop held to discuss LOLA's results developed recommendations on how to improve collaborative Lake Ontario monitoring efforts. This 2008 Intensive Monitoring Year planning workshop is structured around these LOLA recommendations. The International Joint Commission's Council of Great Lakes Research Managers' financial support has been key to maintaining the momentum of these initial collaborative efforts. The findings of the LOLA project are available on the web at http://epa.gov/glnpo/lakeont/lola/lola2006.pdf.

The U.S. Environmental Protection Agency and Environment Canada have established a long term five-year rotating cycle of special monitoring years for each of the Great Lakes with 2008 designated as the next intensive monitoring year for Lake Ontario. Ideally monitoring approaches and collaborative partnerships developed for 2008 could be maintained at a lower level of effort on an annual basis as well. Some of the major 2008 planning topics to be addressed in this workshop include:

1) Reassessing Lake Ontario's lower food web.
2) Improving nearshore monitoring approaches.
3) Conducting a lakewide assessment of lake trout.
4) Coordinating lower food web and fishery assessments.
5) Exploring the use of new technologies to augment traditional sampling approaches.
6) Developing creative funding mechanisms and multi-party funding proposals.
7) Building new collaborative partnerships.

It is unrealistic to think that these issues can be fully addressed in one workshop. However the workshop can be judged a success if key data needs, willing partners and broad sampling approaches are identified as a first step in developing a cooperative binational monitoring plan for 2008.

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Acknowledgements

The U.S.-Canada Lake Ontario Lakewide Management Plan thanks the International Joint Commission's Council of Great Lakes Research Managers (CGLRM) for their generous financial support that made this workshop possible. The CGLRM has served as the International Joint Commission's principal advisor on research programs and research needs since 1984. The purpose of the Council is to enhance the ability of the Commission to provide effective leadership, guidance, support and evaluation of Great Lakes research as it applies to the provisions of the Great Lakes Water Quality Agreement of 1978. Thanks also to the Ontario Ministry of the Environment's Kingston Regional Office who graciously provided additional funding and logistical support to facilitate the workshop planning and hospitality arrangements.

Food web disruption: current and future outlook

Edward L. Mills and Kristen T. Holeck, Cornell Biological Field Station
Marten A. Koops, Department of Fisheries and Oceans Canada

Introduction. The Lake Ontario food web has been permanently altered by invasive species and continues to undergo ecosystem change and ecological disruption (Mills et al. 2003). Ecological disruptions have been common in Lake Ontario over the past two centuries but the pace at which these disruptions have occurred has increased over the past three decades. Certainly, the sea lamprey and alewife have been associated with ecological disruptions since the late 1800s but numerous other management actions, socio-political influences, and unplanned events have changed the Lake Ontario ecosystem since the 1970s. For example, offshore phosphorus levels have declined, piscivorous Chinook salmon have become naturalized, a suite of invaders has become established including dreissenid mussels, predatory cladocerans, and the round goby, native species such as *Diporeia* are in a state of collapse, double-crested cormorants expanded dramatically once toxic chemicals were outlawed, and alewife have shifted from a nuisance species to a valued prey fish supporting a multi-million dollar recreational fishery.

Scientists continue to chase ecological change in the Lake Ontario ecosystem and food web disruptions continue to challenge our understanding of the system. For example, dreissenid mussels modify and facilitate energy transfer from the pelagia to the benthic zone, modify the environment directly by increasing water clarity and providing substrate, kill native mussels through competition for food and shell fouling, promote transfer of toxic substances, promote blue-green algal blooms through selective rejection of filamentous and blue green algae, alter nutrient ratios, and facilitate colonization by co-evolved species such as round goby and the amphipod, *Echinogammarus ischnus*. It has been hypothesized that dreissenids are associated with the decline of the native amphipod, *Diporeia*, an important food source for fish. Round gobies enhance transfer of toxic substances, consume native fish eggs, and have been linked to outbreaks of botulism in Lake Ontario and Lake Erie, resulting in the deaths of several species of waterfowl. The predatory cladocerans, *Bythotrephes longimanus* and *Cercopagis pengoi*, compete with fish for zooplankton prey. Scientists are often charged by society to provide answers to what are the ecological impacts of these disruptions and how can they be mitigated. One approach to help scientists provide such "answers" is to develop long-term datasets that provide long-term views of ecosystems both spatially and temporally. The Lake Ontario 2008 Intensive Sampling Year will build upon earlier lake-wide efforts and contribute significantly to defining the current and future state of Lake Ontario.

The most recent lake-wide effort in Lake Ontario to assess the state of the lake and current ecological disruptions was the Lake Ontario Lower Aquatic Food Web Assessment or LOLA. Some of the major findings of this effort were: 1) D*reissenid mussels (quagga mussels in particular) are causing food web disruption*. Few zebra mussels remain and quagga mussels now dominate the benthic community in Lake Ontario waters < 90 meters deep. Quagga mussels are expanding into waters >90 meters deep, now considered a fragile refuge for native *Diporeia* spp. *This expansion by quagga mussels may be putting Diporeia spp. at risk of extirpation*. *Diporeia* spp. populations are no longer found in their preferred habitat (30 m to 60 m bottom depth) and are now relegated to bottom depths of >100 m. *Diporeia* spp. is a key organism in the historic Lake Ontario food web and an important high-energy food source for Lake Ontario fish; 2) Low nutrient levels (translating to low phytoplankton biomass) combined with an increase in the relative biomass of blue-green algae (attributed to selective filtering by dreissenids) has resulted in an *impaired food supply for zooplankton*; and 3) Two large invasive cladocerans, *Cercopagis pengoi* and *Bythotrephes longimanus*, are major predators of small zooplankton species and therefore compete with other invertebrates (e.g. *Mysis*) and fish for zooplankton prey. These species accounted for up to 10% of the zooplankton biomass in 2003.

Food web disruptions in Lake Ontario. The following are several ecological disruptions that are currently impacting the Lake Ontario ecosystem:

Oligotrophication.
Mandated policies resulting from the Water Quality Agreement between the United States and Canada have resulted in significant reductions in phosphorus from the offshore waters of Lake Ontario (Figure 1). Despite such changes in the offshore, embayment and shoreside areas have not experienced such reductions in phosphorus. In the offshore, nitrate concentrations have increased leading to changing N:P ratios in excess of 50:1. Diatoms have shown a general decline with silica increasing.

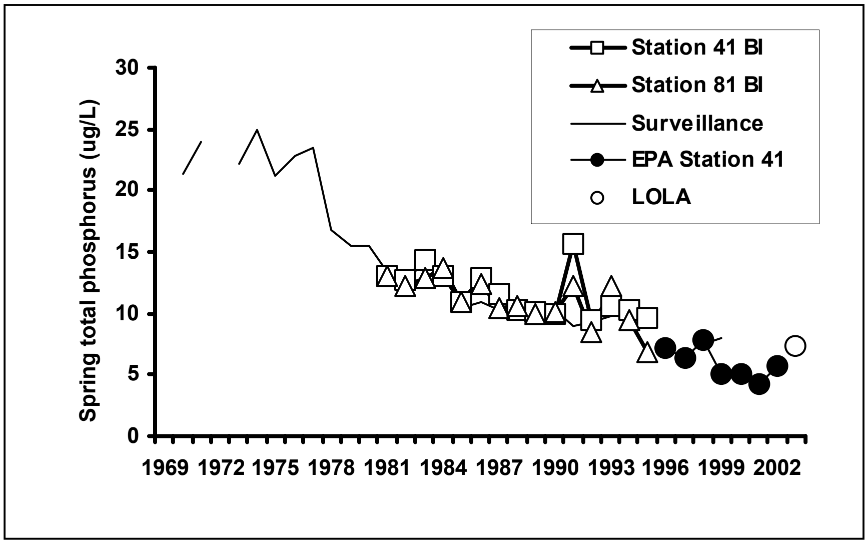


Figure 1. Spring total phosphorus trend in Lake Ontario, 1969-2003. Source: LOLA final report http://epa.gov/glnpo/lakeont/lola/lola2006.pdf

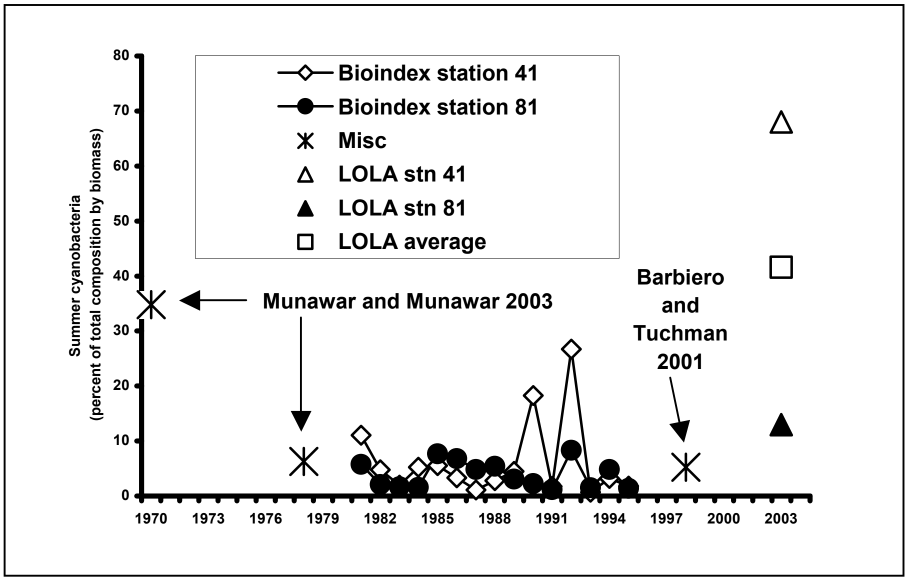


Figure 2. Relative summer biomass of Cyanophyta in Lake Ontario, 1970 – 2003. Source: LOLA final report http://epa.gov/glnpo/lakeont/lola/lola2006.pdf

Phytoplankton and microbial food web.
Recent lake-wide spring and summer phytoplankton biomass appear to be among the lowest ever reported in offshore waters of Lake Ontario. The low biomass in summer 2003 was accompanied by an increase in the relative biomass of Cyanophyta (Figure 2), a poor quality food source for zooplankton. Summer biomass of Cryptophyta, a

high quality algal food resource for zooplankton, declined to 0.05 g/m^3, a level less than one-third of that reported in 1995 (Johannsson et al. 1998). With increased oligotrophication of Lake Ontario, the microbial food web has now become the essential pathway of energy to zooplankton.

Toxic algal blooms. In the Lake Ontario watershed, urbanization and agricultural practices are two major factors contributing to the deterioration of water quality through high nutrient inputs from runoff and point source pollution. Excess nutrients, primarily nitrogen and phosphorous, are causing an increase in the occurrence of cyanobacteria algal blooms (Figure 3) in Lake Ontario's coastal waters. These blooms can produce toxins, and are therefore often referred to as Harmful Algal Blooms (HABs). The production of toxins has raised concerns about negative effects to both human and ecosystem health. Sediment cores can be used to examine the historical presence of cyanobacterial toxins making them a useful tool in the evaluation of long-term algal bloom dynamics in Lake Ontario.

Figure 3. Microcystis bloom in Hamilton Harbor, Lake Ontario, August 18, 2006. Source: NOAA

Alewife dynamics and Chinook salmon. Alewife is both the primary prey of salmonines and important prey on zooplankton. Chinook salmon is the primary predator on alewife impacting the population dynamics of this planktivore. Both wild and stocked populations of Chinook salmon now exist in the lake, factoring heavily on the uncertainty of alewife population dynamics (Figure 4).

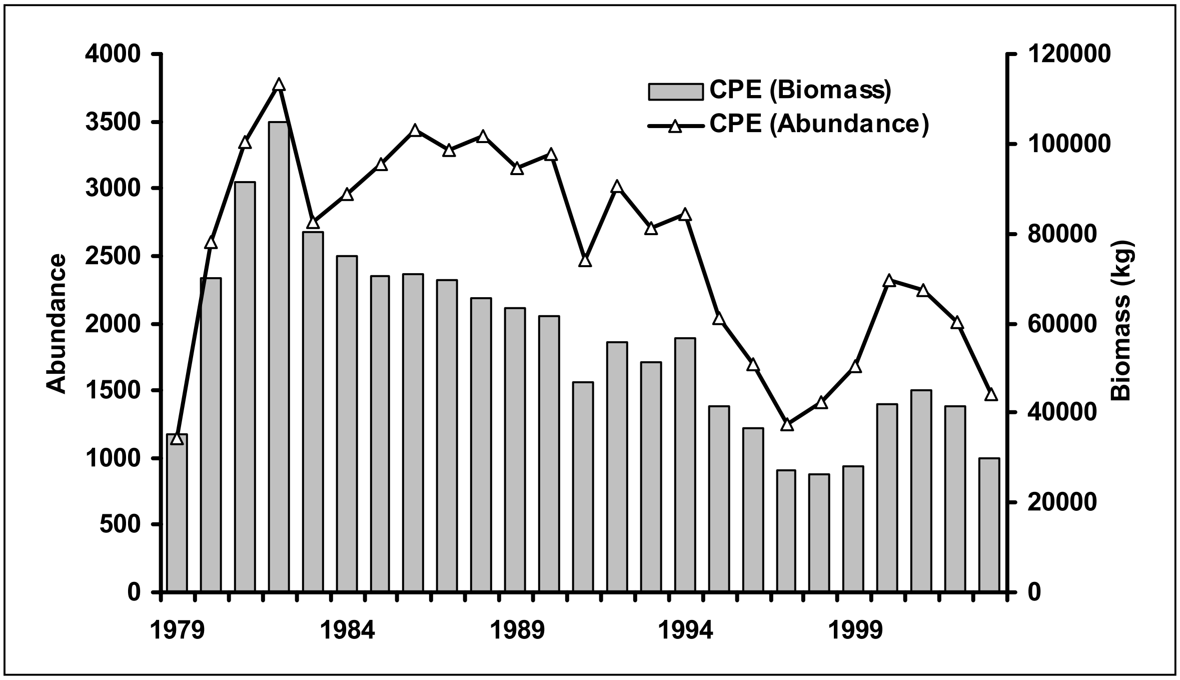


Figure 4. Indices of alewife abundance and biomass in US waters of Lake Ontario, 1979 – 2003. Source: Bob O'Gorman, USGS.

Dreissenid mussels. Quagga mussels have largely replaced zebra mussels in all benthic habitats of Lake Ontario (Figure 5). The dominance of quagga mussels may be due to several factors including a lower thermal tolerance, ability to colonize soft substrate, and lower nutrient requirement. Quagga mussels have expanded into the deep basin of the lake and were even observed at the deepest site (219 m bottom depth). Quagga mussels (*Dreissena bugensis*) now cover more substrate and have attained higher densities than zebra mussels (*Dreissena polymorpha*) ever did in Lake Ontario, even during the early 1990s when concern for the negative effects of zebra mussels were great. In contrast, *D. polymorpha* has decreased in abundance since 1995, particularly on the south shore and the Kingston Basin where large populations were well established.

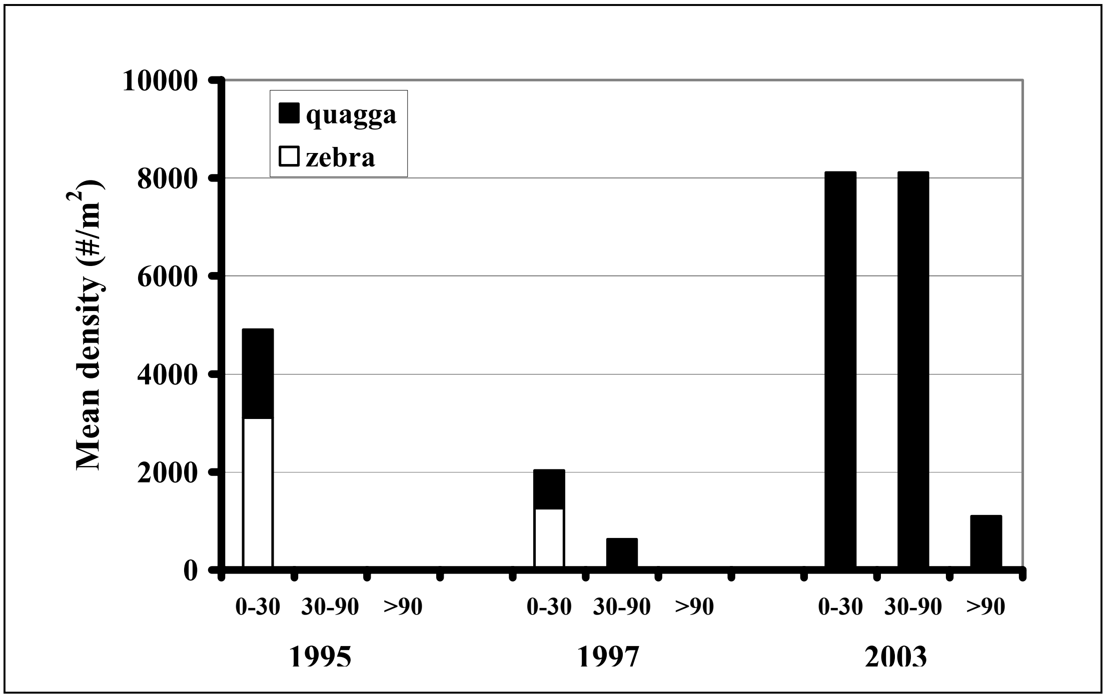


Figure 5. Dreissenid density in 1995 (October), 1997 (September), and 2003 (August), at three depth intervals in Lake Ontario. Source: LOLA final report http://epa.gov/glnpo/lakeont/lola/lola2006.pdf

Round Goby. Round goby was first observed in western basin of Lake Ontario in 1998 and in the Bay of Quinte in 1999. Round goby numbers are high in the western basin of Lake Ontario (Figure 6) and the St. Lawrence River and have the potential to cause further disruption to the lake's food web. Gobies are associated with outbreaks of botulism, mobilizing contaminants from the benthos to pelagic waters, and negatively impacting native species like lake trout.

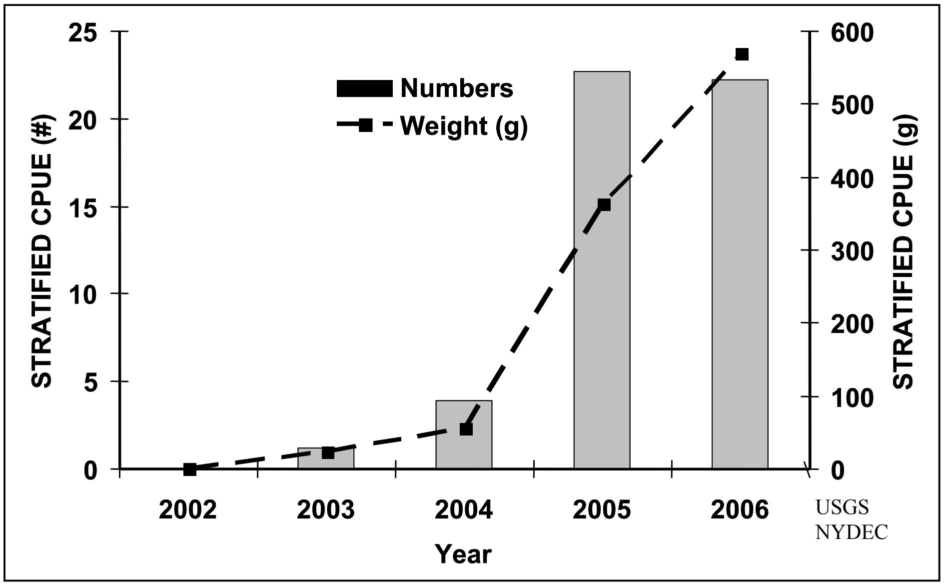


Figure 6. Index of round goby abundance in Lake Ontario, 2002 – 2006. Source: USGS and NYSDEC

***Diporeia* spp**. The native amphipod *Diporeia* historically represented 60%-80% of the benthic community. It is a burrower that depends on organic matter that settles to the bottom from surface production, particularly from diatom blooms. *Diporeia* is an important food source for native benthivorous fish and is therefore considered an important environmental indicator of the benthic community. In 2003, *Diporeia* disappeared from most of the 30-90 m depth interval, with a population averaging only 63/m^2. *Diporeia* were only abundant within the deep central basins (>90 m bottom depth), at densities averaging 545/m^2.

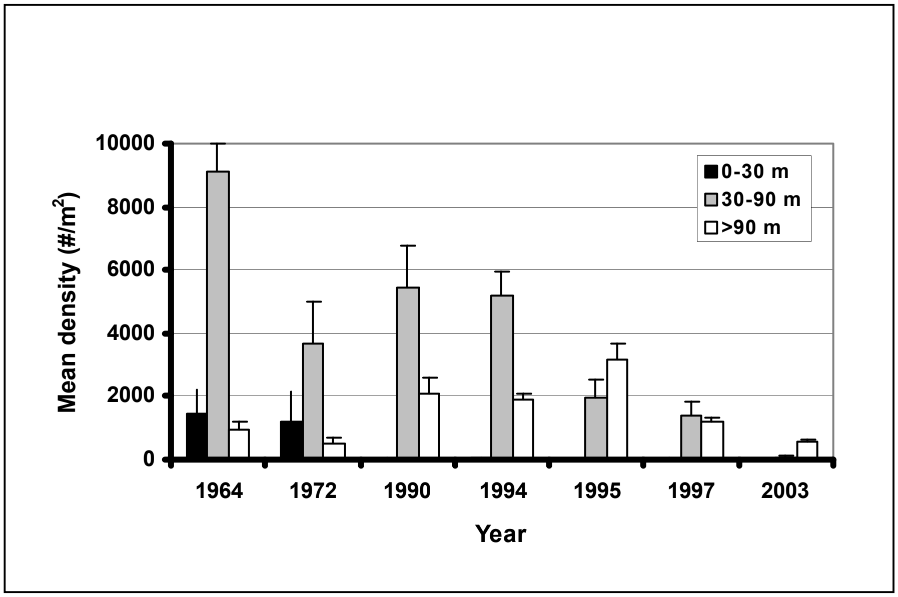
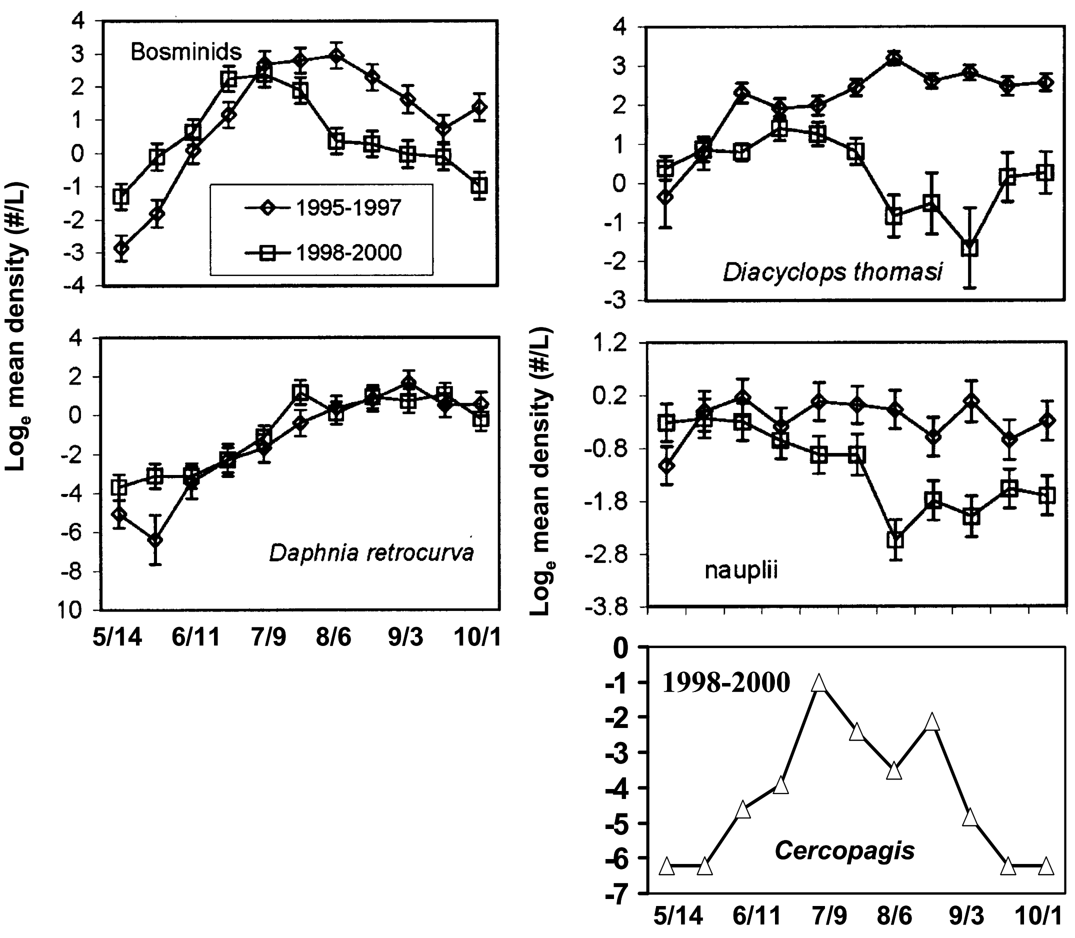


Figure 7. *Diporeia* spp. abundance (#/m^2) for three depth intervals in Lake Ontario: 1964 to 2003. Error bars are +1 SE. Source: LOLA final report http://epa.gov/glnpo/lakeont/lola/lola2006.pdf

The expansion of *D. bugensis* has accompanied a progressive decline of the native amphipod *Diporeia* spp (Figure 7). During the time period 1964 to 1994, *Diporeia* was most abundant in depths from 30-90 m, averaging densities 2,000 – 5,000 m^2. By 1997 *Diporeia* density had declined from > 5000/m^2 to 1380/m^2. This density decrease has continued, and by 2003, *Diporeia* was absent from most of the 30-90 m depth interval, with a population averaging only 63/m^2. The deep central basins represent a fragile refuge for *Diporeia*. The low density observed in 2003 is significantly lower than high densities observed from 1990-1995, but not significantly different from densities reported in depths >90 m between 1964 and 1977 (Hiltunen 1969; Nalepa and Thomas 1976; Golini 1979).

