

2004 Status of the Lake Ontario Ecosystem: A Biomonitoring Approach

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Introduction

The Great Lakes and Lake Ontario ecosystems have been subject to accelerated ecological change since the 1950s. These ecosystems experienced (in the 1950s and 1960s) numerous stresses including overfishing, cultural eutrophication, and contaminant discharge yielding degradation of water quality, loss of habitat, and the depreciation of fish communities. Such stresses raised public concern about the condition of the Great Lakes and led to a new period of environmental awareness and restoration in the 1970s, 1980s, and 1990s. The historic Great Lakes Water Quality Agreement (GLWQA) between the United States and Canada in 1972, later revised in 1978 and 1987 (IJC 1988), marked a new era of ecosystem management and initiated a process we term oligotrophication (reverse of eutrophication). In Lake Ontario, for example, phosphorus levels have declined over the past 20 years, but this event has come at a time when demands for a salmonid sport fishery have increased, non-native species such as the alewife have exhibited highly variable population dynamics, pelagic zooplankton production has declined, oligotrophic fish stocks are recovering,

and exotics such as the zebra mussel, quagga mussel and currently the predatory cladoceran *Cercopagis pengoi* have proliferated (Christie *et al.* 1987, EPA 1993, Mills *et al.* 2003). Clearly, Lake Ontario is an ecosystem in transition, and the public’s interest in and awareness of the Lake Ontario environment continues to increase. It is incumbent upon the scientific and management communities to understand these ecosystem changes and their implications for the life support system of this important freshwater resource.

One approach toward assessing a lake ecosystem in transition like Lake Ontario is to develop a database of key indicators that reflect ecosystem change. From 1995-2004, we have conducted a biomonitoring program in Lake Ontario that has indexed some of the primary indicators of ecosystem health as identified by the Lake Ontario Pelagic Community Health Committee (EPA 1993). The primary objective of the research was to evaluate the indexing variables of total phosphorus (TP), soluble reactive phosphorus (SRP), chlorophyll *a* (Chl *a*), Secchi depth, and crustacean zooplankton (density, biomass, size structure) (1) spatially and

temporally, and (2) in critical habitats including embayments, the nearshore, and the offshore pelagia. The biomonitoring approach we describe has been successfully accomplished through interagency support of the New York State Department of Environmental Conservation (NYSDEC) including regional staffs at Watertown, Cortland, and Avon, the U.S. Fish & Wildlife Service, the Ontario Ministry of Natural Resources (OMNR), the U.S. Geological Survey – Great Lakes Science Center, and Cornell University. The program has also allowed us to (1) provide a benchmark for comparison to evaluate changes in the lower food web of Lake Ontario, and (2) link with closely allied programs such as current Sea Grant projects assessing changes in Lake Ontario's mysid population, and the benthification of Great Lakes ecosystems. The biomonitoring variables we have chosen to examine contribute to research on Lake Ontario's coastal areas and embayments which are crucial to understanding the coupling between ontogenetic patterns of habitat utilization and whole-lake predator-prey interactions, and for understanding the role of inshore habitats in food web dynamics.

Report Objectives

In 2004, we measured total phosphorus (TP), soluble reactive phosphorus (SRP), chlorophyll *a* (Chl *a*), water temperature, Secchi depth, zooplankton density, zooplankton size, and zooplankton biomass. With these data, we investigated the following questions:

- (1) *Embayment - Nearshore - Offshore Comparisons*: Do biomonitoring variables vary between embayment, nearshore, and offshore habitats?
- (2) *East-West Comparisons*: Do biomonitoring variables vary from east to west in nearshore and offshore habitats?
- (3) *Seasonal and Year-to-Year Variability in Embayment and Nearshore Habitats*: Do biomonitoring variables in embayment and nearshore habitats differ significantly throughout the season? Do trends vary between embayments and nearshore habitats from year-to-year?

(4) *Relationships of Variables*: Are any biomonitoring parameters related to each other?

(5) *Zooplankton Community Dynamics*: Does the biomass of major zooplankton groups differ between embayment, nearshore, and offshore habitats? Do trends vary seasonally between embayments and nearshore habitats? Does zooplankton community structure suggest a healthy balance between predatory and prey fish?

(6) *Cercopagis pengoi*: How was *C. pengoi* distributed lakewide during mid-summer to fall? Are there any trends in spatial distribution? Has *C. pengoi* had any major effects on the zooplankton community?

Methods

Sampling

The R/V's Kaho and Seth Green collected offshore water and zooplankton samples during the 2004 season. All samples collected in water equal to or deeper than 25m (82 ft) were considered offshore for habitat comparisons. Offshore sampling totaled 34 samples taken on 23 dates. Between July 12 and August 11, 17 offshore samples were collected on 12 dates.

Water and zooplankton samples, as well as water temperature and Secchi depth data, were collected from seven nearshore and three embayment sites during the May to October sampling season. The eastern nearshore sampling locations (Galloo Island Lake, Chaumont Bay Lake, Sandy Pond Lake, and Sodus Bay Lake), and western nearshore locations (Niagara River East Lake, Niagara River West Lake, and Oak Orchard Lake), along