A negative association of quagga mussels with *Diporeia* is clear but how quaggas have negatively impacted *Diporeia* is unclear. Pathogens, food competition, and other factors in association with quagga mussels have been considered in the decline of *Diporeia* but, to date, no smoking gun has been identified. Clearly, science has not provided an answer to the *Diporeia* decline which suggests we do not understand the Lake Ontario ecosystem in its current state.

Predatory Invasive Cladocerans. Two large invasive predatory cladocerans, *Cercopagis pengoi* and *Bythotrephes longimanus*, are major predators of small zooplankton species and therefore compete with other invertebrates (e.g. *Mysis*) and fish for zooplankton prey. In addition, *Cercopagis* may depress small zooplankton as with evidence of an inverse relationship between *Cercopagis* and bosminids, *Diacyclops*, and nauplii (Figure 8).



after Warner et al.

Figure 8. Changes in Lake Ontario zooplankton and *Cercopagis.* Source: Warner et al. 2006.

Rise of Fish-eating Birds. Population trends of double-crested cormorants have shown resurgence in the last two decades in response to reduced contaminant levels. While impact of these birds on lake-wide fish populations is likely low, they can impact fish at local levels.

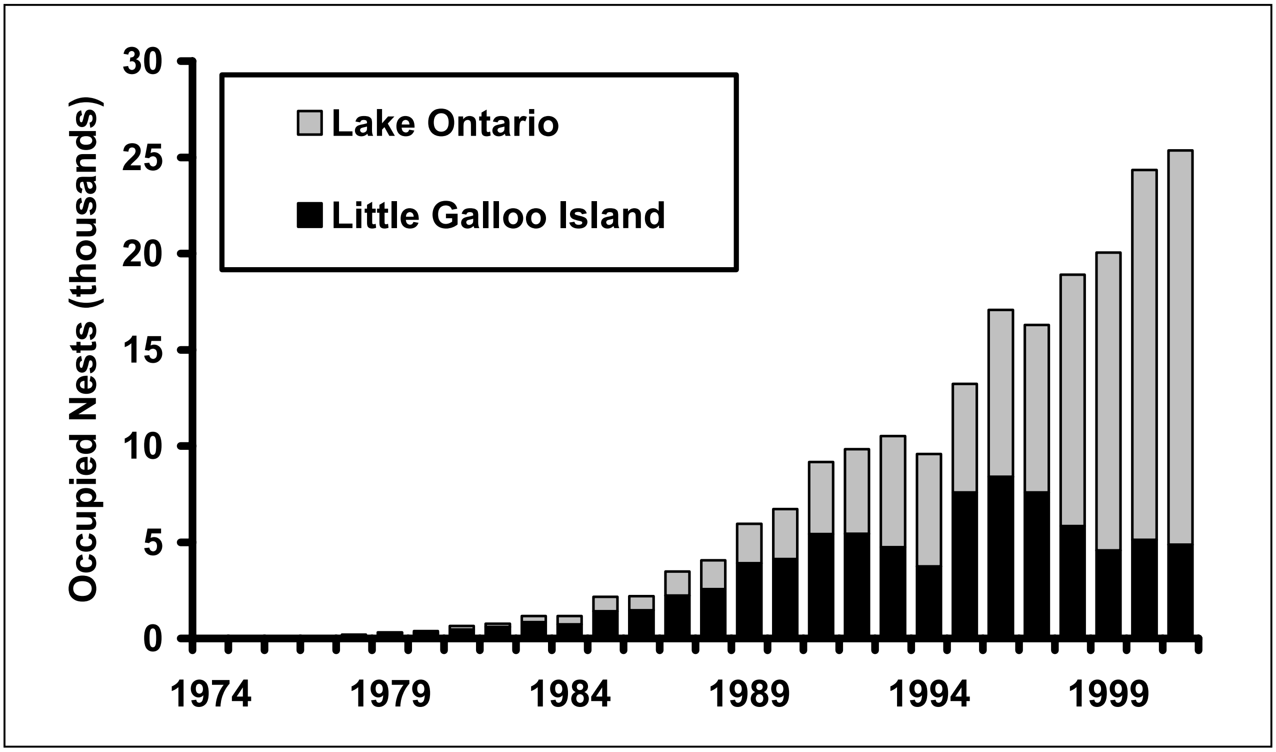


Figure 9. Numbers of double-crested cormorant nests on Little Galloo Island (dark shading) and elsewhere (light shading) in Lake Ontario, 1974-2001. Source: Mills et al. 2003.

STRATEGY: 2008 INTENSIVE YEAR RECOMMENDATIONS

1. **Field Sampling Program.** Field sampling strategies for 2008 should include the transects and parameters assessed in LOLA. Benthic-pelagic coupling in both the nearshore and offshore habitats should be emphasized. Sites should include long-term Bioindex Canadian stations 41 and 81, USGS south shore 2km and 20km sites, and SUNY Brockport sites. Shoreline habitat and embayment habitats should be included to provide a more comprehensive assessment of lake habitat and food web changes.

2. **Assessment of Food Web Disruptions.** An understanding of the Lake Ontario food web both spatially and temporally is critical if we are to assess impacts and offer options for mitigation. Stable isotopes and fatty acid analysis are commonly used in food web studies both in the laboratory and the field. More specifically, stable isotope sampling and analysis identifies the relative source of energy (watershed vs embayment vs shore vs nearshore vs offshore $\delta^{13}C$) and the trophic structure of the food web ($\delta^{15}N$). A major study of the carbon and nitrogen stable isotope patterns in Lake Ontario in the mid-1990s by Dr. Michael Leggett (Ph. D. thesis) provides a valuable baseline against which food web change can be evaluated. Stable isotope sampling in 2008 would provide a logical

extension of this work. Sites, replication, sample size, timing of sample collection, and key species for study need to be identified. The answers to these questions might be best answered by a panel of expert scientists with interests in the Lake Ontario food web and stable isotopes. For discussion purposes, we have identified a list of key species or functional groups that could be targeted in the stable isotope and fatty acid analysis. These include: spring diatoms, cyanobacteria, benthic algae, *Diporeia,* copepod zooplankton, small sized cladocerans, *Cercopagis*, *Bythotrephes*, *Mysis*, quagga mussels, round goby, alewife, rainbow smelt, three-spine stickleback, lake trout, Chinook salmon, lake whitefish, sculpins, walleye, and double-crested cormorants.

3. **Field Sampling Support and Analysis.** Large and small vessel platforms to cover time and space will be needed to make collections for the 2008 intensive Lake Ontario field effort. The collection of organisms for stable isotopes and fatty acids will require an organized effort and individuals on field crews that are responsible for the collections and their preservation. Samples need to be collected, sorted to component (zooplankton/phytoplankton size or functional groups: muscle of fish etc), frozen, dried, pulverized, weighed, and submitted for analysis. A reputable laboratory is also necessary to perform the analyses. Sample analysis costs depend on whether one uses a commercial or university laboratory and who does the preparation of samples.

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Lake Ontario Binational Lower Food Web Task Force

Fred Luckey, USEPA
Vi Richardson, Environment Canada

Background

The US – Canada Lake Ontario Lakewide Management Plan (LaMP) coordinated a major binational evaluation of the status of Lake Ontario's lower aquatic food web in 2003 in order to better understand the dramatic changes that have occurred over the previous decade. The development of this effort, known as the Lake Ontario Lower Aquatic Food Web Study (LOLA) recognized that the scale of multi-trophic level monitoring needed to fully assess the impacts of invasive species in Lake Ontario was beyond the resources available to any one organization. The LaMP's partners on the LOLA project included U.S. Environmental Protection Agency, Environment Canada, Department of Fisheries & Oceans Canada, National Oceanic & Atmospheric Administration, Cornell University, University of Toronto, SUNY College of Environmental Science & Forestry, Ontario Ministry of Natural Resources, Ontario Ministry of the Environment, and the New York State Department of Environmental Conservation.

Four sampling cruises were conducted in Lake Ontario in 2003 using U.S. EPA's *R/V Lake Guardian* and the Canadian Coast Guard's vessel *Limnos*. LOLA transects and stations were selected to allow for the comparison of results to historical lower aquatic food web sampling efforts. In particular, the Department of Fisheries and Oceans Canada performed lake wide surveys during the Lake Ontario Trophic Transfer (LOTT) program of the early 1990s. The LOTT survey results provided a point of comparison to help assess the impact that exotic species and other factors may have had on native benthos and zooplankton communities. The timing of the sample collection efforts was selected to assess the same seasonal events captured by earlier LOTT surveys. Finally, the sampling and analytical methods used in LOTT for total phosphorus, soluble reactive phosphorus, silica, chlorophyll a, microbial food web, zooplankton and mysids were identical to those used in LOLA. Optical plankton counters were tested as a potentially cost effective method to collect information on planktonic food web communities.

Formation of the Binational Lower Food Web Task Force

The LOLA project results were presented at a binational workshop held at Cornell's Shackelton Point Biological Field Station on November 16 & 17, 2005. The workshop included participants from a wide range of active government and academic monitoring programs and resulted in a set of recommendations for how to improve the coordination of Lake Ontario monitoring efforts. These recommendations were reviewed and adopted by the Lake Ontario LaMP Management Committee who then directed the LaMP Work Group to develop a terms of reference for a Lake Ontario Binational Lower Food Web Task Force charged with implementing these recommendations (Attachment 1).

The Task Force will serve the Lake Ontario Lakewide Management Plan and the GLFC Lake Ontario Lake Committee in an advisory capacity by providing information and recommendations to be considered in the development of cooperative monitoring approaches. According to the terms of reference, the Task Force consists of representatives from each of the LaMP agencies in addition to others who are nominated by LaMP agencies. The initial set of Task Force members include:

Lakewide Management Plan (LaMP) Agency Task Force Representatives

Department of Fisheries & Oceans Canada – Mohi Munawar
Environment Canada – Violeta Richardson
Ontario Ministry of the Environment – Todd Howell
Ontario Ministry of Natural Resources – Ted Schaner
US Environmental Protection Agency, Region 2 – Frederick Luckey
New York State Dept. of Environmental Conservation – Michael Connerton
US Fish & Wildlife Service – Betsy Trometer

Additional Task Force Members Nominated by LaMP Agencies

Ed Mills, Cornell University
Dawn Dittman, U.S. Geological Survey
Glenn Warren, U.S. EPA Great Lakes National Program Office

Attachment 1

Lake Ontario Binational Lower Food Web Task Force

Terms of Reference

Lake Ontario Lakewide Management Plan
in cooperation with the
Great Lakes Fishery Commission Lake Ontario Lake Committee

June 2006

Background

The introduction of non-native mussels, zooplankton and fish to the Lake Ontario aquatic ecosystem has significantly disrupted the lower aquatic food web. These disruptions are continuing, and their ultimate impact of Lake Ontario aquatic communities and water quality cannot be predicted at this time. Strong binational lower aquatic food web monitoring programs will be needed if environmental and natural resource managers wish to understand and attempt to manage these ecological changes in order to minimize any potential negative impacts. A Lake

Ontario Lower Food Web Task Force will be formed to: 1) better coordinate binational monitoring efforts, 2) provide needed information to environmental and natural resource managers on the status of the lower aquatic food web, and 3) provide a stimulus for funding.

The 2003 intensive monitoring year effort on Lake Ontario provided a comprehensive assessment of how greatly Lake Ontario's lower aquatic food web has been altered since dreissenid mussels came to dominate the ecosystem. The full report, *Status of the Lake Ontario Food Web in a Changing Ecosystem: the 2003 Lake Ontario Lower Aquatic Food Web Assessment (LOLA)* is available on the web at: http://epa.gov/glnpo/lakeont/lola/lola2006.pdf. The report's recommendations, developed by experienced binational lower food web experts, will serve as a starting point for the Lake Ontario Lower Food Web Task Force's efforts to expand binational partnerships and incorporate new technologies to meet the monitoring needs of Lake Ontario.

Purpose

The Lake Ontario Lower Food Web Task Force will work to improve the coordination and effectiveness of U.S. & Canadian lower food web monitoring efforts in order to meet the information needs of environmental and natural resource managers.

Specific Tasks

1) Improve the coordination of existing lower food web monitoring programs to provide a more complete and comprehensive annual reporting on the status of the lower food web.

2) Serve as the lead in the planning for lower aquatic food web monitoring information needs and monitoring approaches. Lake Ontario Cooperative Monitoring Years are held every five years.

3) Promote the incorporation of new technologies into routine monitoring programs in order to provide more cost effective and comprehensive assessments. Examples of the kinds of technologies to be considered include:
   - Remote buoy systems;
   - Satellite imagery;
   - Stable isotopes to better understand changing food web dynamics;
   - High-resolution methods such as optical plankton counters and fluorometry.

4) Mesh field assessments with experimental studies to help understand cause-effect relationships.

5) Consider new approaches to better define nearshore conditions and problems that are not adequately addressed by traditional open lake monitoring programs.

6) Identify opportunities to coordinate lower food web and fishery assessments.

7) Address specific questions from Lake Ontario Lakewide Management Plan (LaMP) and Lake Ontario Committee (LOC) regarding status of lower food web.

Membership

The Task Force will consist of representatives from agencies participating in LaMP and the Great Lakes Fishery Commission's LOC having experience and knowledge related to lower aquatic food web monitoring issues. Additional members from other government agencies, academia and individuals may also be included as agreed to by Task Force members.

Reporting

The task force will report to LaMP and LOC managers twice a year:

Spring – A summary of key findings from the prior year including suggestions for future monitoring and coordination activities will be provided at the annual Great Lakes Fishery Commission's annual LOC Meeting.

Fall – A summary of planned monitoring activities for the next year including identified resource needs, opportunities for increased coordination and proposed use of new technologies.

Field Sampling Design and Coordination

W. Gary Sprules, University of Toronto
Jack Kelly, USEPA

- Must first identify key objectives for the program.

Is the emphasis on large-scale estimates of seasonal biomass of component organisms or is the emphasis on process-oriented measures such as productivity, and/or seasonal development of certain biological communities/populations? Is there an objective to make an overall and integrative statement on the condition ("health") of the system, or is the main emphasis to make statements on the distribution, biomass, and productivity of important components?

Is the goal: To obtain the best lakewide estimates? To partition spatially into different zones (e.g., offshore, nearshore, embayments)? Or to nest spatial components in a lakewide design?

Should the intensive year involve landscape characterization and some design for tributary sampling in conjunction with lakewide sampling?

Objectives will help determine the balance of effort between spatially extensive efforts to describe the whole lake (or parts), a desire or need to resolve seasonal patterns through repeated sampling over time at intensive sites, and/or efforts to resolve not only what conditions exist but also factors that may be influencing them.

- Balancing objectives also means balancing station-specific sampling with underway survey sampling. The former requires frequent stops and time on station whereas the latter is more continuous with fewer stops.
- It makes sense to incorporate at least some historical fixed stations into the survey design for continuity with past observations. New fixed stations would need to be considered if a survey design seeking to statistically represent morphometric and biological gradients is adopted. A mix between a historical set and a statistically-based set can be achieved.
- Discussion as to whether sampling will be limited to "the lower food web" is required. There is a need to ensure parallel programs on the "upper food web" for information on the complete food web and also associated water and sediment quality measures.
- The use of continuous sensors such as an OPC, fluorometer, CTD, hydroacoustics and others as recommended in the LOLA 2003 report should be emphasized. Study design should permit comparisons of data from these instruments with more traditional approaches.
- Continuous sampling with towed instruments needs to be done along towpaths that reflect study objectives. These could be multiple in nature and include:

    1. Linear cross-lake transects that cover all regions and depth zones of the lake. Apportioning effort in accordance with morphometric/biological gradients could mean something less than complete cross-lake transects.

2. Directly assess the nearshore and attempt to link to landscape/tributary influences, by following a fixed, shallow depth contour around some or the entire lake perimeter to collect data on a consistent habitat across the geographic extent of the lake.

3. Use semi-synoptic towing strategies to "connect the dots" between some fixed stations. This might involve a directed attempt to understand representativeness of fixed station data and allow confidence in spatial or temporal extrapolations.

4. Use a repeated towing strategy at select sites to show seasonality and, again, perhaps put fixed stations in a broader regional context.

- To the extent that night sampling is required, attention must be paid to the varying length of the night across seasons. Limited hours in the night are available around the summer equinox.

- Realistic workloads must be set for the scientific and technical crew with built-in time for the inevitable weather disruptions or equipment malfunction. The priority should be to complete all planned activities, and lost time should be subtracted from each activity. No aspect of the survey design should take precedence over any other. Maybe this means defining specific Data Quality Objectives that define whether or not a partial set of the intended collection is sufficient to meet the objectives.

  Aside: The portions of the sampling that are inflexible, comparable to those that may be designed to have built-in flexibility (perhaps to sample interesting features), need to be identified so that vessel and science crews are not at odds with how surveys should be conducted.

- Near real-time processing of data should be planned as much as possible. This is obviously more possible for continuous sensor data than traditional information such as taxonomic data. Real-time analyses can provide immediate feedback on physical/biological gradients that might justify modifications to survey design.

- The use of satellite observations providing spatial observations on such measures as surface chlorophyll concentration and temperature as recommended by LOLA 2003 should be considered. Discussion of whether such data could alleviate the need for more time-consuming observations of these variables while under way (except for ground-truthing) is required. The use of sensors on moorings or buoys could provide time series of observations to complement the less intensive, large-scale survey data, and could facilitate ground-truthing of remote observations. Siting of buoys should be done in a manner that supports field sampling in the most appropriate way.

Some thoughts on project design (from Fred Luckey)

Projects should be binational and collaborative and build on existing efforts rather than being stand alone projects by an individual. From the Lake Ontario LaMP and GLFC LOC perspective the following types activities are considered high priorities: a) a lower food web assessment similar in scope to LOLA; b) developing better approaches to characterizing/understanding the "near-nearshore" conditions; c) lakewide lake trout assessment and; d) exploring new technologies such as remote buoys.

Questions for consideration by potential collaborators:

a) What is your particular area of interest?
b) Do you have some specific ideas on how existing programs/efforts could be better coordinated in 2008 or on an annual basis?
c) What type of monitoring do you routinely perform on an annual basis?
d) Describe sampling location and frequency.
e) What groups or individuals do you, or could you, collaborate with on this issue?
f) Would you be interested in harmonizing your sampling efforts with other investigators as part of a lakewide assessment?
g) Do you have access to ships or other sampling platforms? If so how much time might be available for this effort in 2008?
h) What types of funding opportunities are you aware of that could support our cooperative efforts in 2008?

Some preliminary resource considerations

- ◊ LIMNOS may be conducting a November 2008 mysid and *Diporeia* whole-lake survey if resources allow.
- ◊ If it occurs, a summer OMNR acoustic survey for mysids could complement the November LIMNOS survey.
- ◊ A USGS/OMNR/NYSDEC whole-lake September lake trout survey would require dedicated use of the vessels Kaho, Seth Green and Steelcraft for approximately 17 days each.
- ◊ Some coastal and “near” offshore survey work could be done on SUNY Brockport's small vessel "the R.V. Madtom” (28')
- ◊ The LIMNOS and Guardian will be in dry dock in November 2007 for major overhauls and may not be ready for their first 2008 cruise traditionally in April.
- ◊ Do the sampling approach and number of stations from LOLA 2003 need to be reconsidered?
- ◊ Is it reasonable to assume many of the same LOLA 2003 partners would be involved? Will there be new ones?
- ◊ Can we tie together a number of "near-nearshore monitoring" efforts being conducted around the lake by academics and municipalities to provide a more lakewide assessment? Are sampling techniques sufficiently uniform among groups?

The Lake Ontario offshore zone: Status and assessment needs

Ora Johannsson, Department of Fisheries and Oceans Canada
David Rockwell, USEPA

The basic roles of monitoring are to determine the state of a system, to detect change in that system, to promote research linking change with causative factors, and to provide advice.

Status of Lake Ontario Offshore in 2003

Numerous physical, chemical, and biological stressors have caused profound changes in the ecosystem of Lake Ontario and its fish community during the last three decades. In the offshore, cultural eutrophication has been reversed with the Great Lakes Water Quality Agreement's Annex 3 target phosphorous loads being attained and with the establishment of dreissenid mussels. The water quality has improved, but the resulting reduction in nutrients and alterations in phytoplankton composition has lowered the carrying capacity of the Lake for offshore fisheries. The LOLA 2003 study confirmed that the offshore ecosystem had changed dramatically. Key findings include:

1) *Ecosystem breakdown, native amphipod Diporeia spp. at risk of extirpation*. *Diporeia* spp. populations are no longer found in their preferred habitat (30 m to 60 m bottom depth) and are now relegated to bottom depths of >100 m.

2) Invasive quagga mussels causing food web disruptions. Few zebra mussels remain and quagga mussels now dominate the benthic community in Lake Ontario waters < 90 meters deep. Quagga mussels are expanding into waters >90 meters deep, now considered a fragile refuge for native *Diporeia* spp.

3) *Nutrient starved offshore fish community*. Target concentrations of total phosphorus in offshore waters of Lake Ontario (10 µg/L) have been exceeded. Current levels are 5 µg P/L resulting in phytoplankton and zooplankton populations at historic lows, limiting offshore fisheries.

4) *Impaired food supply for zooplankton*. Low phytoplankton biomass has been exacerbated by an increase in the relative biomass of blue-green algae (a poor quality food source for zooplankton) combined with a decrease in biomass of cryptophytes (a preferred food source for zooplankton).

In order to determine the state of the lake in 2008 and test for possible changes, the sampling strategy and methods employed must be consistent with and build on those of the past, particularly LOLA 2003. LOLA 2003 consisted of 4 spatially extensive cruises during which 30 stations were sampled in spring (ice out conditions), summer (stable stratified conditions), and fall (prior to overturn) for all lower trophic level, nutrient and physical parameters, and 50 sites were sampled in late fall (after overturn) for mysids (Figure 1). The cruises were planned to coincide with organism life cycles and provide a spatial component of the season cycle. Spring is the time of isothermal water temperatures and provides the initial chemical conditions for the year prior to significant uptake of nutrients by the biota. The spring survey provides a picture of the amounts of nutrients available for the biological activity that will occur during the year. Summer and fall surveys (August and September) characterize the summer and late summer zooplankton production and community structure. Mysid biomass and reproductive effort peak later than that of the zooplankton and is tracked by the late fall survey in November. Benthic sampling is not time sensitive so samples are collected during the summer stratified period.

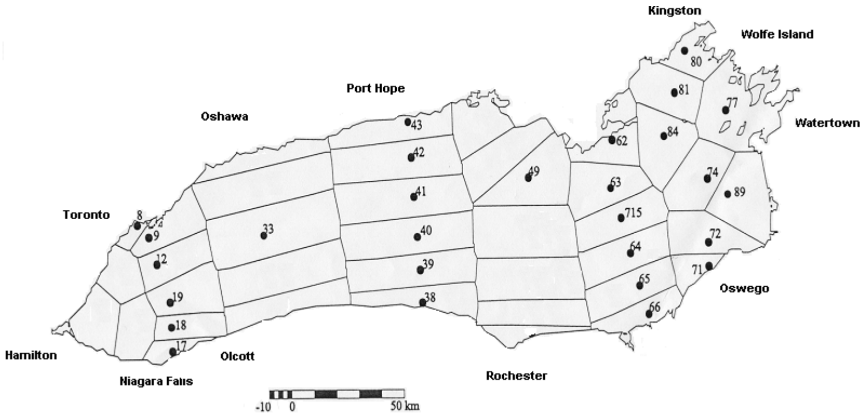

Fig. 1. Lake Ontario 2003 sample locations. Sampling vessels: April & August R/V Limnos, September – R/V Lake Guardian. Additional sites were added to the empty transects and deep hole (near station 64) for the mysid November survey.

Assessment Needs

Factors capable of altering the offshore ecosystem include direct management actions, indirect anthropogenic behaviour and natural events. Depending on the factor, the impacts may alter spatial patterns or seasonal extent, timing or patterns in the lake. We could expect change in, and therefore, should monitor the following components on both spatial and seasonal scales: habitat, food web structure, food web productivity and food quality.

Habitat: Physical - temperature, thermal structure, light regime, oxygen levels, upwelling. With increases in storm frequency and duration associated with climate change, we should measure the resultant upwelling extent, duration and intensity through the year as these events affect the biota.

Chemical – nutrient supplies and ratios (TP, SRP, Si, TN, NO2NO3, Ca?, Fe)

- toxins (microcystins) when suspected to be present and not covered by other programs

Food Web Structure:

A number of metrics or measures should be examined in order to ‘quantify’ food web structure. Biomass size spectra (BSS), especially the un-normalized curves, provide considerable information on the structure of the food web in a generalized form. Changes in BSS are generally related to shifts in predator-prey relationships going down to the herbivore-phytoplankton level. One metric to come out of these analyses would be an assessment of the match between zooplankton size and the needs of planktivorous fish.

Stable isotopes would provide more specifics on shifts in predator-prey relationships. The possible use of stable isotopes is discussed in detail in the white paper on 'Use of new approaches to assess predator/prey linkages'. Other more specific indices could include:

1. The relative proportion and seasonal timing of the various groups of algae and cyanobacteria are key metrics. Phytoplankton determine the potential biomass and productivity of the food chain and each group differs in its role and nutritional qualities. Cyanobacteria are a poor source of nutrition and some can produce toxins. Increases in this group, either in relative proportion or length of period of abundance, can be detrimental to the growth of zooplankton. Chrysophyta, Cryptophyta and many of the small Chlorophyta are excellent food for summer cladocerans while Bacilliophyceae are important for larger zooplankton and benthos.
2. The relative balance between the microbial food web and the direct zooplankton grazing food chain has been considered a measure of the efficiency of utilization of primary production. The microbial food web normally increases in importance as a system becomes more oligotrophic. The ratio of rotifer biomass or of cyclopoid copepodid biomass to that of herbivorous cladoceran, calanoid and naupliar biomass may be indices of the relative strength of these two food web streams. Although the direct grazing chain is considered more efficient because energy passes through fewer trophic levels, the presence of both may be more efficient for the system as a whole because the MFW has the capability of utilizing dissolved carbon (Dinoflagellates) and decaying material to build new biomass and recycle nutrients.
3. The diversity and abundance of predatory invertebrates relative to their herbivorous/detritivorous prey within both the zooplankton and the benthos are indices of the potential resilience of the invertebrate predator trophic guild and their ability to monopolize lower trophic production. Small planktivorous fish usually compete with these invertebrate predators (as well as consume them). To date, the optimum balance between invertebrate and planktivorous fish biomass, which would lead to the greatest transfer of energy to fish or the most stable system has not been determined.
4. Exotic invertebrates have invaded the Lake Ontario food web, particularly over the past 25 years. Their influence on food web structure could be roughly assessed by determining the proportion of biomass at each 'trophic level' that is composed of these exotics and which other components of the food web are dependent on their presence (or absence).
5. The last component of food web structure that requires assessment is the degree of benthic-pelagic coupling. In the offshore of Lake Ontario that coupling is mediated through the sinking of material, largely diatoms, to the benthos. Now much of it is utilized by dreissenids and less by the native benthos. Some of that material is returned to the pelagia, primarily by *Mysis*, although other pelagic food sources constitute the majority of its diet. To assess this component of food web structure one could put out sediment traps and/or compare the biomass of benthic and pelagic animals, weighting for size which is related to metabolic rates.

Food Web Productivity and Food Quality

A monitoring program undertaken for the LaMP and LOC will be interested in productivity of the lower trophic levels because that is the base for the fish and fishery. The ability to measure productivity is dependent on how the system is sampled. Biomass is a rough substitute for productivity. If the biota are sampled once in each season and the estimates extrapolated to the ice-free period based on some knowledge of the manner in which the biomass at the sampling time represents the average biomass for that season, production can be estimated from pre-determined P/B ratios. Although P/B ratios are often used to estimate production, they may not be the best method if one is trying to detect change because they will only reflect changes in biomass not reproductive effort. The variability associated with P/B estimates is large and they should be tailored for the system in which they are used. This means that several direct estimates of production should be made for the organism of interest and the P/B estimates weighted accordingly. Direct measures of production will require more frequent sampling and are best undertaken over the season at fixed sites. These corrected P/Bs could then be applied to whole lake estimates of biomass in order to calculate whole lake production.

Do we need production estimates for more than the animals directly eaten by fish: namely, zooplankton, mysids, and *Diporeia*? Dreissenids are also eaten by fish, but at the moment their populations would not appear to be limiting consumption. The only other exception might be phytoplankton, which forms the base of the food web. Seasonal estimates of primary productivity from one or two key sites are needed occasionally to understand how shifts in phytoplankton composition and in their nutrient/light regimes might be affecting rates and properties of primary productivity. Extensive baseline data exists for earlier periods (87-95).

Production is not enough. The nutritional quality of food has significant impacts on health, behaviour and performance of fish (and other organisms). We should monitor the essential fatty acid content of key fish prey; such as, *Mysis, Diporeia* and zooplankton. This is discussed more fully in the white paper 'Use of new approaches to assess predator/prey linkages'.

Monitoring Approaches

Given the assessment needs, we strongly recommend a program which combines key stations, sampled at two week intervals, annually from April-May until the end of October, with spatial cruises in spring, summer and fall every fifth year. The key stations would provide the backbone of the biological data, estimates of inter-annual variability, seasonal context for the spatial surveys, and improved sensitivity to detect change. The spatial cruises would define and track spatial patterns in the lake, link the nearshore and offshore, and provide the basis for whole lake estimates of biomass and production.

With intensive biological sampling at two to four key sites in the lake, could we drop phytoplankton and zooplankton sampling from the spatial surveys, except for that done by other monitoring programs (EPA). The OPC (and eventually acoustics) and the Fluoroprobe could be used to get spatial estimates of zooplankton and phytoplankton biomass and composition for the offshore. One could envisage intermittent towing paths along the LOLA 2003 transects for the OPC. The Floroprobe is under calibration – could we use it between stations or only at specific sites? Do we still need chlorophyll *a* measures? Could we get that information from satellite data instead? We would still need some zooplankton and phytoplankton samples to calibrate the OPC and Fluoroprobe data and rotifers and other MFW components from the integrated water samples.

With this scenario, spring, summer and fall cruises would be undertaken along the LOLA 2003 transects for nutrients (TP, SRP, Si, TN, NO2NO3, Ca?, Fe), physical parameters (light, temperature and oxygen), small plankton, and the OPC and Fluoroprobe, and calibration data. Benthos would be collected in summer and fall. The OMNR does an acoustic survey of mysids (as well as fish) in mid-summer which compliments DFO's annual early November cruise to assess mysids across the lake and *Diporeia* and dreissenids at set locations. At the annual, key sampling locations, physical conditions, zooplankton, phytoplankton, rotifers, and the MFW would be sampled every two weeks from April-May until the end of Oct. Nutrients would be sampled three times: on the first cruise, just after stratification and in late July. Benthos would be sampled on 4 occasions. Mysids would not be sampled as they need to be collected at night. In the best of all possible worlds, primary productivity would be measured at one offshore site. These stations would provide information on inter-annual variability, production of benthos, zooplankton, rotifers and MFW components, weighted P/B ratios for use with the spatial data, species diversity and indices of food web structure.

Why can we not depend on spatial surveys every five years? Our ability to detect change (response to management actions) is very low with this monitoring strategy, especially for the biological parameters. Measures of the larger biota (zooplankton and benthos) can be highly variable. Zooplankton biomass would have to decline by more than 50% -60% before a significant difference could be detected based on the LOLA 2003 data (Table 1). This could be improved by increasing the number of samples collected per station and collating them before analysis. For instance, in two sets of 8 replicate zooplankton samples from Lake Ontario (August 1986), the coefficient of variation (sd/mean) was reduced by approximately half when the data were collated for all possible sample pairs (Johannsson, unpublished data). This indicates that collating several samples at each station would reduce the total variability by reducing the component due to sampling variability. In another exercise, the ability to detect change in seasonal zooplankton abundance at different sampling frequencies (1 to 10 week intervals) was investigated assuming a 20%, 30%, 40% and 50% decline over six years using the 15 years of DFO Bioindex data. The probability of detecting change at a sampling frequency of two weeks increased from 26% to 98% over the decline scenarios of 20% to 50% in the mid-lake (station 41), and 58% to 100% in the Kingston Basin (station 81). Sensitivity declined if the frequency was extended beyond two weeks. Therefore, key stations to provide a more sensitive method of detecting change and the sensitivity of spatial sampling can be improved by collating replicates.

Table 1. Percent decrease in mean epilimnetic zooplankton biomass which could be detected by the LOLA 2003 sampling program

	Aug	N	Sept	N
All Stations	68%	27	65%	27
Stn Depth >100m	50%	12	56%	9

Logistical Needs and Cost Elements

Optimally, one would want 4 key stations: Kingston Basin, mid-lake north, mid-lake south-east, and south-west in the Niagara stream. The west is not as suitable because the seasonal patterns can be disrupted by upwellings. Data here (at least at station 12 south of Toronto) and in the open-lake south of Cobourg were very similar: the west could be a substitute for the north if necessary. Presently, Joe Makarewicz is sampling a station at 100-m depth in the Niagara stream. Perhaps that could be one of the key sites. OMNR and DFO are trying to set up sampling again in the Kingston Basin at station 81 which has a long term record of biological data (1981-1995). That leaves the open lake in the south east and north. Some creative collaborations need to be envisaged to include these sites.

The actual logistical needs for both the spatial and key station sampling are presented in Appendix 1. Cost elements are listed in Appendix 2.

Appendix: 1

Logistical Support:

		Spatial Cruise	Key Station
		3 spatial cruises	13 sampling events
Equipment	Ship/boat	Limnos/Guardian multi-day vessel	Sea worthy day boat
	Winch	x	x
	Profiling System	SeaBird etc	Hydrolab
	Light system	Licor, Secchi Disk	Licor, Secchi Disk
	Water sampler	Rosette or Integrator	Van Dorn bottles
	Ponar	x	x
	Metered Zooplankton Nets: 64 um	2008 full suite later For OPC calibration?	x
	Metered Zooplankton Nets: 153 um	2008 full suite later For OPC calibration?	x
	Mysid nets**	x	
	OPC	x	
	Flourometer	x	x? calibration studies
	Filtering Apparatus for nutrient samples	x	On ship or on shore
	Incubations for primary productivity, MFW		On shore – specific stations in a few years only
Manpower	Sampling	Tech Ops + 4 -3 cruises, 2 people for Nov cruise (104 days)	2 people/event-26 people days/year
		15 days of lab prep and take down - 3 cruises	Included in above
	Chlorophyll analyses	5 days – 3 cruises	1.5 day
	MFW microscope work		3.5 days
	Primary Productivity, MFW incubations		13 days
	Cercopagis/Leptodora counts from samples	120 samples – 2 hrs/sample = 30 days	7 days
	Benthic sample preparation – remove dreissenids & pick other organisms	23 days for 30 samples	15 days for 20 samples
	Samples to	9 days	2 days

	contractors and archiving		
Analyses	Data into electronic finished files (put in Cerco and Lepto, check ids of phyto, zoo etc	4 days	1 day
	Data Analysis and writing	Couple of months	10 days
Total Man Power	Not including Tech Ops or ship's personnel	230 days	79-80 days

*do flourometry at key stations to cross calibrate

** with out new estimates of growth rate I doubt it is worth doing mysids more than once a year (Nov)

Appendix 2:

Cost Considerations: Canadian Funds			
Manpower	Students	8-10K - 4 months	
	Technical Personnel	40-60K - year	
	Biologists	40-60K - year	
	Scientist	80-90K - year	
	1 key site	15 K (@50K/yr)	
	1 spatial cruise	17K (@50+K/yr)	
		Key Station	1 Spatial Cruise
Contracts	Rotifers,Ciliates & Zoopl @ $80 per sample	$4,160 (52 samples)	$9,600 (120 samples)
	Phytoplankton @ $250 per sample	$3,250 (13 samples)	$7,500 (30 samples)
	Benthos @ $250 per sample	$5,000 (20 samples)	$7,500 (30 samples)*
	Nutrients	$2,000	
TOTAL		$29,410	$41,600
Equipment & Supplies	Filters, jars, chemicals etc, petro - maintenance	$500-$1000	
Per diem and Lodging	Depends where they sample	?	0
Boat and Ship Costs	Guardian or Limnos for 15 days	210 K	
	Day Boats	Up to 2K/d	
Associated Sampling	Nov mysid cruise	12K + 40 DFO personnel days	
	OMNR – acoustic cruise		
	Makarewicz station		
	EPA cruises (2)	300K for biology and chemistry	
Communication of Results	LOC, LaMP, conferences		

* Assuming 90 samples over the whole season

The Lake Ontario Coastal Zone - Status and Assessment

Joseph C. Makarewicz, SUNY Brockport
Todd Howell, Ontario Ministry of Environment and Energy

Introduction

We define the coastal zone to include, but not limited to, the embayments, drowned river mouths and the nearshore zone; it is that portion of the lake from the shoreline to a depth of 30m (1) beyond which lies the offshore zone. The coastal zone is a transition zone influenced both by the waters of the offshore zone and by land use and drainage from watersheds. Lake Ontario's large coastal zone encompasses 1,020 km[1] of shoreline. The Canadian and the American shorelines of Lake Ontario are nearly equal in length (537 km Canada; 483km USA) (2). The coastal zone also represents the primary zone where Canadians and Americans come in contact with the waters of Lake Ontario. Lake Ontario coastal waters are a valuable resource for drinking water and industrial usage, recreational boating, fishing and swimming, tourism, and waste water processing, and are a key asset in the economies of upstate New York and Ontario Province. New York's 2006 New York Ocean and Great Lakes Ecosystem Conservation Act (3) states "… coastal ecosystems are critical to the state environmental and economic security and integral to the states high quality of life and culture. Healthy coastal ecosystems are part of the state's legacy, and are necessary to support the state's human and wildlife populations…".

Despite significant water quality improvement in the open waters of the lake over the last three decades, Lake Ontario shoreline and embayments—bays, river and creek mouths and their associated wetlands—are suffering from many impairments that severely limit their recreational use and ultimately affect the economic development of the region (4). These impairments include invasive species; habitat destruction; algae blooms; erosion, sedimentation and associated nutrient enrichment; turbidity; navigational impairments; beach closings, property loss; and fish consumption advisories due to toxicants. For example, Ontario Beach in Rochester, NY, was closed 94 and 155 days in 2005 and 2004, respectively (5). In addition, six Areas of Concern (Eighteenmile Creek, Oswego River, Niagara River, Hamilton Harbor, Toronto and Region, and the Bay of Quinte) impact the coastal zone. Although there have been environmental improvements in six areas of concerns, problems still remain. Impairments of drinking water quality, shoreline property values, the attractiveness of the lakeshore to shoreline residents, the general public using the beaches and walking the shoreline, tourists and boaters are continuing concerns (6).

Status

Water Quality: Some recent chemical and biological data exist for the coastal region of the American and Canadian sides of Lake Ontario. Using New York as an example, an intensive study of the coastal region is underway that provides unprecedented spatial coverage of the New York coastline ranging 483 km from the Niagara River on the west to Chaumont Bay in eastern Lake Ontario (Figure 1). One goal of this study was to spatially examine water quality along the coastline, where the majority of the people swim, recreate and come in contact with the waters of Lake Ontario. Thirty-seven embayments, streams and Lake Ontario itself were sampled at a

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[1] Does not include shoreline of islands

depth of 1m (swimmable depth) and are referred to here as shoreside samples. Two sites due north of Hamlin Beach State Park in open water were sampled biweekly at the nearshore/offshore boundary (30-m depth) and offshore (100-m depth). Analyses reported here are total phosphorus, total suspended solids and phycocyanin. Data are also available for sodium, nitrate, total Kjeldahl nitrogen, turbidity, chlorophyll, pH, phycocyan, microcystins, anatoxin, conductivity, dissolved oxygen and light transmittance.

Total Suspended Solids (TSS): TSS at the 100-m offshore (average = 2.7 mg/L) and the 30-m (average = 3.0 mg/L) site were low. In contrast, shoreside, embayment and stream TSS concentrations from the Niagara River to the Genesee River were often significantly higher than the offshore and nearshore boundary sites (Fig. 1). Average concentrations at the shoreside of the Niagara River, Eighteenmile Creek, Oak Orchard Creek, Braddock Bay, Long Pond and the Genesee River were 124.4, 39.5, 72.3, 99.4, 98.4 and 21.1 mg/L, respectively. Maximum TSS concentrations were observed at the shoreside site of the Niagara River (541.7 mg/L) and Braddock Bay (366.7 mg/L), Long Pond (300.7 mg/L) and Oak Orchard (257.0 mg/L). East of the Genesee River, total suspend solids were generally low relative to the region west of the Genesee River but were still relatively high compared to the offshore and nearshore/offshore boundary sites. For example, average TSS at the shoreside site of Port Bay and Sandy Pond were 20.0 and 17.0 mg/L – almost an order of magnitude higher than the offshore site. Turbidity, which is a measure of particles in the water and of concern to treatment of potable water supplies, was generally over 1 NTU in coastal waters. At 22 of the 37 sites, average turbidity exceeded 1 NTU. Maximum turbidity observed exceeded 1 NTU at all but one site (Sackets Harbor) during the three-year study.

Total Phosphorus (TP) and Soluble Reactive Phosphorus (SRP): Coastal concentrations of TP along the American side of Lake Ontario often surpassed the NYSDEC Ambient Water Quality Guideline of 20 µg/L. For example, the average concentration of TP exceeded the NYSDEC guideline at 29 of 37 sites over the three-year study (Figure 2). Maximum TP values reached as a high as 1.09 and 1.57 mg/L at the shoreside of Lake Ontario at the Niagara River and Oak Orchard Creek sites, respectively. TP concentrations at the 30m nearshore/offshore boundary (30-m depth) and at 100-m depth offshore site averaged 9.0 and 10.0 µg/L, respectively, for the same period. As comparison, Figure 3 provides a snapshot of total phosphorus levels near Ajax, Canada, on one day in 2006. TP concentrations near the shoreline often exceeded 100 µg P/L (maximum of 306 µg P/L); however, 600 meters from the shoreline, TP concentrations at Ajax dropped to the 10 to 20 µg P/L range. Average soluble reactive phosphorus (SRP) exceeded the NYSDEC Guidelines at 11 of 37 sites. Maximum SRP values of 213.3, 172.2, 163.0, 157.9, 154.6 and 147.4 µg/L were observed at the shoreside at Oak Orchard Creek, Irondequoit Bay, Eighteenmile Creek, Port Bay, Long Pond and Sandy Creek. Spatially, shoreline TP concentrations were generally higher west of the Niagara River than east of the Genesee River (Figure 1). Also, shoreside concentrations were substantially higher than concentrations in embayments/creeks west of the Genesee River while east of the Genesee River, embayment and creek concentrations were similar or slightly higher than concentrations in the shoreside sites (Figure 2).

Phycocyanin: Cyanobacteria are often considered nuisance species and indicative of high nutrient concentrations. Cyanobacteria and chlorophyll levels along the coastal zone can reach fairly high levels. For example, average shoreside levels of phycocyanin, a pigment characteristic of cyanobacteria, in Lake Ontario near Oak Orchard Creek and Braddock Bay were 46.98 (Chl *a*=27.6 µg/L) and 51.04 µg/L (Chl *a* =24.4 µg/L)(Figure 4) with maximum concentrations reaching 393.60 (Chl *a* =199.8 µg/L) and 244.80 µg/L (Chl *a* = 131.6 µg/L), respectively. Phycocyanin level in embayments and rivers can also be very high. In Long Pond and the Genesee River, average phycocyanin levels were 99.1 (Chl *a* = 59.5 µg/L) and 70.5µg/L (Chl *a*=3.0 µg/L), respectively. In general, cyanobacteria levels were higher in stream, embayment and the shoreside waters than at the nearshore/offshore boundary (6.9 µg/L, Chl *a* = 2.6 µg/L) and offshore (6.6 µg/L, Chl *a*= 2.3 µg/L) waters of Lake Ontario. Overabundance of cyanobacteria in Ontario appear to be limited to Hamilton Harbour and the Bay of Quinte (7). Thus the potential for production of cyanotoxins exists along the shoreline of Lake Ontario. Of the 418 samples taken along coastal Lake Ontario from 2003 to 2005, 93% had detectable levels of microcystins (>0.003 µg/L) (8). At the Lake Ontario offshore (100-m depth) and the nearshore offshore boundary (30-m depth) sites, the maximum level of microcystins observed never exceeded 0.023 µg/L (mean = 0.005 and 0.004 µg/L, respectively) while maximum levels along the shoreline (lake side), bays and rivers were often higher, by an order of magnitude (e.g., 0.225 µg/L [Braddock Bay shoreside]; 0.435 µg/L [Genesee River]; 0.795 µg/L [Long Pond North]; 0.325 µg/L [Niagara River shoreside]; 0.123 µg/L [Sandy Pond shoreside] (Figure 4) but still significantly lower than the World Health Organization guidelines of 1.00 µg/L.

<u>Cladophora:</u> Striking changes in the nearshore ecology of Lake Ontario have occurred since the arrival of dreissenid mussels in 1989. Dreissenid mussels, mostly quagga mussels (*Dreissenia bugensis*), carpet large areas of the lake bottom in the nearshore including areas of hard and soft substrate (9) (Figure 5). The high density of filter-feeding mussels has demonstrated and further hypothesized the potential to affect lake-wide ecological processes and aquatic resources, with enhanced effects in coastal areas. Hecky et al. (10) presented a conceptual framework, termed the nearshore shunt, which describes the implications of dreissenids in the retention of particulate matter in the nearshore areas and the re-focusing of energy and particulate matter from the open water to the lake bottom. The effects of dreissenid mussels on the disruption of established patterns of energy flow and particle flux, and particle retention in the nearshore present a substantial challenge to understanding and managing water quality in the coastal zones of Lake Ontario. Depression of phytoplankton levels and increases in water clarity associated with dense communities of dreissenid mussels are well-appreciated phenomena. However, the consequences of enhanced retention and deposition of particulate material laden with nutrients, contaminants and microorganisms are less well understood. Tributary, municipal and industrial outfall and non-point source inputs to the shoreline of Lake Ontario are numerous and in many cases are expected to have elevated levels of particulates enriched in nutrient and other compounds of interest. A key question is to what extent has the retention (and accumulation) of nutrients and pollutants increased in the nearshore and conversely has the supply to the offshore declined. This question is particularly relevant to phosphorus since much of the total phosphorus inputs to the lake are in particulate form, originate from the nearshore, and are now more susceptible to being retained in the nearshore than prior to establishment of dreissenid mussels. It can also be hypothesized that nearshore areas where inputs of nutrients and contaminants are more extensive (e.g. urban areas) would be at greater risk of deteriorating conditions.

There is a strong potential for dreissenid mussels to enhance benthic algal growth. Increases in water clarity attributable to dreissenid mussels extends the depth to which benthic algal colonization can occur and thereby increases habitat availability. Dreissenid mussels may also enhance nutrient supply directly through excretion or indirectly through the accumulation of particulate material in the mussel beds. From the late 1970's to the mid-1980's Painter and Kamaitis (11) noted a declining trend in the biomass and tissue phosphorus concentrations in the nuisance benthic algal species *Cladophora glomerata*. In departure from this trend, it now appears that *Cladophora* is once again widely distributed across the rocky shorelines of Lake Ontario and is achieving high biomass levels especially in western Lake Ontario. Along the Canadian shorelines of Lake Ontario, Wilson et al. (9) estimated that 57% of the lake bottom, at 5m depth, was covered by *Cladophora* mats with an average mat thickness of 4.7 cm, and that in some areas *Cladophora* was noted as deep as 20m. Areas along the north shore with *Cladophora* beds of up to 10 cm in height were observed (Figure 3). Several groups in Ontario are actively studying *Cladophora*, (e.g. University of Waterloo, Ontario Water Works Research Consortium see owwrc.com); however, there has yet been limited documentation of the occurrence of *Cladophora* in the literature. The occurrence of *Cladophora* in Lake Ontario has features similar to that reported recently for the north shore of eastern Lake Erie (12). Wash-up of *Cladophora* resulting in fouling of shoreline has been observed in diverse locations ranging from St. Catharines, Oakville, Newcastle, Presqu'ile, Kingston, Ontario, and Rochester and Hamlin, NY.

Summary:

*Embayment, shoreside and stream water in New York coastal waters have greater sediment loads, have higher nutrient levels (TP, TKN, nitrate), have greater amounts of Cyanobacteria and algae, and have higher levels of cyanotoxins than offshore waters.

* Coastal New York phosphorus levels generally exceed the NYSDEC Ambient Water Quality Guideline for phosphorus. In the Province of Ontario, TP levels do not generally exceed the Provincial Water Quality Objective (10/20 µgP/L). However, there are many locations in the coastal zone such as embayments, river mouths and locations near the shoreline where TP will periodically, if not frequently exceed 10 or 20 µg/L (7).

*There are spatial differences along the New York coastal zone. Sediment loads, nutrient concentrations and Cyanobacteria appear to be higher in the streams, embayments and at shoreside sites compared to offshore sites west of the Genesee River.

*In general, water quality of the coastal zone is generally poorer than water from the offshore zone.

* Other coastal ecosystem impairments include an over abundance of aquatic weeds, shoreline erosion, invasive species, and habitat destruction. Dreissenids have altered nutrient cycling and increased water clarity resulting in a rebound of the benthic green alga *Cladophora* (13). It is possible that the pods or mats of algae, often several meters in diameter floating into beaches, are associated with *Cladophora* scouring during wind events and seasonal die-back.

* Public beaches are often closed or posted due to elevated levels of fecal pollution indicators and poor water quality. Elevated levels of fecal indicator may result from factors other than strictly poor water quality in a conventional sense (e.g. beach sediments, gulls).

* Structure and function of the coastal zone are influenced by the proximity of the shoreline, localized sources of meso-scale variability (e.g., tributaries, land-use in the watershed, embayments, geology, effluent pipes) and variations in the current regime (wind direction,

upwellings, etc.). Current regime, in turn, controls transport and distribution of temperature, nutrients, contaminants, and planktonic organisms, as well as bottom shear stress and erosion potential.

* Environmental integrity and sustainable use of coastal habitats are threatened by anthropogenic forces including rapid population growth - especially in the Greater Golden Horseshoe region (Lake Ontario's western basin). One hypothesis suggests that the high levels of nutrients observed along the New York coastal zone from the Niagara River to the Genesee River may be related to land use within the "Golden Horseshoe" area of Canada.

*Coastal zone waters receive large amounts of anthropogenic inputs, and associated ecological responses likely reflect the character of the adjacent watersheds. Such responses in water quality and plankton in the coastal zone may foreshadow lake ecosystem change.

In conclusion, portions of the coastal zone continue to be plagued by cultural eutrophication with high nutrient levels leading to the unwanted growth of Cyanobacteria and *Cladophora* (?) and other water quality problems. Until the significance of habitat extension and internal nutrient supply mediated by dreissenids is evaluated using growth models and experimentation, it will be to difficult to demonstrate that further controls on point and non-point P sources will have the desired effect of substantially reducing nearshore growth of *Cladophora*. The principal nutrient of concern, phosphorus, comes from a variety of point and non-point sources, including domestic animal waste, fertilizers, soil loss, combined sewer effluent, leaky septic systems, and sewage treatment plant effluent.

Assessment:

Programs: Several important federal and state plans, strategies and policy initiatives address restoration and prevention of adverse impacts, including the Lake Ontario Management Plan (LaMP), the Great Lakes Water Quality Agreement, the Great Lakes Regional Collaboration, The Lake Ontario Coastal Initiative, NYS's Clean Water Act, the Comprehensive Wildlife Conservation Strategy, the Finger Lakes - Lake Ontario Watershed Protection Alliance, Local Waterfront Development Plans, local watershed protection plans and community-based initiatives and more. Most recently, through the New York Ocean and Great Lakes Ecosystem Conservation Act of 2006, the "policy of the State of New York shall be to conserve, maintain and restore coastal ecosystems so that they are healthy, productive and resilient and able to deliver the resources people want and need". However, the remediation efforts recently proposed through the New York Ocean and Great Lakes Ecosystem Conservation Act are limited to one watershed in the eastern half of Lake Ontario (Sandy Pond) and fail to tackle the issues of coastal region through an integrated ecosystem planning process developed through careful science and an adaptive management approach. **Research and remediation efforts of the coastal zone continue to be fragmented, with projects, communities, and counties competing for attention for state, provincial and federal agencies and limited funds**

Data: The Lake Ontario offshore zone has been intensively studied for decades via the Great Lakes National Program Office of EPA, the Bioindex program of Fisheries and Oceans Canada as well as state and provincial programs. Some data comparing offshore phosphorus and chlorophyll levels to a limited number of embayment and nearshore sites on the south shore of Lake Ontario are available for the 1995-97 period (14). Some loading data are also available for watersheds. For example, programs of various NY County Soil and Water Conservation Districts primarily funded through the Finger Lakes Lake Ontario Watershed Protection Alliance have developed nutrient loading data for several of the watersheds. In Canada, Lake Ontario nearshore environmental conditions are periodically (1990, 1994, 1997, 2000 and 2003) monitored by the OMOE at a network of approximately 70 sites throughout the Great Lakes. Sites selected for study are located in shallow water (<30 m) and are removed from the direct influence of point sources. In general, the stations are sufficiently deep and removed from the shoreline so as not to be acutely affected by wind-induced resuspension of sediments and shoreline erosion. The information collected is intended to describe the more spatially wide-ranging conditions in the nearshore and will not represent the extremes of conditions in an area.

As discussed above, a limited systematic set of environmental data, mostly nutrient and biological, exists for the south shore of Lake Ontario only. No such data set exists for the entire coastal region of Lake Ontario. **For the coastal zone of Lake Ontario, information gaps are readily apparent. Water quality and biological data that do exist are spatially limited, are often not comparable due to different sampling designs between Canada and the U.S., and are generally focused on the offshore region rather than the coastal zone of the lake.**

Recommendations:

***Determine and evaluate the ecological status of the coastal zone of Lake Ontario.** Coastal monitoring of total phosphorus, soluble reactive phosphorus, nitrate, organic nitrogen, sodium, total suspended solids, turbidity, chlorophyll, phycocyanin, cyanotoxins, and coliforms should include coastal waters of the Canada and the United States. The sampling design should be spatially extensive with a minimum of monthly sampling from May through October to include embayments, drowned river mouths, and the nearshore zone of the coastal zone. An element of the work plan should focus on documenting the occurrence levels of *Cladophora* at limited nearshore suite of sites spatially at or near peak abundance.

Other aspects of this recommendation should include:
1) a unified assessment over the U.S./Canadian shoreline;
2) a sampling design/framework to stratify natural habitats, anticipated scales of variability in water quality, and types of anthropogenic influence on environmental conditions to allow spatial integration of results and appropriate comparisons (note discussion in Appendix A);
3) an element focusing on collection of the physio-chemical information needed to run existing Great Lakes *Cladophora* growth models; and
4) an element of the work plan to evaluate the spatial distribution of cyanobacteria and phytoplankton in the coastal zone with the objective of linking distribution patterns to local or lakewide drivers.

*** Develop new approaches to evaluating the coastal zone.** Geo-positioned continuous monitoring with a CTD (temperature, fluorometer, conductivity, light transmittance) and a laser optical plankton counter (LOPC) coupled with a Towfish along selected transects parallel (100 km in length) to the shoreline and perpendicular (depth of 40m) to the shore are recommended (15). The continuous high-resolution data will provide an image of spatial variability for each parameter at local, meso-scale and regional scale. Spatial patterns not easily detected by traditional sampling methods are likely to be revealed which may be related to landscape characteristics along the coastline. Such spatially intensive information would allow us to evaluate/characterize scales of effect of a suite of recognized anthropogenic influences on the coastal zone (STPs, storm water, tributaries stratified by land-use and size).

* **Develop an Integrating Coastal model** to explore the relationships between the physical environment, modified by local chemical conditions, on the biological response of the ecosystem, and feedbacks from the biota to the physical and chemical environment form. The development of an integrating coastal ecosystem (ICE) model should be developed to synthesize data and evaluate system responses to multiple stressors (physical, chemical, and biological) acting in concert, as well as to provide predictive capabilities for further hypothesis formulation and testing. If development of a new model is not practical, an integrated project utilizing one of the current generation of 3D hydrodynamic models, tributary (possibly other source types) discharge modeling and spatially detailed field-based water quality surveys, is suggested. With this combined approach, we can evaluate water quality over three types of shoreline: 1) urban, 2) agricultural, and 3) relatively limited development. We can then assess the degree to which the unified framework can be used to interpret and predict coastal water quality. The desired product would be a demonstration of an approach that could be used to better understand coastal water quality.

* **Long-term monitoring of selected sites** is recommended to evaluate remediation and restoration and to employ an adaptive management strategy. Monitoring efforts should track conventional water quality (nutrients, fecal indicators, chlorophyll, phycocyanin, macro ions, DOC, solids, transparency) at a limited number of locations dispersed around the open shores and embayments of the lake on an ongoing basis. These sites will have to be selected carefully based on yet undeveloped criteria.

Resources Available for Nearshore Work (U.S.):

1. SeaBird CTD equipped with the following sensors: Temperature, turbidity, pH, chlorophyll *a*, dissolved oxygen, and conductivity.
2. Hydrolab with temperature, oxygen, pH, chlorophyll *a*, and phycocyanin.
3. R.V. Madtom (27' vessel) equipped with motorized winch and crane, GPS, etc.
4. NELAC Certified Water Quality lab with Bran Luebbe Auto Analysers, Atomic Absorption Spectrometer, G.C., Mass Spec, etc.

Cost Estimates:

1. Determine Ecological Status of the Coastal zone
    Canada: $170K Canadian
    USA: $200K American (Year 1: $150K, Year 2:$50,000)
2. Develop new approaches to evaluating the coastal zone. Geo-positioned continuous monitoring with a CTD, LOPC and Towfish along a 100km transect, etc.
    Equipment: LOPC: $60K, Towfish/V-Fin $12K
    Sampling and Analysis: $15,000 per transect

3. Model Development: No cost developed.

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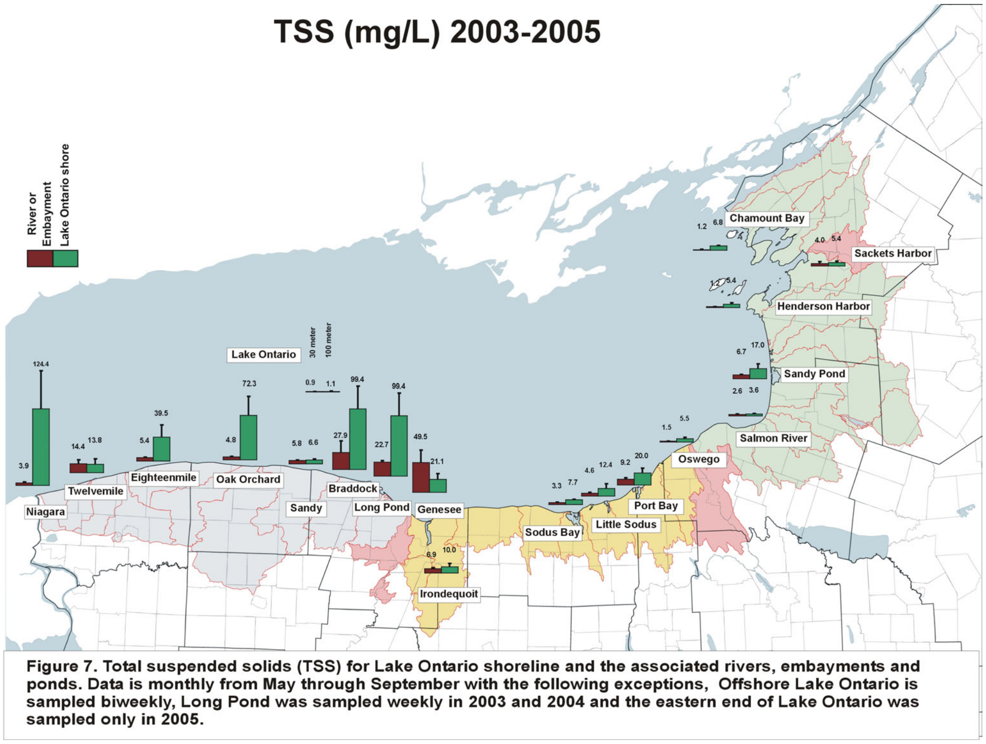
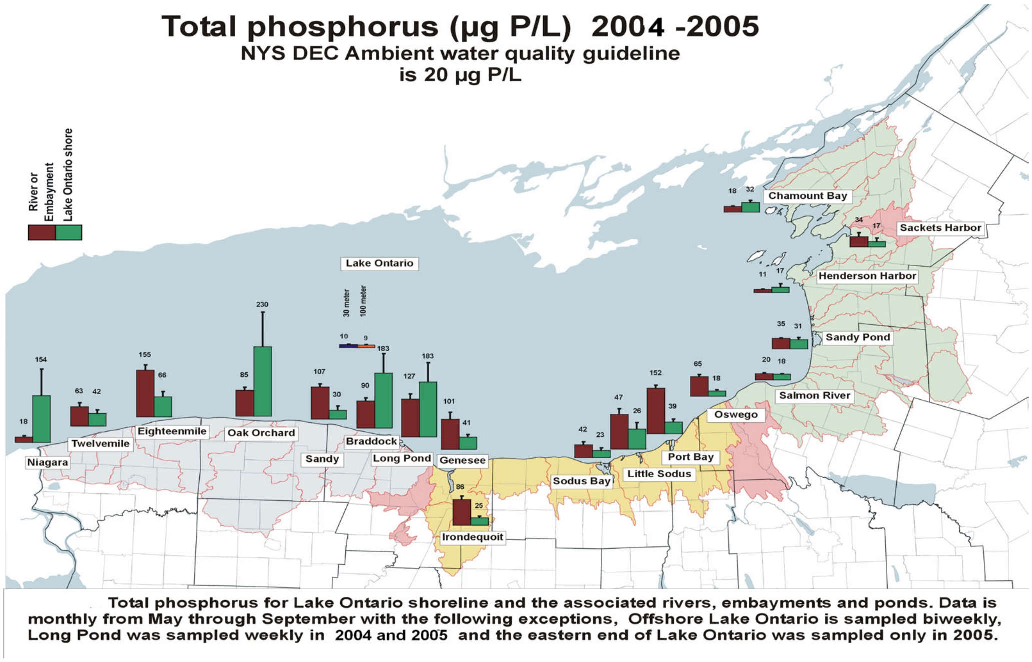


TSS (mg/L) 2003-2005

Figure 7. Total suspended solids (TSS) for Lake Ontario shoreline and the associated rivers, embayments and ponds. Data is monthly from May through September with the following exceptions, Offshore Lake Ontario is sampled biweekly, Long Pond was sampled weekly in 2003 and 2004 and the eastern end of Lake Ontario was sampled only in 2005.

Figure 1. Ambient levels of total suspended solids in the coastal zone of Lake Ontario.



Total phosphorus (µg P/L) 2004 -2005
NYS DEC Ambient water quality guideline
is 20 µg P/L

Total phosphorus for Lake Ontario shoreline and the associated rivers, embayments and ponds. Data is monthly from May through September with the following exceptions, Offshore Lake Ontario is sampled biweekly, Long Pond was sampled weekly in 2004 and 2005 and the eastern end of Lake Ontario was sampled only in 2005.

Figure 2. Ambient levels of total phosphorus in the coastal zone of Lake Ontario.

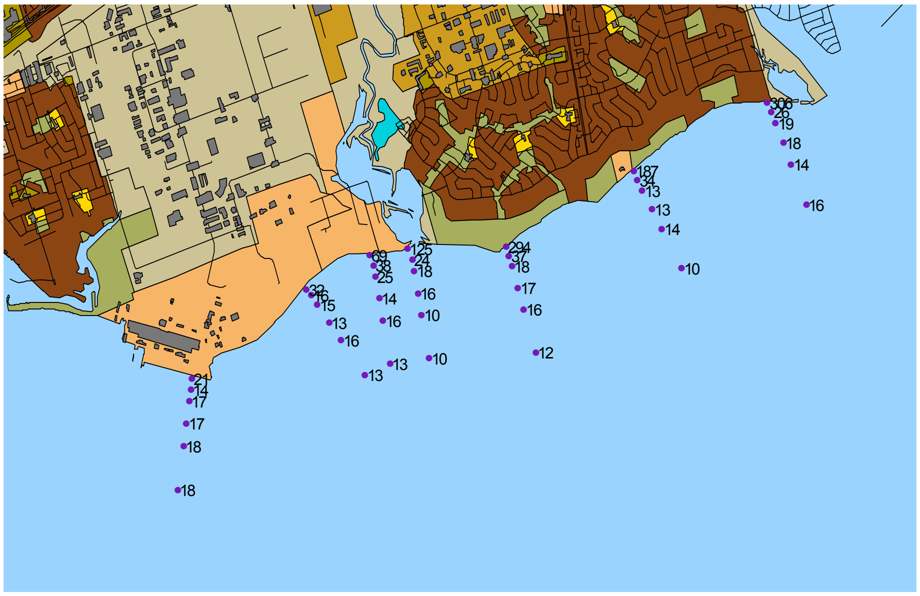
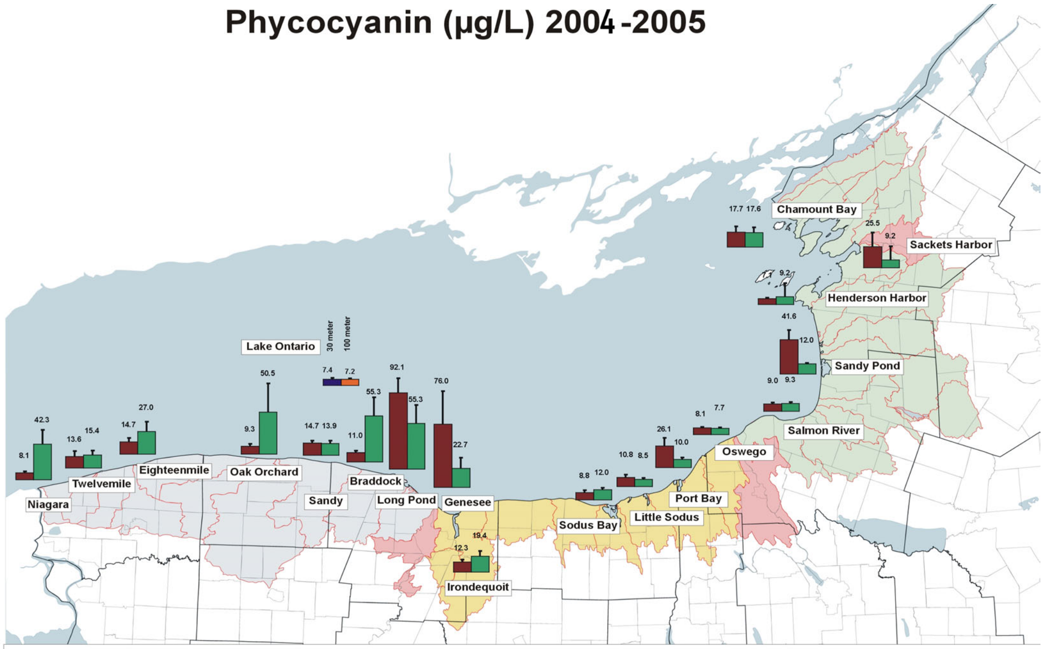


Figure 3. Total phosphorus (µg/L) concentrations at the Town of Ajax waterfront on 29 August 2006. Samples sites are 0, 100, 200, 200, 600 and 1000 m from the shoreline. Samples taken by the Metro Toronto Region Conservation Authority and the Town of Ajax. Data courtesy of Gary Bowen, MTRCA)



Phycocyanin for Lake Ontario shoreline and the associated rivers, embayments and ponds. Data is monthly from June through September with the following exceptions Offshore Lake Ontario is sampled biweekly, Long Pond was sampled weekly in 2004 and 2005 and the eastern end of Lake Ontario was sampled only in 2005.

Figure 4. Ambient levels of phycocyanin along the south shore of Lake Ontario.

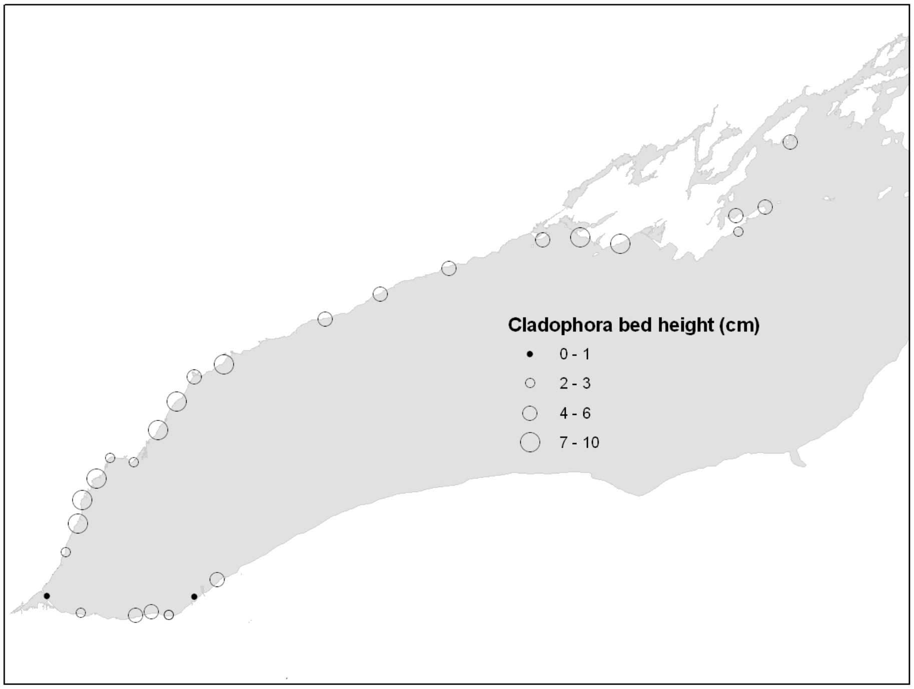


Figure 5. Mean bed height of benthic algae, predominately *Cladophora*, at 5-m depth on the Canadian shores of Lake Ontario in late August to early September 2003. Estimates are based on diver-observation of five 0.25-m^2 quadrants OMOE unpublished data (see Wilson et al. 2006 for study background).

Appendix A. Sampling design issues in the coastal zone.

High levels of variability in physical, chemical and biological features have been a persistent impediment to the realistic characterization of conditions and to efforts in understanding cause-effects relationships in the coastal zone (e.g., Figure A1). The sources of variability are diverse but can be grouped to some extent as resulting from physical process (e.g. circulation, upwellings, and bed/shoreline erosion) within the lake, discharges to the nearshore from the shoreline, dreissenid related re-engineering of the lake bed, and temporal variability in weather and biological activity. Some of the dimensions of the challenge and several features of variability that are typical of Lake Ontario are illustrated in Figure A2 using spatial patterns in turbidity and total phosphorus (TP) measured over a 10 km stretch of the Toronto waterfront in late spring 2000 (OMOE unpublished data). Areas of moderately high and low turbidity occurred in relatively close proximity; turbidity was unrelated to distance from the shoreline. Turbidity plumes associated with mixing gradients of two small rivers were oriented parallel with the shoreline moving to the northwest. Shore-parallel flow is characteristic of the nearshore of the Lake Ontario (Rao and Murthy 2001) and frequently serves to move shore discharges along and often directly onto the shoreline. The onshore-offshore and along-shore gradients account to some extent for the apparent discrepancy in results between surveys conducted by vessel with those conducted from the shoreline in very shallow water. Small-volume discharges may not move into water deep enough for a survey vessel to access but may be readily apparent from the shoreline. Acute concentration gradients extending from the shoreline over the first several meters depth of water are environmentally relevant but a difficult feature to evaluate. However, issues concerning recreational water quality and aspects of nutrient supply to benthic algae require resolution of conditions on this scale.

The area of low turbidity along the rocky, and dreissenid infested, shoreline south of Mimico Creek (Figure A2) illustrates the potential influence of dreissenid filtration on water column particulate concentrations and water clarity. Support for this interpretation of low turbidity along the shoreline is provided by the variation in chlorophyll *a* concentrations over the survey area as a function of depth. Minimum concentrations increase from 3 to 18 m depth reflecting the greater removal of particulate material from the water column by dreissenids at shallow depth. The wide variability in concentration in the shallow depth illustrates the challenge in separating the enrichment-related effects of inputs from the shoreline from the particulate-stripping effects of dreissenids.

The spatial variability in TP concentrations in the vicinity of Mimico Creek illustrates the difficulty in obtaining an accurate representation of nearshore conditions using mean or integrated values. Over a relatively limited area, TP values ranged from 6 to 28 µg/L (with the exception of a high value within a river mouth). While some of the variability can be ascribed to river discharges (in one case proximity to a STP discharge: SW corner), there remains moderate variability away from areas of elevated turbidity. While it is not immediately testable using the data presented here, it is tempting to speculate that the low TP values along the immediate shoreline result from the hypothesized nearshore shunt effect of dreissenid mussels (Hecky et al. 2004).

In 2000 the OMOE conducted limited experimental surveys in Lake Ontario in efforts to develop a field-based approach capable of describing fine-scale patterns in water quality adjacent to shoreline. The basic approach is to track a suite of sensors along the shoreline collecting spatially-detailed field measurements. The field data is supplemented with more limited laboratory-based data on the day of survey and through-time information from deployments of ADCPs, temperature recorders, and other sensors. Since 2000 the development of survey methods continues largely in other areas of the Great Lakes. The approach is used as part of the OMOE nearshore monitoring program in studies in which resolution of local-scale linkages between features of the shoreline and water quality is an objective. Two areas of method development are ongoing: integration of the field survey approach with hydrodynamic modeling to extend the depth of interpretation particularly with respect to time; acquisition and setup of a towed undulating vehicle with a more diverse sensor payload and potential for wider spatial coverage. Lake Ontario has specifically been targeted in the later activity.

Despite the appreciable variability in environmental conditions encountered in the nearshore, monitoring initiatives attempt to achieve a useful representation of conditions with limited resources. Future monitoring designs should select the features of variability to be highlighted or downplayed consistent with the questions that monitoring is meant to inform. In the nearshore, this is invariably a compromise because of the wide diversity of scales on which environmental conditions are affected.

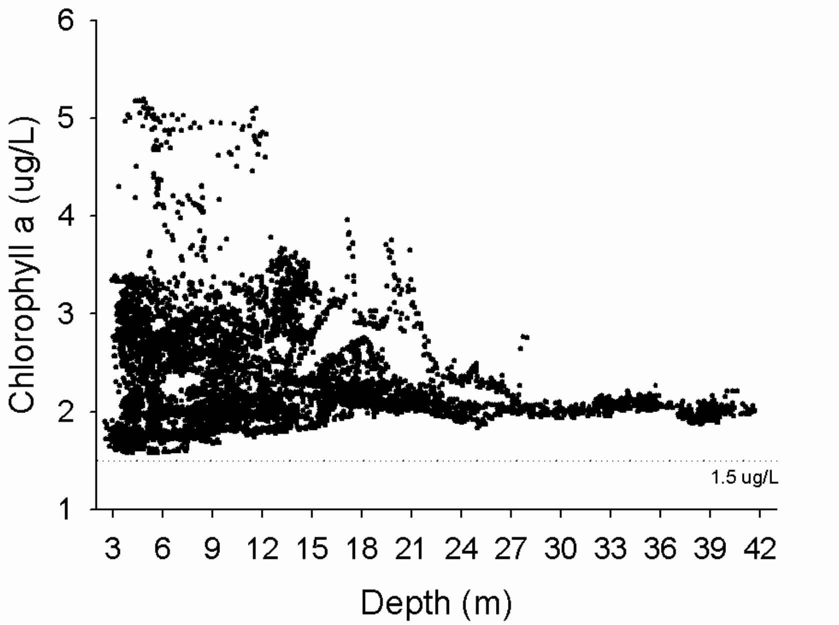


Figure A1: Near surface chlorophyll a concentrations over the area of Toronto waterfront depicted in Figure 2 on 24 May 2000 plotted against lake depth. Extracted-equivalent chlorophyll a concentrations were estimated from field measurements of chlorophyll a fluorescence based on a linear regression of paired lab-field measurements for the day of survey.

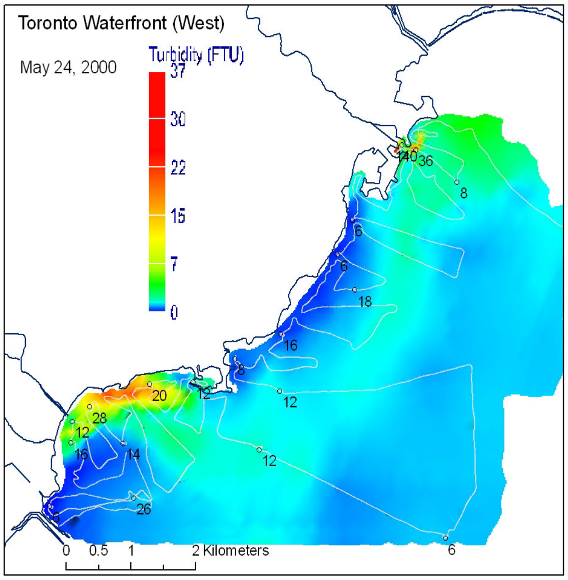


Figure A2: Turbidity on 24 May 2000 over a section of the Toronto waterfront extending from NE of Mimico Creek to SW of Etobicoke Creek. Turbidity was empirically estimated from field measurements of beam attenuation coefficient (660 nm) at 1.5 m below lake surface. The coloured layer is a kriged surface based on 8.2 K measurements over the track shown in grey. The numeric values indicate total phosphorus concentrations in point samples collected at 1.5-m depth.

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Evaluation of Fish Assessment Needs Including Consideration of a Lake-Wide Lake Trout Survey

Robert O’Gorman, USGS, Great Lakes Science Center, Lake Ontario Biological Station
Ted Schaner, Ontario Ministry of Natural Resources
Jana Lantry, NYSDEC, Cape Vincent Fishery Research Station

The Lake Ontario fish community is increasingly dominated by non-native species, and many formerly abundant native species are extirpated or reduced to rarity (Casselman and Scott 2003; Owens et al. 2003). Until recent years, however, native fishes still comprised the bulk of the fish community in the shallow, warmer nearshore waters, with non-native alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) only abundant seasonally when spawning (O’Gorman and Burnett 2001; Eckert 2006a). In 1998, round goby (*Neogobius melanostomus*) invaded Lake Ontario and their numbers are presently increasing in the nearshore. Although some round gobies migrate to offshore waters in winter (Walsh et al. in press), others apparently remain near shore. Moreover, the latest native fish to suffer an extreme population decline is American eel (*Anguilla rostrata*), a nearshore resident (Casselman and Scott 2003). In offshore waters, the fish community has been dominated by non-native alewife and rainbow smelt since the mid-20th century disappearance of lake trout (*Salvelinus namaycush*), deepwater ciscoes (*Coregonus* spp.), and deepwater sculpin (*Myoxocephalus thompsonii*) (Christie 1973; Mills et al. 2005). Although deepwater sculpin have recently reappeared in assessments, they are still rare and their recovery to former levels of abundance is uncertain (Lantry et al. in press).

Alewives have been shown to negatively impact a variety of native fishes by predation on larvae and, for lake trout and Atlantic salmon (*Salmo salar*) which have alewife rich diets, by lowering thiamine levels in eggs thereby reducing survival of early life history stages (Fitzsimons et al. 1999, 2005; Madenjian et al. in review). To reduce nuisance levels of alewife, create an economically valuable sport fishery, and restore lake trout, the New York State Department of Environmental Conservation (NYSDEC), Ontario Ministry of Natural Resources (OMNR), Department of Fisheries and Ocean (DFO), and the U.S. Fish and Wildlife Service (USFWS) began large scale releases of hatchery reared salmon and trout, including lake trout, and initiated a program to suppress sea lamprey (*Petromyzon marinus*). Vigorous populations of piscivores were established in the 1980s and by the early 1990s, alewife numbers had declined to such an extent that concern about the ability of prey fish populations to support the salmon and trout and the economically valuable sport fishery led to reductions in stocking (Jones et al. 1993; O’Gorman and Stewart 1999). Since then, alewife numbers have continued to decline, due to predation and reductions in phosphorus levels which decreased system productivity (Mills et al. 2005).

Maintaining societal and ecological benefits from expensive management programs like fish stocking and sea lamprey control demands a continuous flow of current information to managers. This is particularly true for Lake Ontario where a recent influx of invasive species has severely disrupted the food web.

Ongoing Fishery Assessments

Nearshore - Assessments of the nearshore fish community are concentrated in the relatively shallow northeastern basin of Lake Ontario where about 42% of water <30 m deep in the lake is located. The OMNR has conducted a fish community indexing program in the northeastern basin since 1958 (Casselman and Scott 2003). As part of this indexing program, annual assessments of nearshore waters have been conducted with bottom trawls since 1972 and with gill nets since 1977. The NYSDEC has conducted a warmwater assessment in the northeastern basin with gill nets each year since 1976 (Eckert 2006a). More recently, the NYSDEC began conducting bottom trawling for young-of-year yellow perch (*Perca flavescens*) in northeastern bays each fall in a program modeled after a study conducted by O'Gorman and Burnett (2001) during 1978-1997. Ongoing assessments of the nearshore zone in northeastern Lake Ontario are sufficient to detect changes in the fish community particularly since most of the assessments have been conducted for decades and thus have measures of "normal" interannual variability.

The nearshore fish community in most of the main lake basin lacks a targeted annual assessment. The only exception is along a 70 km stretch of the northeastern shore between Brighton and Long Point, where annual index gillnetting has been conducted since 1988 (OMNR 2006). Other assessments have occurred sporadically over the years (Eckert and Pearsall 2002) and there have been short-term localized assessments associated with industrial water use projects such as power plants. Much of the nearshore is rocky, prohibiting bottom trawling, but the major factor confounding the conduct of, and interpretation of data from, nearshore assessments is the relatively unstable thermocline which changes fish density as it rises and falls.

Offshore - A considerable amount of effort is aimed at assessing the fish community in the offshore waters of Lake Ontario, by far the largest area of the lake. In U.S. waters, three bottom trawl surveys are conducted annually to assess prey fishes, one survey each for alewife, rainbow smelt, and slimy sculpin (*Cottus cognatus*; Owens et al. 2003). Canadian waters are mostly unsuitable for bottom trawling due to rough bottom except for limited areas in the extreme west and east ends of the lake. In the west, a bottom trawl assessment for rainbow smelt and juvenile lake trout (see below) was conducted each year during 1986-1993 (Schaner and Schneider 1994). In the east, bottom trawls are conducted annually in the northeastern basin as part of OMNR's community indexing program (Casselman and Scott 2003). A hydroacoustic assessment of prey fishes that encompasses the entire lake has been conducted annually in midsummer by OMNR and NYSDEC since 1991 (OMNR 2006). Trends in alewife abundance from the spring trawl survey in U.S. waters are in general agreement with those of whole lake estimates of alewife abundance from the midsummer hydroacoustic survey.

Assessment of the relative abundance of most salmon and trout is difficult in offshore waters because the fish are widely and unevenly dispersed and at mid depths. For Pacific salmon (*Oncorhynchus* spp.), biological information is collected when the fish ascend streams to spawn (Bishop and Prindle 2006; OMNR 2006). Biological information on piscivores is also collected during creel surveys which track angler catch rates and harvest in both jurisdictions (Eckert 2006b; Prindle et al. 2006). Sea lamprey, an important member of the offshore community, are also assessed when they ascend streams to spawn by a trapping program that covers both shores of the lake (Young and Klar 2006). An early spring gillnet assessment conducted in nearshore

U.S. waters during the 1980s, was successful at tracking growth of brown trout (*Salmo trutta*) and coho salmon (*Oncorhynchus kisutch*) (O'Gorman et al. 1987). However, springtime distribution of these piscivores apparently shifted offshore after water clarity increased following dreissenid colonization in the mid 1990s and so it seems doubtful that the results from a similar assessment today could be compared to that of the 1980s.

Lake trout, the focus of a binational restoration program (Elrod et al. 1995), can be assessed in offshore waters with conventional bottom trawls and bottom set gill nets. Juvenile lake trout have been assessed annually since 1981 with bottom trawls in midsummer from the west side of the Niagara Bar eastward into the northeastern basin (Elrod et al. 1993; Lantry and Prindle 2006). Bottom trawling for juvenile lake trout in extreme western waters (Grimsby-Hamilton-Toronto) during 1986-1993 caught very few lake trout except at the mouth of the Niagara River and was generally viewed as an unsuccessful assessment. In contrast, gill netting adult lake trout was a successful assessment technique throughout the lake and gill nets were fished lakewide during 1985-1995 (Bowlby et al. 1996; Schneider et al. 1996) but only in N.Y. waters during 1980-1984 and 1996-2006 (Elrod et al. 1995; Lantry and Prindle 2006).

Fishery assessments are rarely conducted in the mid-lake profundal zone. However, since the disappearance of native deepwater fishes, the area has generally been thought devoid of fish for much of the year (Christie 1973) and a recent survey with trawls and gill nets confirmed that few fish are there in midsummer (Strang et al. 2006).

Assessment Needs

Important fishes lacking sufficient assessment efforts are those that are difficult to capture (salmon in the open lake) and those for which catch data is difficult to interpret (nearshore fishes in the main lake basin). The one exception is adult lake trout. Although there are regional lake trout assessments, there is a need for conducting an integrated, whole lake assessment such as was done during 1985-1995. Restoration of a self-sustaining lake trout population is a goal of New York and Ontario resource managers and gauging progress towards the goal should be done on a whole lake basis. Since the cessation of whole lake assessment, stocked lake trout have begun reproducing (O'Gorman et al. 1998), and regional differences in occurrence of naturally produced juveniles have been documented (Lantry and Prindle 2006). An important measure of progress towards restoration would be the proportion of naturally produced fish in the spawning population. A whole lake assessment, aside from collecting valuable demographic information, could also be used to collect information on the genetic makeup of naturally produced fish, thiamine status of mature females, and general population health. We herein outline the resources needed to conduct a comprehensive whole lake assessment of adult lake trout in September 2008 by the USGS, NYSDEC, and OMNR.

Sampling sites – The whole lake assessment of lake trout was last completed in 1995 and consisted of nets fished at random sites in 14 geographic regions in N.Y. waters and at 10 fixed stations in Ontario waters (Fig 1.). At a minimum this level of sampling effort should be repeated and, if resources allow, one or more sites should be added along the north shore.

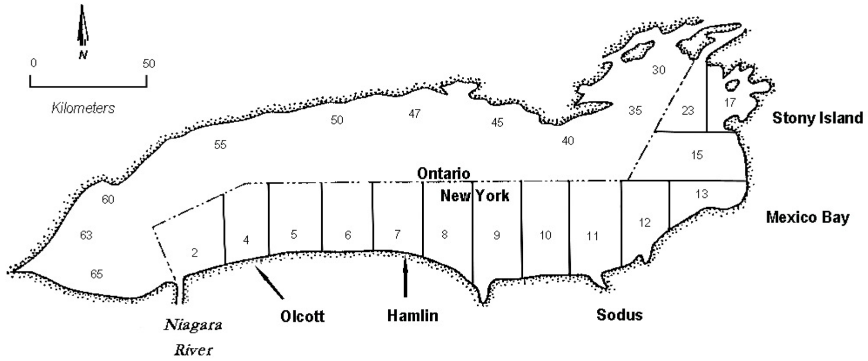

Figure 1 – Lake Ontario showing the 14 geographic regions in U.S. waters (regions 2-23) and the 10 fixed sites in Canadian waters (stations 30-65) where gill nets were fished to assess adult lake trout.

Vessels – Three vessels, one each from USGS, NYSDEC, and OMNR were used to conduct whole lake assessments of adult lake trout during 1985-1995 and a minimum of three vessels would be needed in 2008. In calculating the additional vessel days needed to expand the annual assessment, we assumed that geographic deployment of agency research vessels would be similar to that of the past – USGS (*Kaho*) in the west, NYSDEC (*Seth Green*) in the southeast, and OMNR (*Keenosay*) in the northeast. For the *Kaho*, ten additional vessel days would have to be devoted to adult lake trout assessment (assuming that the *Kaho* would sample the western half of the lake). For *Seth Green*, five additional vessel days would have to be added to the schedule and for the *Keenosay*, eight vessel days would have to be added to the schedule.

Field personnel – At least, one additional person would be needed on each vessel if studies are conducted on thiamine status of mature females and fish health. Additional shore support would be needed to co-ordinate transfer of fish health samples to the laboratory.

Identification of Naturally Produced Fish - Concentrations of stable isotopes of carbon and oxygen in the region of the otolith that is deposited during the first year of life, can be used to distinguish fish that spent their first year in a hatchery from those that spent their first year in the lake. Assuming processing costs $30 per fish (includes mounting, micromilling and isotope analysis) and 125 fish (only those without any marks would need to be examined), the total cost would be $3,750 (CAD). Additionally, fish identified as wild would be aged, using the otolith, at a cost of $10 (CAD) per fish.

Thiamine status of females - A portion of the ovary from each mature female would be taken and frozen on dry ice for determination of thiamine status. Assuming a total catch of 150-200 mature females and the current cost of thiamine determination ($70), total cost would be $10,500 to $14,000 (USD). Emerging techniques for thiamine determination could reduce costs by 50% or more by 2008. Additional costs include $2,000 for dry ice and field supplies plus funding for technicians to collect ovaries in the field (40 days).

Fish health - Bacteriology, virology, and parasitic samples would be collected, placed on ice and shipped next day air to the laboratory for processing. Samples would consist of bacterial cultures from the kidney and external lesions, kidney and spleen tissue, and gill arches. These samples would be screened for a variety of fish diseases including, but not limited to, bacterial kidney disease, furunculosis, infectious pancreatic necrosis virus, viral hemorrhagic septicemia, and whirling disease. Ideally, we would collect samples from 20-60 fish collected at each of the 24 sites gill netted. Assuming that we process 60 lake trout per site and the current cost of disease screening of $1000/60 fish/site, total cost would be $24,000 (USD). Additional costs include supplies and shipping expenses of approximately $2,000 per vessel, plus funding for a technician to collect the samples in the field (40 days). The same technician who collects ovaries could collect the fish health samples to reduce personnel costs.

Genetics - Samples for genetic analysis would be collected from all lake trout that do not have a clipped fin or a coded wire tag. After analysis of otoliths, samples from those fish identified as naturally produced could be used to determine genetic origin (many genetic strains have been stocked in Lake Ontario).

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Modeling the Lake Ontario Ecosystem: Next Steps

Joseph V. DePinto, Limno-Tech
Thomas J. Stewart, University of Toronto at Mississauga

Introduction

The Lake Ontario ecosystem has undergone many significant changes over the past thirty years as a result of external natural and anthropogenic perturbations. These perturbations (or stressors) have led to changes in lake primary production, trophic structure and function, nearshore and wetland habitat, and fish production and diversity. Among the significant stressors that have led to the ecological responses are: phosphorus load reduction to reverse the consequences of cultural eutrophication, persistent toxic chemical exposure, invasion aquatic nuisance species such as sea lamprey and *Dreissena* spp., fisheries management by stocking of exotic salmonids and sea lamprey control, fish harvest pressure by sport fishing and cormorants, and reduction of natural water level fluctuations as a result of the St. Lawrence Seaway regulation program. Considerable research, monitoring, and modeling have been conducted in order to support water quality and fishery management in Lake Ontario. In most cases, those data-supported modeling efforts have led to rational and defensible management decisions; however, our quantitative understanding of the Lake Ontario ecosystem structure and functioning have not been able to keep pace with the latest stressor-induced changes that were not considered at the time management actions were taken for a specific issue. Recent research has been focused on assessing the changes that have taken place in the structure and function of the Lake Ontario lower food web in order to better support management decisions in face of multiple stressors (Mills, et al. 2006). The purpose of this paper is to review the history of Lake Ontario trophic modeling and to make recommendations for model refinements to better integrate the current research and monitoring and to better support Lake Ontario management that is consistent with an Ecosystem Approach.

Previous Modeling Efforts

The first major modeling of water quality in Lake Ontario was undertaken in support of eutrophication management that was a major goal of the Great Lakes Water Quality Agreement (1972). There were three models used determine the total phosphorus loading to Lake Ontario necessary to achieve the target water quality objectives of 10 μgP/L of total phosphorus and 2.6 μg/L chlorophyll *a*. Of the three models, the Thomann LAKE 1 model (Thomann, et al. 1975; 1976) was the most sophisticated from a process perspective. The LAKE 1 model had both available and unavailable phosphorus and nitrogen state variables, and also modeled phytoplankton (as chlorophyll *a*) and zooplankton biomass. Chapra's model was a Great Lakes basin-wide total phosphorus dynamic model, with chlorophyll concentration computed from an empirical phosphorus to chlorophyll relationship (Chapra 1977; 1980a; 1980b). The third model was a Vollenweider empirical model. Based on these models, a target TP load to Lake Ontario of 7000 metric tonnes per year (mta) was chosen (Task Group III 1978).

At the same time as the phosphorus load reductions to Lake Ontario were occurring, the fishery management community was expanding its Salmonid stocking program in response to the great success the stocked Salmonids were having and the rapidly expanding recreational fishery (O'Gorman and Stewart 1999) (Figure 1). The accelerated stocking rates through the 1970's and early 1980's led to a high fishery yields but also led to concern over the sustainability of the fishery due to decreasing alewife populations as well as other prey fish. In the mid-1980's New York and Ontario agreed to reduce Salmonid stocking to 8 million per year. Based on continued data analysis and fish population dynamics and production modeling, the stocking limit was set to 4.5 million per year in 1993.

Upper food web modeling conducted in the mid-1990s was used to support the decision to maintain the reduced stocking level. An example of the management modeling that was done is the nutrient-trophic food web model of Jain and DePinto (1996). This model was one of the initial efforts at developing an ecosystem model that quantitatively linked nutrient-primary production as governed by nutrient loads with top predator fish production as effected by both the lower food web production and stocking and harvesting forcing functions from above. This modeling effort demonstrated that, under current mid-1990's conditions, long-term Salmonid production was sensitive to both phosphorus loading rate and Salmonid stocking rate in a non-linear way (Figure 2). The model also confirmed that at the current phosphorus loading rate, increasing stocking will not significantly increase long-term Salmonid production but it will likely put undo pressure on the forage fish in the system.

Halfon and Schito (1993) were the first to attempt to trophically balance a multi-trophic level food web model of Lake Ontario. This work highlighted the challenges of quantitatively describing a relatively simple food web in such large system. Additionally, tools were not available to dynamically link the food web model to potential management actions.

Evaluation of Previous Modeling Relative to Current Lake Ontario Status

Lake Ontario first achieved its target load of 7000 mta in 1983, dropping from values above 10,000 mta prior to the mid-1970s (see Figure 1). Since 1983, the Lake Ontario TP load has exceeded its target value five times – in 1984, 1986, 1987, 1990, and 1991 (TP loading estimates are not available for Lake Ontario beyond 1991). These excursions suggest that Lake Ontario has not been consistently meeting its target load (at least through 1991). Furthermore, it seems that the years when the Lake Ontario target is exceeded align with those years that have a high load to Lake Erie (over its target load).

Despite not consistently meeting its target TP load, the mean spring total phosphorus concentration has dropped from levels over 20 μgP/L prior to the mid-1970s to values well below its 10 μgP/L goal (Figure 3). These current TP levels in the 4 – 6 μgP/L range indicate that offshore waters of Lake Ontario are very oligotrophic. The summer average chlorophyll *a* concentrations have dropped from levels in the 4-6 μgP/L range down to the 1-3 μgP/L level over the past 10-15 years, thus confirming the open water is oligotrophic (Figure 4).

Recently, Chapra applied his model to the Great Lakes to evaluate whether the previous models were still valid for predicting open water trophic conditions as a function of TP load. The results of this analysis are shown in Figure 5 (Chapra, personal communication). Since TP loads were not available after 1991, Chapra determined the rate of load reduction from 1974 – 1991 to be a first-order rate of 3.35% per year and decreased loads after 1991 at this rate. Despite using what are probably underestimates of the load for the last 10 years or so, the model still over-predicted both the phosphorus and chlorophyll *a* levels and under-predicted the Secchi depth. This is evidence that the nutrient – phytoplankton response to TP loads in Lake Ontario offshore waters is no longer the same as it was 20-30 years ago when the targets were being established.

While the offshore waters appear to have decreased in productivity beyond expectations, there is recent data that indicates what seems to be an inconsistent situation in the nearshore waters. Coastal waters, including bays, drowned river mouths, and nearshore waters up to about 30 meters depth, seem to have returned to the conditions experienced in the 1960's and 70's prior to significant load reductions (Makarewicz and Howell 2006; Tomlinson, et al. 2006). Mats of blue-green algae and dense Cladophora beds cover many nearshore areas of the lake. Obviously there has been a change, perhaps as a result of *Dreissena*, in the way that phosphorus entering the lake as runoff or tributary flows is being processed in the coastal zone of the lake. A possible hypothesis for this apparently anomalous behavior is that phosphorus entering the lake via nearshore direct runoff or tributary transport is either entering in a particulate form or is converted to particulate phosphorus by phytoplankton and then trapped in the nearshore by *Dreissena* filtration of particulate phosphorus where it is recycled and becomes available for benthic primary production. This is a phenomenon that has been called the "nearshore shunt" by Hecky, et al. (2004).

From a food web perspective, major ecological changes since the last major trophic modeling efforts include the loss of Diporeia, continued expansion of Dreissenids and round goby in the offshore, the proliferation of Bythotrephes and Cercopagis as both predators and prey, shifts in diet and depth distribution of prey-species, and unknown levels of wild salmon production.

It is our opinion that lake trophic management models must be revised to better simulate these ecological changes. Below we offer suggestions for future model development and the collection of data to support that development.

Future Modeling and Data Needs

Future Modeling Approach

Given the significant ecological changes that have taken place in Lake Ontario over the past 10 – 15 years, we believe there is a need to revise our conceptual and quantitative models of the Lake Ontario trophic structure and function. There are two basic goals of proposing the development of a whole-system ecological model: 1) we sorely need a quantitative framework within which to synthesize and integrate the recent experimental and monitoring data on the Lake Ontario ecosystem; and 2) we need a model that can inform management decisions on how to move the Lake Ontario fishery toward a more healthy and diverse community in the face of the multiple stressors that act concurrently on this system.

Building on the modeling that has already been conducted on Lake Ontario, we propose the following refinements in a Lake Ontario ecosystem trophic transfer model that can support the above two goals:

1. Formulation of a fine-scale ecosystem model that is linked to a fine-scale hydrodynamic model. This model would be able to capture the differences in nutrient inputs and cycling in the nearshore environment versus the offshore environment as well as the transfer of biogeochemically important materials between the two environments. The approach here would be similar to that taken by DePinto and Atkinson (Limno-Tech, Inc. 2004) in linking a fine-scale hydrodynamic model – the Princeton Ocean Model (POM) run at a 5 Km grid resolution – to their Lake Ontario toxic chemical mass balance model, LOTOX2. Atkinson is currently refining his POM application to Lake Ontario as part of the MERHAB project being conducted by a consortium of New York schools in the lower Great Lakes.

2. Incorporation of Lake Ontario coastal wetlands into the model in terms of their contribution to fish spawning and recruitment. This could build on the ecological response model that Limno-Tech, Inc. built in order to evaluate wetland flora and fauna (including fish) responses to alternative water level regulation plans being considered during the IJC Lake Ontario – St. Lawrence River (LOSL) Study (Limno-Tech, Inc. 2005).
3. *Dreissena* bioenergetics and their impact on nutrient cycling and energy flow should be built into the ecosystem model. The approach for coupling *Dreissena* in the model would be similar to what was done by DePinto and co-workers in developing their Saginaw Bay Ecosystem Model (Bierman, et al. 2005; Kaur, et al. 2002; 2004). This model also recognizes six different algal functional groups: diatoms, greens, non-nitrogen-fixing blue-greens, nitrogen-fixing blue-greens, other phytoplankton, and a benthic green alga.
4. Incorporation of a Cladophora sub-model using the frameworks that have been developed by Auer (Auer and Canale 1982; Auer, et al. 1982; Canale and Auer 1982) and Higgins (Higgins, et al. 2005a; 2005b, 2006) for simulating shoreline Cladophora growth.
5. Development of a sediment diagenesis sub-model to accurately represent nutrient fluxes from sediments to water and how those processes may be influenced by the presence and activities of *Dreissena*.
6. Finally, and perhaps most importantly, we need to develop a whole-system trophic transfer model that incorporates all of the above components with a complete lower and upper food web carbon (and/or energy) flow model that includes both benthic and pelagic food webs coupled with nutrient dynamics in both the nearshore and offshore environments.

A diagram of the full linked hydrodynamic-ecosystem model (LOEM), along with the necessary input and data flow for the model is presented in Figure 6. Each of the food web model boxes contains a complex structure of organisms, whose biomass would be expressed in common units of organic carbon content to facilitate mass balancing through the trophic transfers in the system as well as spatially in the lake. This diagram also depicts the loads and boundary conditions that must be known in order to run this model. Any data gathering program must measure or somehow specify these inputs. In particular, we really need to measure phosphorus loads to the lake, especially direct runoff and tributary loads, on an annual basis with a daily time scale. Considerable thought has gone into the structure of the Lake Ontario offshore food web and how it has changed since the 1980's to today by Stewart (2006) in proposing a study to quantitatively describe changes in the offshore food web and evaluate whether the re-establishment of bloater is ecologically possible and what the consequences might be. The diagram in Figure 7 depicts Stewart's proposed food web and the material and energy flow through the trophic system in the direction of prey to predator. This food web would form the basis for the lower, upper, and benthic food webs identified as model boxes in Figure 6.

Data Needs

In general it would be ideal to run the above model from about 1980 – 2005 in order to understand why the system has evolved the way it had over the last 25 years. To accomplish this, we require some basic long-term trend data, including loads, stocking and harvesting, hydrometeorology, biomass trends of important food web species, knowledge of distribution and feeding interactions, and invasive species density history. We also need to parameterize certain basic nutrient cycling and trophic transfer processes. Much of the knowledge and parameterization of material and energy flow processes can come from calibrating the model to the intense studies done in LOLA 2003 (Mills, et al. 2006) and to be done in LOLA 2008. Stewart (2006) has compiled a list of relevant biological data that can be used in developing this model, presented in Tables 1 – 3. While it appears that much of the data is potentially available, there are still major technical challenges to appropriately scaling available estimates to describe whole-lake biomass and production of key components.

As mentioned above, water quality data, both offshore and some nearshore, has been monitored by the Federal, State, and Provincial agencies responsible for managing the lake. Also, TP loads are available for 1967 – 1991; it would however, be extremely important to do a good job of measure the phosphorus load to the lake during the 2008 LOLA year as a means of estimating the loads between 1992 and 2008, perhaps by using a flow – load relationship that can be developed from available data. In addition to measuring phosphorus loads, it will be extremely important to focus measurements of biomass, production, and trophic transfers of key populations in the nearshore zone of the lake in order to better understand the role of the nearshore zone in the overall functioning of the Lake Ontario ecosystem.

Obviously, considerable detail is needed on the development of a data collection plan for the 2008 intensive field program; however, it is our contention that development of a conceptual model such as presented herein can greatly facilitate the prioritization of the elements of that plan.

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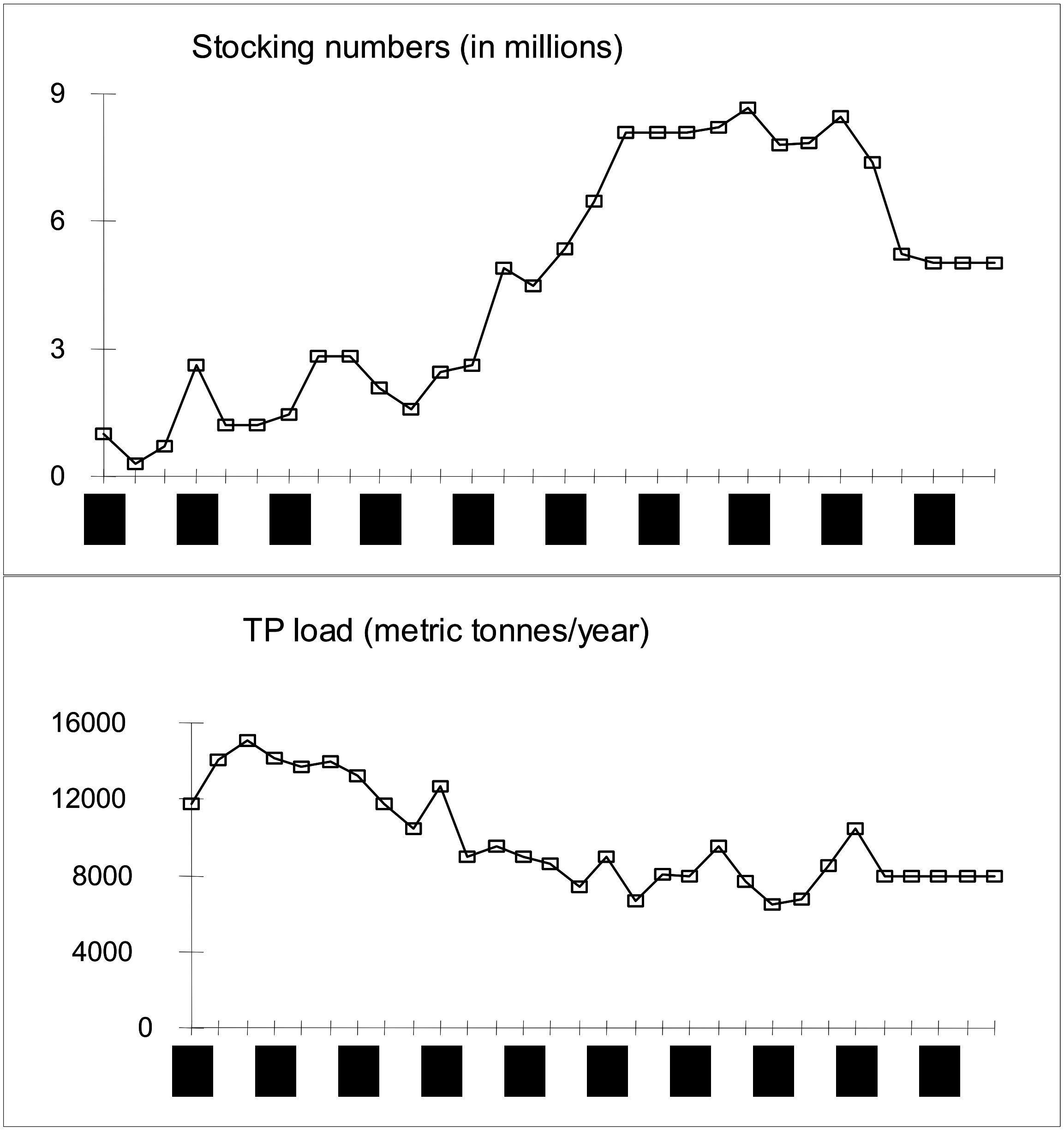

Figure 0. Time trends in salmonid stocking and TP loads to Lake Ontario from the late 1960's to the early 1990's.

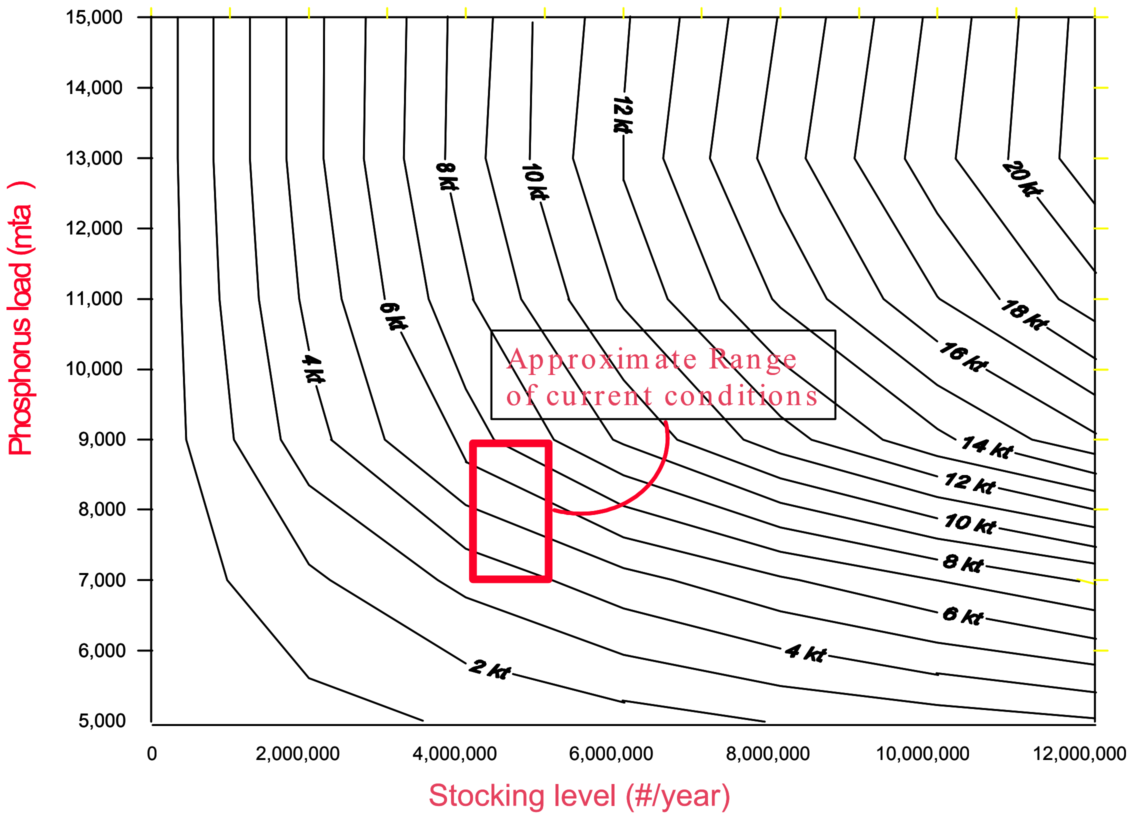

Figure 0. Annual salmonid production in Lake Ontario as a function of TP load and stocking rate.

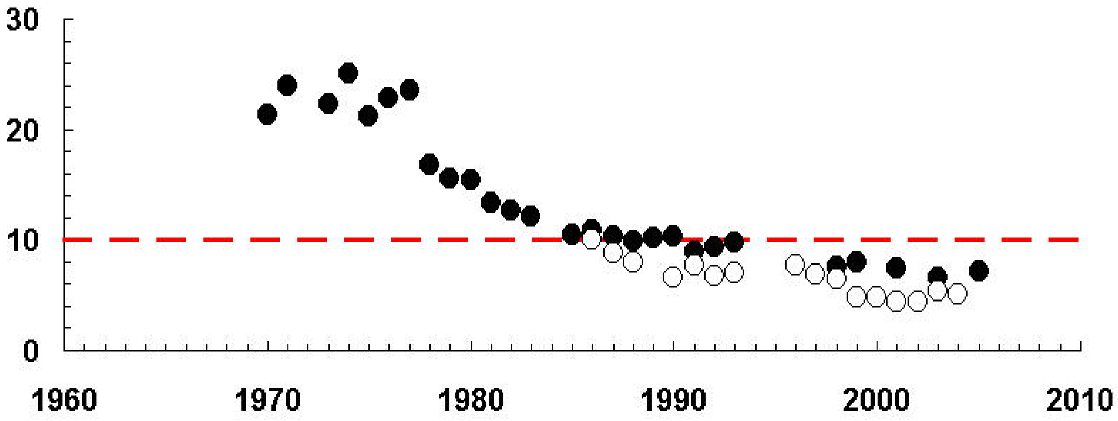

Figure 1. Mean spring TP concentrations (mgP/L) for the offshore waters of Lake Ontario. The filled and open circles represent Environment Canada and EPA-GLNPO data, respectively.

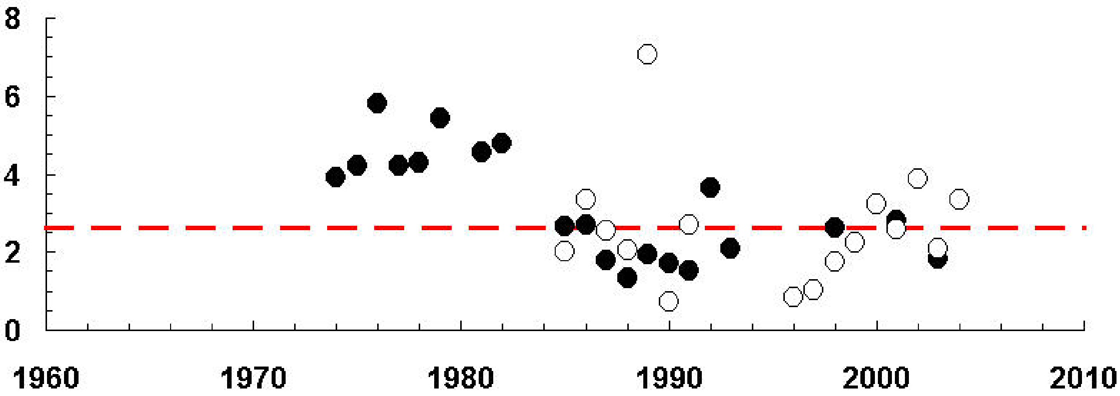

Figure 2. Mean summer chlorophyll a concentrations (mg/L) for the offshore waters of Lake Ontario. The filled and open circles represent Environment Canada and EPA-GLNPO data, respectively.

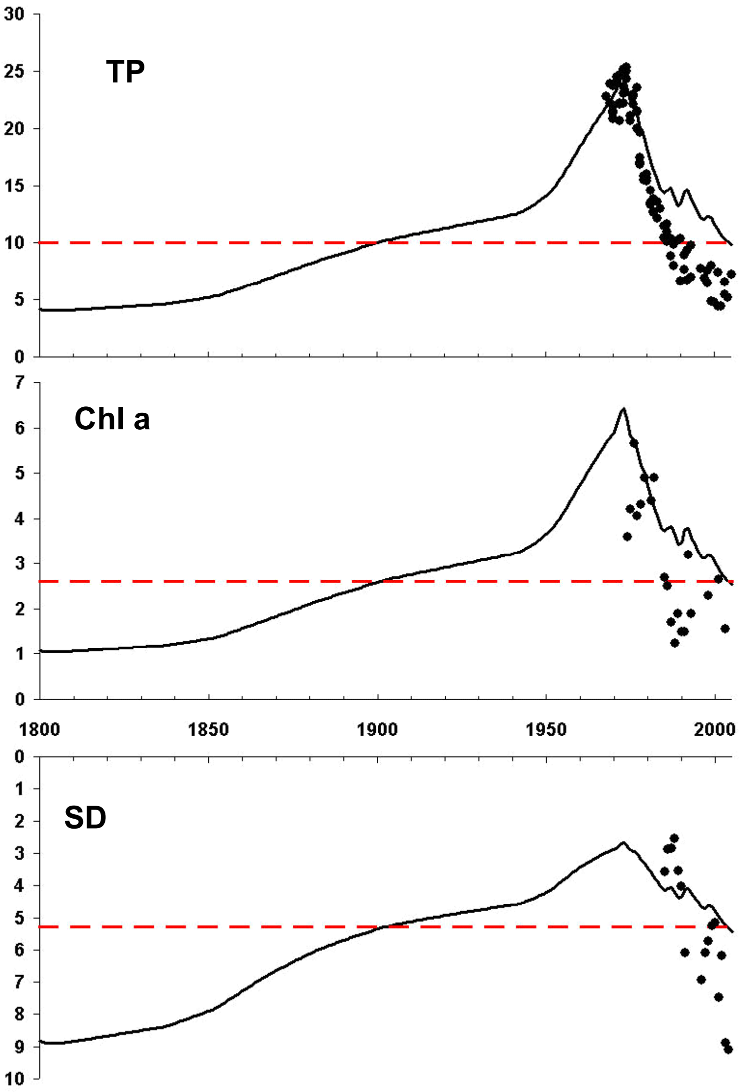

Figure 2. Plots of Chapra model simulation results for Lake Ontario and data for (a) TP (mgP/L), (b) chlorophyll a (mgA/L), and (c) Secchi depth (m). The water-quality objectives are shown as dashed lines.

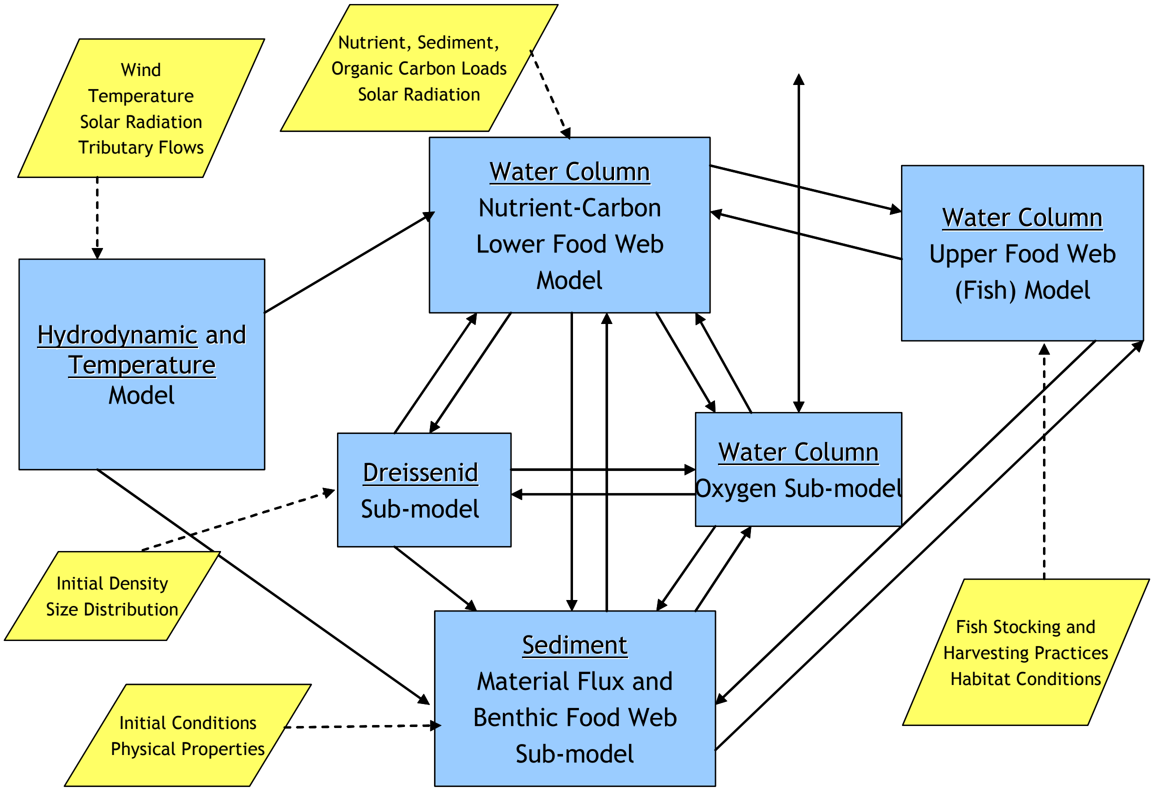

Figure 2. Input needs and material and energy flow among the various components of a Lake Ontario Ecosystem Model (LOEM).

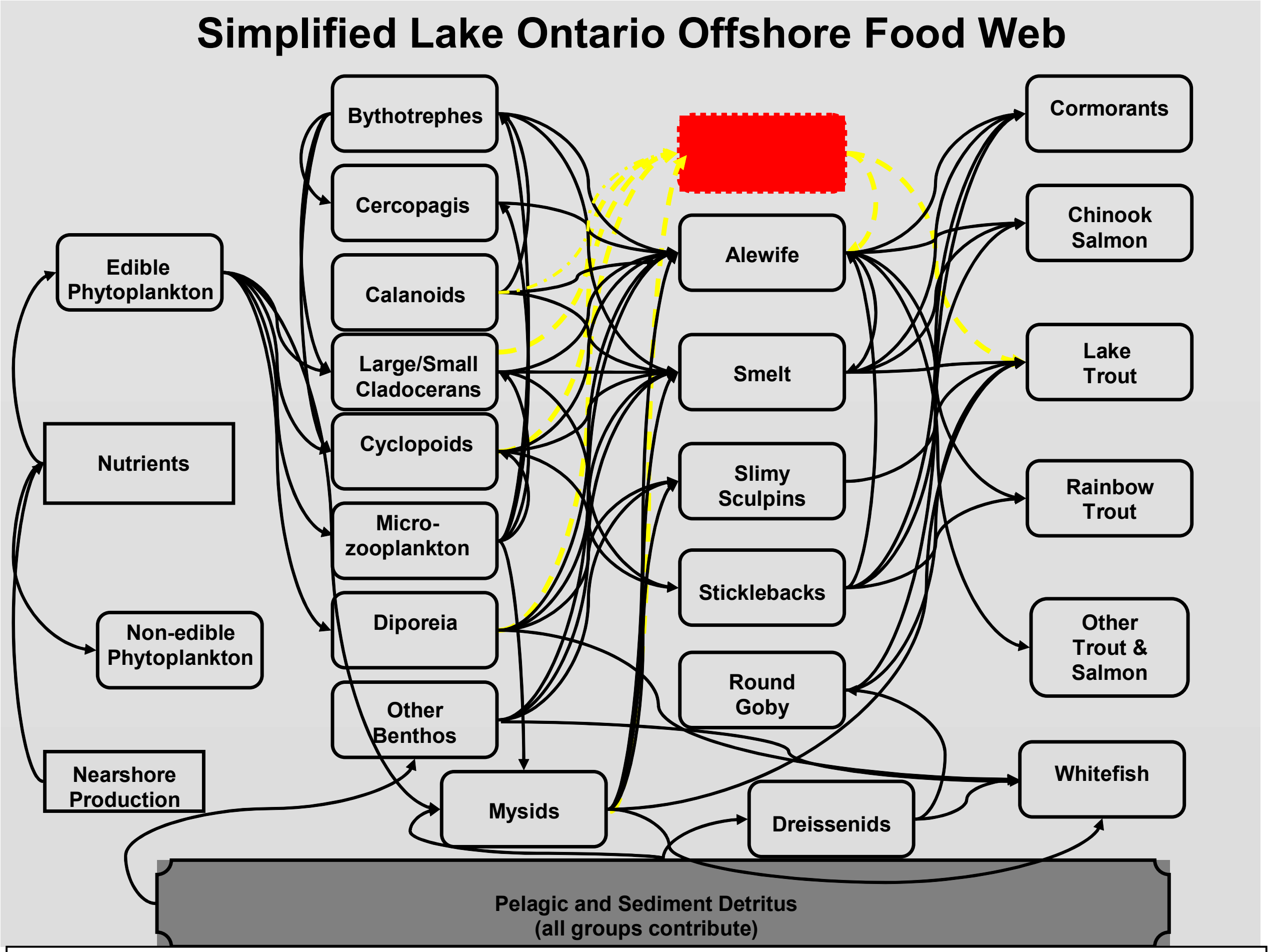

Figure 2. A depiction of the proposed food web structure for offshore Lake Ontario. Arrows indicate flows from prey to predator. (Stewart 2006)

Table 1. Inventory of relevant data and studies for the model period (1987-1991)

Lake Ontario food web component	Years	Source
Phytoplankton biomass and photosynthesis	1987-1992	Millard et al. 1996,1999, Johannsson et al. 1998
Zooplankton biomass	1981-1995	Johannsson et al. 1998
Zooplankton biomass and production	1990	Johannsson et al. 1994, Sprules and Goyke 1994
Mysid density and production	1990	Johannsson et al. 1994, 2001,2004 Johannsson 1995.
Benthic community biomass	1982-86, 1992	Dermott (2001), Owens and Dittman (2003), Mills et al. 1993, Haynes et al. 2005
Dreissenid densities and distribution	1993-1994	Bailey et al. 1999, Mills et al. 1999, Mills et al. 1993
Smelt diets	1984-1986, 1992	Urban 1988, Urban and Brandt 1993, Mills et al. 1995
Alewife diets	1988, 1989, 1992	Iancu 1989, Mills et al. 1992, Rand et al. 1995, Urban and Brandt 1993, Mills et al. 1995
Sculpin diets	Pre-1991	Owens and Weber 1995
Alewife biomass and production	1990, 1992-94	Rand et al. 1995, Goyke and Brandt 1993, Mason et al. 2005, Gal 1999, Ontario Ministry of Natural Resources (OMNR)/ New York Department of Environmental Conservation (NYDEC) Hydroacoustics
Smelt production and consumption	Generic	Lantry and Stewart 1993
Energy density of pelagic prey species	1978-1990	Rand et al. 1994
Chinook biomass, consumption and production	1978-1994	Rand and Stewart (1998)
Coho biomass, consumption and production	1978-1994	Rand and Stewart (1998)
Lake trout biomass, consumption and production	1978-1994	Rand and Stewart (1998)
Rainbow trout biomass, production, and consumption	1975-1990	Rand et al. 1993
Salmonid diets	1983-1993	Summarized by Rand and Stewart 1998, Lantry 2001, OMNR unpublished
Cormorant biomass, consumption, diet		Wesloh and Casselman 1992

Table 2. Inventory of relevant data and studies for the model period (2001-2005).

Lake Ontario food web component	**Years**	**References**
Total phosphorus, Chlorophyll *a*	2003	LOLA (see Luckey 2003)
Zooplankton biomass and production	2003	LOLA (see Luckey 2003)
Mysid density and production	2003	LOLA (see Luckey 2003)
Benthic community biomass	2003	LOLA (see Luckey 2003), Haynes et al. 2005
Dreissenid densities	2003	LOLA (see Luckey 2003)
Dreissenid filtering rates and bioenergetics		Madenjian (1995), Bailey et al. 1999, Lozano 2004 (http://www.glerl.noaa.gov/res/Task_rpts/aislozano04-01.html
Prey fish diets	2004-2005	this study
Alewife and smelt biomass	1997-2005	OMNR/NYDEC Hydroacoustics
Energy density of pelagic prey and predator species	2003-2005	this study, USGS (unpublished)
Trout and salmon biomass	19??-2004	Bence et al. 2003, OMNR/NYDEC unpublished
Chinook consumption	2004-2005	this study
Alewife consumption	2004-2005	this study
Salmonid diets	1998-1999	Lantry 2001
Cormorant biomass, production, consumption rate and diet	2000-2004	OMNR unpublished

Table 3. Inventory of independent time-series of the relative abundance of biomass groups available for model calibration (1987-2003).

Lake Ontario food web component	**Years**	**References**
Total phosphorus, Chlorophyll-*a*	1995-2005	Cornell/NYDEC/USGS bio-monitoring program (see Hall et al. 2003), Ontario Ministry of the Environment (OMOE) nearshore water quality monitoring, Schelske 1991
Zooplankton biomass	1995-2005	Cornell/NYDEC/USGS biomonitoring program (see Hall et al. 2003)
Mysid biomass	1990, 2003-05	Independent time series may not available will need to use data from Table 1 and 2
Benthic community biomass		USGS unpublished
Prey fish abundance (smelt, alewife, sculpin)	1978-2005	USGS bottom trawl surveys (unpublished and O'Gorman et al. 2000, O'Gorman et al. 2004)
Salmon and trout abundance	1987-2005	Stocking records[2], OMNR/NYDEC/USGS unpublished index gillnetting , OMNR Ganaraska River fishway rainbow trout counts
Cormorants	1987-2005	Canadian Wildlife Service nest counts

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[2] Need to adjust for estimates of wild production and lag time from stocking to onset of piscivory

Data Management (Binational Repository and Web Presence)

Tim Johnson, Ontario Ministry of Natural Resources, Lake Ontario Fisheries Station

In preparing this white paper I visited several electronic data archives describing programs within the Great Lakes basin. An excellent template for what we are trying to accomplish for the 2008 Lake Ontario Intensive Year would be the NOAA-GLERL website for the International Field Year on Lake Erie (IFYLE) (http://www.glerl.noaa.gov/ifyle/). This website provides easy to find, publicly accessible information about the project as well as housing a password protected portal to the data archives. The interface (website) was developed with ColdFusion (http://www.adobe.com/products/coldfusion/), is hosted on an external server ($360/yr), and provides password protected links back to the GLERL ftp site where the data are archived. The data retrieval interface includes fields to allow the user to narrow their search to a specific data type – available fields (provided as pick lists) include vessel, cruise type, month, Julian day, station, data type, activity type, and operations log number. The results of this query draw from a table which in reality provides the reference (url) to the ftp site where the data is located. It is a simple, user friendly, and cost effective way to archive and provide access to the data. The user can view or download the data table to their local workstation for manipulation / analysis – there is no capacity to link data tables or query the data from the website as this would create tremendous complexity (slower access due to computational complexity), rigidity (trying to anticipate all the ways users might want to access the data), and cost (since data would now need to be archived with the interface on the external server). Three considerations in planning the site were: 1) what types of data and associated fields are needed (i.e. sample data sheets / data sets), 2) what the site would look like (contents and how it would be used by different users), and 3) data standards (naming conventions, format, structure of tables, etc. to minimize pre-upload manipulation). A person with some knowledge of ColdFusion could create the interface in “a couple of weeks”, and on-going maintenance is nil (since the server maintenance is handled by the owner of the server). New data is forwarded to a database technician to verify format and the information is uploaded upon receipt. I recommend everyone visit this site.

Data Management

Data management is possibly the most important concept that should be addressed before any study is undertaken. Large volumes of dissimilar information (character, document, image, etc.) collected by many different agencies must be stored in a single, secure, and easily (rapidly) accessible repository to ensure information can be integrated and analysed. With multiple users spread across a vast geographic and political climate (i.e. agency firewalls), having a single repository for all project data that permits fast and easy access for all project members is necessary. A password protected ftp site or web portal is the recommended format to address the multiple considerations of reliability, security, simple and rapid access, and standardisation. The site can be easily located (searched for and / or bookmarked) and readily accessed, but the data themselves remain protected (remote) so accidental or malicious corruption of the data is not of concern. Relational databases use key variables to link separate tables through a common identifier, facilitating rapid selection and retrieval of pertinent information. In contrast, a spreadsheet or flat file may contain a large number of fields (variables, columns of information) that are unnecessary to the current query (question, subset of information), and multiple spreadsheets containing different types of information (physical limnology, abundance of zooplankton data, contents of fish stomachs) necessitate considerable redundant information to permit future cross-referencing (i.e. relating fish diet to available zooplankton within a given temperature stratum or station). Further, databases can be constructed to contain lookup tables (pre-programmed lists of potential values) that minimise inconsistencies in naming (i.e. Chironomidae, chironomid, chironomids, midges, midge larvae, etc. all intended to describe the same taxonomic group). Cross referencing of information (data types) requires standardisation in documenting, collecting, and processing samples. International and regional standards regarding naming and protocols can be found at various websites (www.iso.org/iso/en/ISOOnline.frontpage, www.itis.usda.gov, etc.). Naming conventions for primary (key) variables that link data tables must be agreed upon *a priori* and should be sufficiently intuitive and descriptive both when recording at time of data capture, during processing, and at data retrieval. Components could include lake_name, vessel_name, year, Julian day, and activity type. Each of these components could be coded or abbreviated for example ON_LIM_07_183_ZOOP to describe a Limnos cruise on Lake Ontario on July 3, 2007 where zooplankton were collected.

Database development

We recommend a web-based project interface with password protected access to sensitive areas (data, correspondence, protocols) depending on need. Careful thought should be given to the purpose of the data management interface – is it to provide general information easily found and readily accessible to the public and media? is it to be the “single source” reference for the entire project (archives for protocols, contacts, historic data, as well as current data?. What is the expected life expectancy of the archive (leased vs owned server space, data format)? What sorts of information are to be housed in the archive (data tables, images, pdf / scanned documents, etc.) and how much capacity (server space) is anticipated. Knowing how the interface will be used will influence its design and development. For the data archive portion of the interface, it is valuable to have sample data sheets or past data to indicate the data types and fields (variable names) that need to be incorporated. *A priori* knowledge of the type of information to be stored will allow agreement on standardisation, minimizing the amount of post-collection audit and potential duplication or errant omission of data. A host agency and database manager must be identified early. All information to be uploaded to the interface / archives must go through this database manager to minimize risk of accidental corruption, duplication of records, etc. Pre-defined data formats and standards will require the source provider of the information to provide it to the database manager in the appropriate format, increasing accuracy (the collector knows their data best and can conduct all validation exercises before submission), and minimizing workload on the database manager. Responsibility for each data table (“owner”) should be clearly identified in the metadata so that corrections and questions can be directed to that individual. The owner is the only individual authorised to request changes to an existing data table. A database maintenance log, accessible to all authorised users, is strongly recommended so that a user can view the log to determine if any updates affect their current or previous analysis.

There is a large distinction between a searchable database and one that can be queried to extract subsets of data or link data from separate sources / data types (i.e. zooplankton net hauls + fish diets). We strongly recommend limiting the interface / archive to a data repository where users are given access to data files, but can not manipulate them. The user can easily download the data from one or more tables to their local workstation and then analyse them with their software of choice. Common fields (key variables) will allow the user to link tables during analysis. Building or allowing a user to construct a query within the database will substantially increase the database complexity (server space) and affect performance (run time). As such all data tables should be created and archived in a universally acceptable format. While text files (*.txt, *.csv, *.tab) are more compact, they are less user friendly than a spreadsheet such as Excel which now resides on virtually every desktop of all anticipated users. WE therefore recommend having the interface serve as a searchable directory, where each data table is an Excel spreadsheet conforming to standard naming, data type, units, and precision.

Security and Access

With many individuals and organisations contributing data and needing to access information an electronically accessible database is most appropriate. To protect against corruption, a single master database, maintained by a Database Manager is essential. Passwords will be used to limit access to various parts of the webpage and data archives. A publicly accessible interface can provide general information on the project, links to news / media items, lists of collaborators, etc. User specific passwords can restrict access to different areas of the archives depending on need. It should be reinforced that a user is only viewing a copy of the master dataset, and no user can edit, append, or delete any record or file online. The authorised user will copy the file(s) of interest to their workstation via remote ftp access where all manipulation and analysis occurs. The online archive is the only "official" version of the datasets, and the database manager will keep users informed of changes through a maintenance log. A master copy of the entire interface and datasets will be backed up and stored in a secure location (off line, off site) to protect against critical server failure.

Costs

Data archive costs fall into three areas: development, maintenance, and server. Costs have been estimated using the IFYLE project experience. Initial development of the interface is estimated at $3-5K (2-4 weeks programming time). After the initial development, the amount of time invested by the database manager is small (periodic programming changes to accommodate uploading data) and should be no more than 0.1 PY annually ($3-5K). Server space is expected to cost $1K or less per year.

Summary

- password protected website
- data archives available from secure, searchable list downloaded to local workstation in Excel format
- links to historic data, past reports, and essential publications
- archive to include all protocols and data dictionary (definitions for codes and abbreviations).
- capable of supporting multiple data types (character, pdf, image, etc.)
- 0.1 PY database manager responsible for all posting and maintenance.
- Individual responsibility for each data table; this "owner" is only person authorised to request changes from database manager
- database manager to maintain maintenance log to keep users aware of updates and changes.

New Techniques for Environmental and Lower Food Web Monitoring

Steve Lozano, NOAA-GLERL
Mohiuddin Munawar, Department of Fisheries and Oceans Canada

Bioassessment programs should undergo periodic evaluation, not only to reconsider modifications to historic sampling regimes, but also to determine the appropriateness of new technologies. Technological advances have the potential to enhance bioassessment programs by reducing sampling costs and providing new and/or more comprehensive data. Monitoring the physical, chemical, and biological condition of the Lake Ontario has traditionally been conducted by ship board surveys. Advances in remote sensing technologies and computer storage & computation offer opportunities to add new information and expand spatial and temporal observations of environmental and biological community condition. Several technological advances related to the assessment of lower food webs of freshwater ecosystems have been developing over the past two decades including optical plankton counters, hydroacoustics, fluorometry, FlowCAM imaging, and buoy systems.

I. Optical Plankton Counters (Peder Yurista and Jack Kelly, US EPA)

Optical plankton counters (OPC) is an operational instrument that detects, sizes, and counts individual particles based on measuring the reduction in intensity of a light beam intercepted by transmitting particles. In many lake surveys, the optical plankton counter is used to measure zooplankton biomass and size spectra. Additional sensors can be added to measure temperature, fluorescence, light transmittance, and conductivity. Together they provide a more detailed snapshot of patchiness in spatial distributions of plankton and can improve accuracy of biomass estimates compared to those of traditional net hauls. For example, the figure below (Figure 1) shows a partial optical plankton counter transect taken on June 14, 2003. The distribution of zooplankton biomass is uneven both vertically (a condition that would be masked by use of a traditional net haul) and horizontally (a condition that could be masked depending on the number and location of traditional net tows on any given transect. The use of an OPC gives a more accurate picture of true conditions. In many applications, OPC surveys are supplemented with net collection of zooplankton at discrete depths.

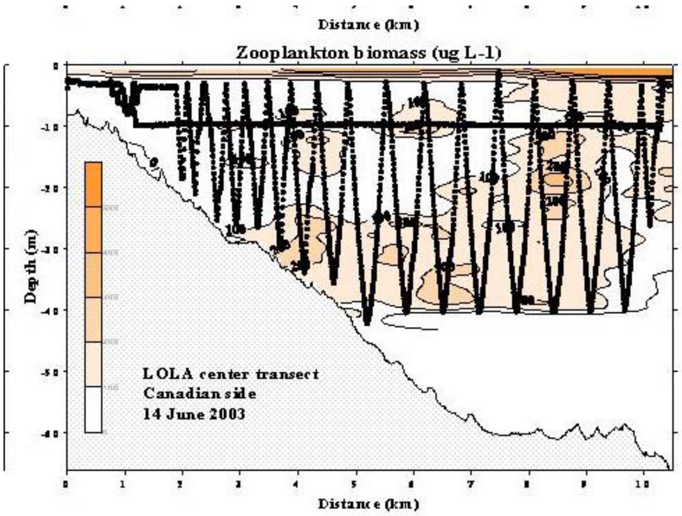


Figure 1. Optical Plankton Counter (contributed by Peder Yurista and Jack Kelly, US EPA Duluth)

Laser-Optical Plankton Counter (LOPC)

The Laser-Optical Plankton Counter (LOPC) is an optical plankton counter with an imaging capability. Particles that are passing through a laser light beam block the light falling on an array of sensors positioned perpendicular to the flow direction. For larger particles, cross-sectioned shapes (1.5-35 mm) can be resolved and automated classification algorithms can be applied to the shapes. The LOPC also has a higher processing speed and improved detection plane which provides detection counts at higher resolutions and higher concentrations with lower coincidence. Tow speeds are up to 12 knots.

Limitations

There is a question on the accuracy of the OPC in measuring zooplankton densities especially in turbid or productive waters. Several authors have measured the performance of the OPC in large lakes, estuaries, and oceans. Zhang et al. (2000) found that the OPC did produce accurate estimates of zooplankton biovolume after correcting for the influence of background detritus but accurate estimates of zooplankton abundance were only possible in water with detritus <100 particles l^{-1}. Liebig et al. (2006) found that the OPC overestimation of zooplankton biomass when compared to net zooplankton tows. Most overestimation of biomass was associated with the presence of non-zooplankton particles. In conclusion, worst agreement was seen in shallow nearshore zones during periods of high total suspended mater. Best agreement was found in low total suspended matter associated with offshore waters. Moore and Suthers (2006) found limited success using OPC measurements in three Australian estuaries with high concentrations of particles smaller than 250 μm.

Application:

Zooplankton biomass and size spectrum -other sensors include temperature, fluorescence, conductivity, light transmittance

Cost Estimate:

LOPC	$46,000
CTD	8,250
Fluorometer	3,000
Transmissometer	3,500
Flow meter	1,500

Processing time (OPC) can be streamlined provided the data structure needed/desired has been defined, metrics have been fully defined, and data templates constructed. Present processing is investigative to identify an appropriate analysis format and to identify useful versus peripheral data or metadata and more than might be needed for an assessment program. In general, under good conditions, one week of data processing is required for a season's worth of sampling to final analysis.

Groundtruthing: Transects are accompanied by plankton tows (153 um total water column or 63 um epilimnion).

Potential Use in Lake Ontario:

The OPC comparison in the 2003 LOLA study included both 64-µm and 153-µm nets. OPCs generally cannot detect zooplankton smaller than 250 µm, so the use of both mesh sizes in the comparison weakened conclusions since a large proportion of the plankton from the 64-µm hauls were smaller than 250 µm. We recommend using just the 153-µm nets, which sample many of the organisms detected by the OPC. In future studies, we recommend towing the nets at the same depth interval as the OPC.

II. Hydroacoustics (Lars Rudstam, Cornell University)

Hydroacoustic technology can been used to estimate fish, mysid, and zooplankton biomass. The primary application of hydroacoustics is for fish stock assessment. Fish biomass, numerical abundances, and mean sizes have been measured in diverse aquatic habitats. The use of hydroacoustics has several advantages over standard techniques. Large portions of the water column can be sampled quickly and detailed maps of fish densities and mean sizes can be obtained over large areas thereby alleviating some of the problems created by the spatial patchiness of fish distribution (Brandt 1996).

Currently, the Ontario Ministry of Natural Resources (OMNR) and NY Department of Environmental Conservation (NYDEC) conduct surveys of pelagic fish abundance along 7 transects and an area around Cape Vincent in the end of July or beginning of August. Frequencies used in the past include 420kHx and 120kHz. Currently, the survey uses a Biosonics Dt-X digital 120kHz split beam scientific echosounder. Concurrent with the acoustic surveys, the agencies collect midwater trawl samples targeting aggregations observed with acoustics, and do occasional temperature profiles.

Cost Estimate:

Estimates of current ship costs are US $2,000 per day, for a total of $20,000 (8 areas plus transportation time. The equipment is a one-time cost of 35-45K (either Biosonics or Simrad). Cost for software to analyze data varies. Both Biosonics and Simrad supply their units with a program package that can analyze fish density. Another software package (EchoView) is used by many of the agencies around the Great Lakes and cost 10K for fish and an additional 10K for multifrequency analysis. The software for multifrequency is presently at Cornell (Rudstam and Sullivan), USGS-Great Lakes lab in Ann Arbor (Warner) and is being purchased by DFO in Burlington (Koops and Doka). The fish analysis versions are available at NYSDEC (Region 8 and Lake Erie Unit) and OMNR (Glenora – Schaner and Port Dover – Witzel). Processing is time consuming and not automated at this point. For fish, we anticipate a processing time of at least 1 month. We do not know the time necessary for multifrequency analysis.

Limitations

There are several limitations to the use of hydroacoustics. The most severe limitation is that fish species cannot be identified directly (Brandt 1996). There are also restrictions on which parts of the habitat can be sampled. Fish at the surface and near the bottom 0.5 m of the water column cannot be easily detected. The maximum depth that fish can be detected is also limited.

Potential Expansion:

Schaner, Rudstam and Gal are funded by New York Sea Grant to develop the analysis techniques required to also assess mysids using the existing data collection. They are building on previous work by Gal et al. (1999). By constructing various thresholds, it is possible to remove most fish echoes from the data collected and estimate biomass of *Mysis relicta*. (Details may be obtained from Dr. Rudstam)

III. Fluorometry (Michael Twiss, Clarkson University)

Equipment & Application. Traditional methods to establish the health of a phytoplankton community require intensive water sampling efforts and labor-intensive sample analysis (phytoplankton identification, pigment analysis) and experimentation, e.g. use of light:dark dissolved oxygen method or radioactive carbon method to measure gross photosynthesis (Ostrom et al. 2005), and techniques establish photosynthetic efficiency. Recent advances in fluorometry enable aquatic scientists to establish qualitative and quantitative assessments of phytoplankton community composition (Gregor and Maršálek 2004) and photosynthesis (Smyth et al. 2004) in situ. The Great Rivers Center at Clarkson University possesses several instruments that are able to assess to map phytoplankton community composition and health of the community. Such tools are also being used by the Ontario Ministry of the Environment in Georgian Bay Monitoring (Todd Howell) and by the University of Waterloo (Ralph Smith).

Instrument/Platform	Description	Endpoint/Purpose
FluoroProbe, (bbe Moldaenke GmbH, Series 7) Fig. 3	Submersible fluorometer that uses several excitation wavelengths of light to simultaneously detect algal and cyanobacterial pigments	x_ Phytoplankton division pigment concentrations x_ Water temperature x_ Depth
Fast Repetition Rate Fluorometer (FRRF; Chelsea Instruments, Mk I)	Submersible fluorometer that uses light utilization by photosynthetic apparatus in phytoplankton	x_ Photosynthetic efficiency x_ Photosynthetically Active Radiation (PAR) x_ Primary productivity (photosynthesis)
Flow cytometer (Guava Tech., model PCA)	Analytical flow cytometer (to be purchased)	x_ Measure size and count phytoplankton and bacteria

Field fluorometer, (Turner Designs, model 10-AU)	Ruggedized instrument with flow-through cell	x_ Colored Dissolved Organic Matter (CDOM)
Field computer (Panasonic, CF-29)	Fully ruggedized computer	x_ Integrates water quality data from sensors with geographic positioning
R/V *Lavinia*	25’ Boston Whaler-Challenger, 2 × 150 HP, DGPS, 25 mile radar, marine radio, navigational software	x_ Stable research platform for coastal transects

Two sampling methods can be employed: (i) vertical sampling at fixed stations using FRRF and FluoroProbe, and (ii) horizontal sampling uses a towed fish at depth, trace metal clean pumping system, and Ferrybox with in line sampling (in a laminar flow hood) for discrete sampling. The Ferrybox is a 9 L chamber in which water collected during underway sampling is collected, and passed though the fluorometers. Data are collected at 3-30 seconds intervals. Spatial resolution is 0.5 km at a hull speed of 12 knots.

Cost Estimate: FluoroProbe, $35k; FRRF Mk I, $60k; flow cytometer, $40k; 10-AU, $20k; CF29, $5k. Operating costs are limited to replacement of sampling tubing, laminar flow hoods, ancillary chemical measurements, and cartridge filters.
Ship time requirements: We have used the R/V *Lake Guardian* and CCGS *Limnos* platforms on three lake wide transects in Lake Erie in 2005. A speed of 12 knots allows sampling at 1 m depth;
slower speeds will provide greater depth. An ideal sampling depth for the epilimnion would be 5 m.
R/V *Lavinia*: surface (0.4 m depth) sampling is possible at 20 knots. Vertical profiling is feasible
(100 m cable with FluoroProbe; autonomous sampling using FRRF); a heavier winch on the davit
would be required.

Goundtruthing: Two research cruises (June, September) were conducted on Lake Erie during 2005, as part of the International Field Year (IFYLE) – Lake Erie program. During these cruises, satellite imagery was collected and information of water quality was determined by G. Leshkevitch (NOAA GLERL). In July 2005, surface water transects were conducted in fluvial Lake St. Lawrence in conjunction with a fly-over by aircraft borne hyperspectral instruments. This information was collected in collaboration with A. Vodacek (RIT). Exercises in 2005 wait processing of data using light extinction parameters measured during each exercise.

Investigative surveys for Lake Ontario. This array of instruments will allow investigative mapping exercises to be conducted. These maps will increase our ability to visualize spatial and temporal changes in phytoplankton communities. Such investigative mapping will allow the detection of the onset and movement of phytoplankton blooms, including harmful algal blooms (HABS). In conjunction with measurements of physical (e.g. light penetration, thermal profile of the water column, currents), chemical (e.g. water color, nutrients), and biological (e.g.

zooplankton community, bacteria, viruses) parameters, this information can be used to decipher the dominant forces affecting phytoplankton community structures, health and productivity.

Full potential of this instrumentation can be realized from the use of a large stable platform (ship) on fixed transects and in a mode that will allow identified features, such as the apparent peak in cyanobacteria in the west basin of Lake Erie (Fig. 3b), to be followed or sampled at a higher degree of spatial resolution. A robust coastal vessel such as the R/V *Lavinia* can provide a low cost supplement for coastal transects. Seasonal lake-wide surveys are needed to assess seasonal changes on phytoplankton, sources of cyanobacterial blooms, and functional changes in community composition and health.

Figure 3a: Fluoroprobe.

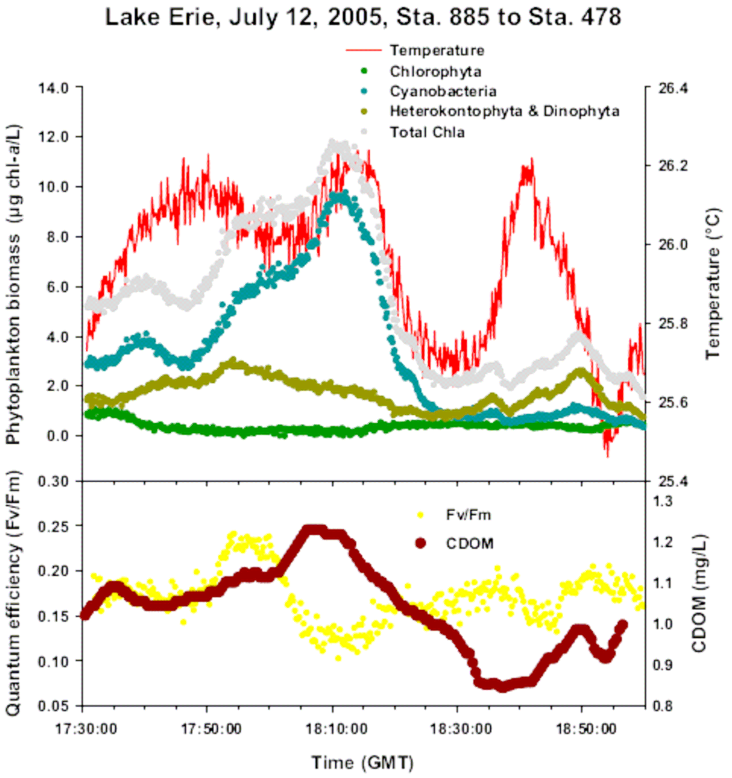


Figure 3b. Phytoplankton community composition, photosynthetic health, and water color along a 27.3 km transect that was sampled continuously from a depth of 1 m onboard the CCGS Limnos. The transect began offshore of Sandusky Bay (41° 31.156 N, 82° 38.884) to offshore of Put-in-Bay, South Bass Island (41° 39.578 N, 82° 48.993).

IV. FlowCAM II Fluid Imaging System (Mohiuddin Munawar, Fisheries and Oceans Canada)

Equipment:

The microbial and planktonic food web in aquatic ecosystems can be assessed using the state-of-the-art FlowCAM II fluid imaging system (Fig. 4a) which combines flow cytometry, microscopy, and imaging techniques to provide rapid imaging and recording of micro-particles in a fluid stream. The FlowCAM measures particle size, ESD, length, width, shape, fluorescence and other parameters; and records data in an interactive scattergram for instant display and analysis. The instrument captures detailed digital images of every particle sampled (2 – 2000 µm) while also providing an array of traditional particle analysis tools. Each particle image is automatically collected and stored in a digital library using pattern recognition software.

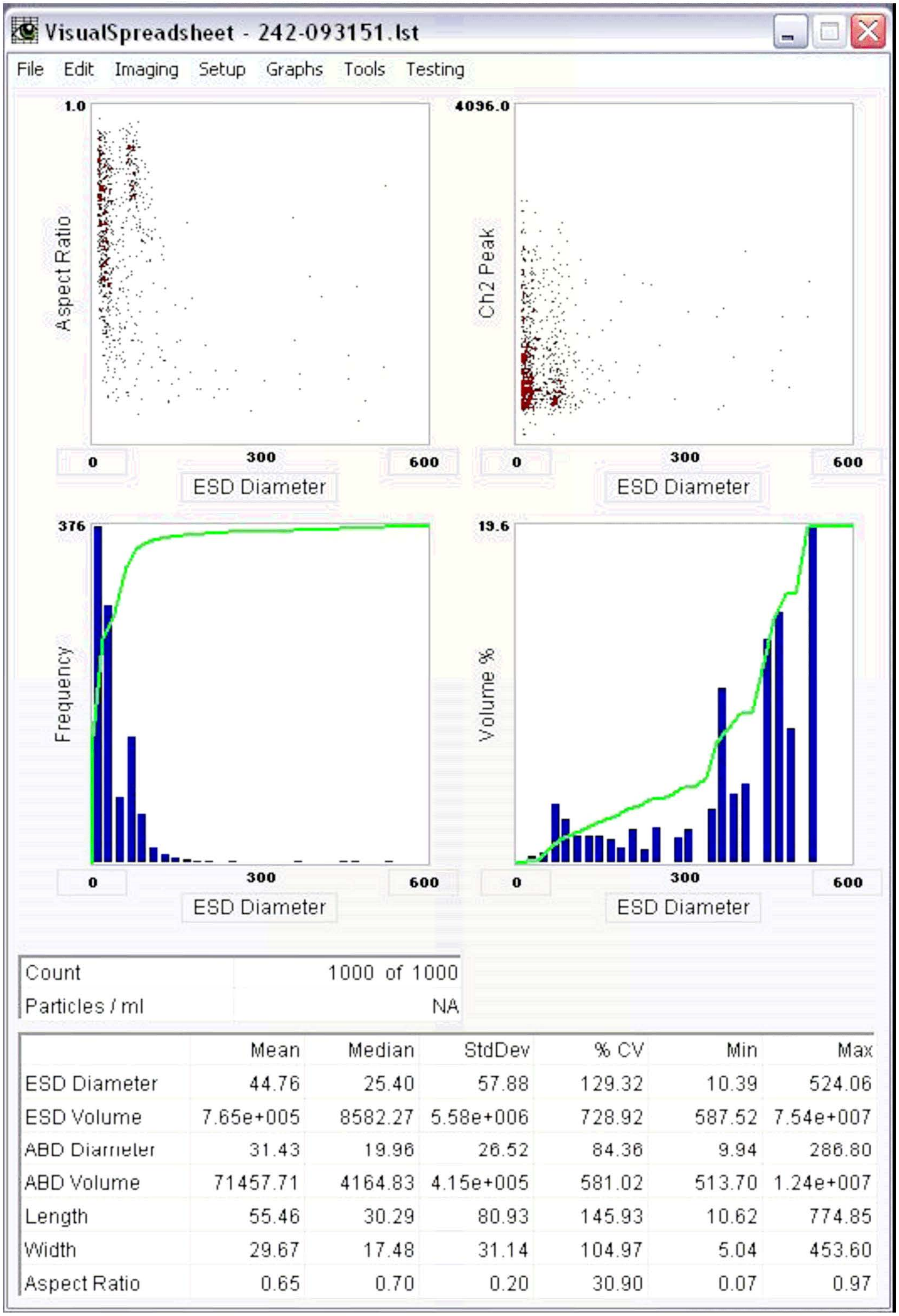
Application:

Although the use of FlowCAM is common in Europe especially in marine ecosystems, its use in the Great Lakes has just begun. The equipment is currently being tested by various institutions. The FlowCAM is being used at Laurentian University, Sudbury, ON (Dr. Ramacharan) and the Fisheries & Oceans Canada (GLLFAS). In the latter study, a preliminary assessment of the suitability of the FlowCAM for studying the planktonic communities of Hamilton Harbour, Ontario is compared with taxonomic – microscopic data during the summer of 2006 (Fig. 4b). In this study, Munawar et al. (unpubl.) showed that major taxonomic groups and particle size distributions could be identified rapidly. Although the preliminary results are promising for conducting crude assessments of dominant taxa, but a lot more effort may be required to identify species, if at all possible. The application of this tool is being explored for monitoring of algal blooms and ballast water samples for detecting alien species. The FlowCAM was also used in 2005 in Lake Erie by Peter Lavrentyev (University of Akron). Phytoplankton abundance, including cyanobacteria and eukaryotes, and microzooplankton (ciliates and rotifers) abundance and composition were measured along four nearshore-offshore transects.

Cost Estimate & Suitability:

This emerging technology requires further testing and evaluation against standard microscopic techniques for the enumeration of planktonic food web components to ensure that the quality of the phytoplankton database is maintained. The initial cost of $90 000 (US) would be offset in the long term by reducing the costs of individual sample analyses and the time required for sample processing and publishing results. This new technique has considerable potential in the planktonic surveys in the Great Lakes and would be an excellent tool to add to the battery of emerging techniques, however groundtruthing is required. Caution should be exercised in the use of FlowCAM in monitoring of aquatic ecosystems since the tool is not designed to replace authentic microscopic – taxonomic data which will always be needed as a standard.

Figure 4a: FlowCAM II fluid imaging system



Count	1000 of 1000
Particles / ml	NA

	Mean	Median	StdDev	% CV	Min	Max
ESD Diameter	44.76	25.40	57.88	129.32	10.39	524.06
ESD Volume	7.65e+005	8582.27	5.58e+006	728.92	587.52	7.54e+007
ABD Diameter	31.43	19.96	26.52	84.36	9.94	286.80
ABD Volume	71457.71	4164.83	4.15e+005	581.02	513.70	1.24e+007
Length	55.46	30.29	80.93	145.93	10.62	774.85
Width	29.67	17.48	31.14	104.97	5.04	453.60
Aspect Ratio	0.65	0.70	0.20	30.90	0.07	0.97

Figure 4b: Data collected from the >75 µm fraction of an offshore station in Hamilton Harbour. Total particle count and summary statistics for the entire run are included. (4X objective with 300 µm Flow Cell).

V. Buoy Systems (Jim Watkins, Cornell Biological Field Station)

Equipment & Application: Buoys are remote environmental observatories capable of providing real-time observations of chemical, biological, and physical parameters, even during extreme weather events. Data can be transmitted wirelessly from buoys to stations on shore, so that boats are only necessary for routine maintenance.

Planning new buoy monitoring systems in the Great Lakes falls under the jurisdiction of the Great Lakes Observing System (GLOS) program. This program is a regional branch of the Integrated Ocean Observing System (IOOS), a primary source for observation system research funds. The NOAA Great Lakes Environmental Research Laboratory (GLERL) is leading the development of a buoy observation network. Currently they have started demonstration projects using three buoys in Lake Erie in collaboration with the International Field Years on Lake Erie (IFYLE). There are also projects on Lake Huron at the Thunder Bay National Marine Sanctuary and on Lake Michigan collaborating with University of Wisconsin-Milwaukee.

These demonstration projects have considerably advanced buoy technology, sensor capability and communication. Design improvements have made buoys stronger, more stable, easier to maintain, and better able to run on solar power. Sensors for temperature, oxygen, chlorophyll a, PAR, turbidity, conductivity and currents (ADCP) have been tested successfully.

Data including high resolution images have been successfully relayed from buoys to shore based stations using wireless technology. None of these projects have been tested very far from shore. There are currently no long-term buoys on Lake Ontario with profiling capability. Environment Canada maintains meteorological buoys at Grimsby, West Lake Ontario, 16 Mile Creek, and Prince Edward Point. NOAA has a meteorological buoy 20 nm NNE of Rochester NY. These stations measure surface water temperature, wind speed and direction, and wave height. The National Water Research Institute (NWRI) of Canada has a field program which set up seasonal transects of current meter and thermistor moorings offshore of Toronto (Yerubandi Rao).

Cost Estimate: Buoy costs can easily exceed $300,000 per buoy (with instruments installed for profiling capability). Another configuration includes a “base station” buoy ($500,000) surrounded by lower cost buoys ($50,000). Data processing and buoy maintenance are not included. Existing National Data Buoy Center (NDBC) meteorological buoys cost $165,000 for the first year of operation (including purchase, installation, and equipment) and $36,000 per year to operate and maintain. A GLERL buoy system with ADCP, CTD, and meteorological station could be built and deployed for under $150,000.

Suitability: GLOS intends to improve existing buoys and deploy 3-4 new ones per lake over the 2007-2011 time period. IOOS intends to provide funding to support Great Lakes open water observing starting in 2007 on a seven year timeline. It is not currently clear when or where the buoys for Lake Ontario would be.
Key questions are-

-where would the buoys be?
-which institution(s) would provide support as collaborator with GLERL?
    maintenance, data download processing, scientific goals
-what sensors would be included?

VI. Remote Sensing (Ricky Becker, Western Michigan University)

Equipment & Application: Remote sensing technology can provide lake-wide coverage of surface temperature, lake color (chlorophyll), and whiting (calcium carbonate precipitation) events. Satellite imagery provides a temperature regime context for LOLA 2003 sampling (see images at bottom of page). There are a suite of satellite sensors which provide data for Lake Ontario on a daily or more frequent basis. These include: the MODIS instrument on the Aqua and Terra platforms, the SeaWiFS sensor on the Orbview -2 platform, the NOAA AVHRR sensor on POES (polar orbiting), imager on GOES (geostationary) satellites, and TMI on the TRMM platform. All of these have a resolution of $1km^2$ pixels, or larger. In addition to these, Landsat TM/ETM has a much higher spatial resolution (30m pixel spacing), but only a 14 day repeat cycle, and cannot cover the entire lake at one time. The ESA sensor MERIS also has good potential for being used for ocean color parameters, as it has 300m pixels, and improved spectral resolution.

Visible – near infra-red sensors (used for ocean color parameters) include: MODIS on Aqua and Terra - these images are available once per day for each satellite, and SeaWifs – available once per day. MODIS and SeaWifs have a nominal resolution of $1km^2$ at full resolution.
Thermal data sets (for SST) include: Aqua and Terra (2 times each per day total), AVHRR (roughly 8 times per day), GOES imager (every 3 hours), and TMI is available once per day. These products have spatial resolutions ranging from 1km to 6km on a side.

Most of these datasets are available at no cost shortly after acquisition from the NASA Oceancolor website: http://oceancolor.gsfc.nasa.gov and NOAA Coastwatch website: http://coastwatch.noaa.gov. Delayed-mode, low resolution SeaWiFS data is available through the NASA oceancolor website to authorized users, as well as historical full resolution data (pre Dec. 2004). Full resolution data can be acquired through separate agreements with Orbview. MERIS data is only obtainable through the ESA, as part of a cat-1 proposal through their website: http://eopi.esa.int/esa/esa.
Cloud cover can obscure a significant portion of or all data for indefinite periods (frequently 1-7 days).

NASA and the NOAA Coast Watch have developed software programs such as CDAT for displaying coast watch images and SeaDAS for displaying and analyzing MODIS and SEAWIFS temperature and color data. These programs are free and available on the web. Cruise data can be compared to satellite data easily using SeaDAS for both temperature and chlorophyll *a*.

Groundtruthing. Surface temperature images are accurate to 1.5°C RMS, with a bias ranging from
0.2 to 1.0°C (Li et al. 2001; Schwab et al. 1999). Upwelling events, thermal bars, and stratification are clear features. The thermal bar's influence on nearshore/offshore chlorophyll *a* gradients is evident in lake color.

The standard chlorophyll *a* algorithms used for MODIS and SeaWiFS data were derived from, and works well for non-polar Case I (open ocean) waters (Gregg and Casey, 2004; O'Reilly et al., 1998). They are still very useful in showing chlorophyll distribution, but are less accurate when used for the more optically complex Case II (inland and coastal waters), where they tend to overestimate the concentration of chlorophyll *a* in areas dominated by inorganic sediments (Lavender et al., 2004). Several models have been used to overcome this for case II waters. These include an algorithm developed by Carder et al. included in SeaDAS (Carder et al., 1999). This semi-analytic model has been found to improve the accuracy of estimates of the chlorophyll *a* concentrations in Lake Erie and Lake Ontario based on a limited data set acquired in the summer of 2004 (Becker et al., 2005). This is currently being expanded to include data acquired from cruises in 2005. In addition, a biooptical model has been developed specifically for Lake Ontario (Bukata et al., 1991; Bukata et al., 2001), and compares favorably with the in-situ data.

Suitability:

How do we incorporate this technology into a real time monitoring system?
We can design a web based GIS interface (ArcIMS or an open standard interface)

- images to provide context
- updated automatically from NASA, NOAA ftp data pulls
- links to station data
- ability to extract data either spatially or temporally
- add calculated indices such as
  - average lake wide temperature
  - average lake wide chlorophyll *a*
- make line graphs of these parameters over season
- upwelling indices (areal coverage)
- whiting alerts
- harmful algal bloom alerts

The spring cruise on the *Limnos* was from April 28 to April 30, 2003. At this time there was little surface temperature variability, and the water column was completely mixed. The lake was isothermal until June 1, when a thermal bar formed (warming and stratification nearshore) and was maintained for the month of June. Upwelling developed on the NW coast during the entire month of July, but a warm lake-wide epilimnion was set up by August 1. The summer Lake Guardian cruise in western Lake Ontario was August 10-11. The summer *Limnos* cruise was August 19-21. The stable epilimnion was existent throughout this period. The fall *Lake Guardian* cruise was September 19-26. By August 27 upwelling had developed on the NW coast from strong winds from the west. By September 9, the winds had shifted to coming from the east and localized upwelling developed on the south coast. On September 18-20, the passage of a storm system related to Hurricane Isabel passed over the Great Lakes. On September 19, sustained winds of 65 km/hr with gusts to 80 km/hr were reported. This wind event intensified upwelling on the south shore.

VII. Hydrography (Jim Watkins, Cornell Biological Field Station)

The EPA *Lake Guardian* has collected hundreds of hydrographical profiles in the Great Lakes over the past 10 years. These include data for temperature, fluorescence, oxygen, light transmittance (particle concentration), ph, conductivity, and PAR. This data collection has the potential to reveal a considerable amount on the status of Lake Ontario. It could potentially document subtle changes (e.g. changes of water temperature <1C is often significant) over time to pinpoint effects of climate change or oligotrophication. There is a need to access this information in an easy, interactive platform.

We have such data for the entire lake in September and only western Lake Ontario for August 10-11. The April and August cruises on the Limnos only have temperature data. We have put this data (and an EPA data set from 1994) into a data viewing software named Ocean Data View. This freely distributed software program is a good way to organize and plot hydrography data. Its usefulness includes property-property plots and sections.

VIII. Evaluation

The application of new technologies to the **Lake Ontario 2008 Intensive Sampling/Monitoring Year** will enhance but not replace the spatial and temporal coverage of lower trophic level condition and interactions as compared to traditional ship board methods. Based on the goals and objectives of the study, a suitable sampling design will be established. At this time, it would be important to determine which of the new techniques would enhance the ecological assessment.

To enhance the spatial coverage, the optical plankton counter, fish acoustics, and fluorometry/FlowCAM could be used on the same ship. This design was used in several previous studies. A buoy system (1-??) could be established at key locations to provide continuous in lake measurements. Finally, remote sensing can provide lake-wide coverage from spring to fall.

Important questions remain:

1. Costs: Can we form partnerships and use Great Lakes equipment that has already been bought. Are there personnel available for collection and analysis of the data?
2. Sampling design: Will the equipment and personnel be available for seasonal studies?
3. How can we maximize the return between ship board sampling and remote sensing?
4. Can we leverage other agencies to provide logistical and financial support?
5. Other issues….?

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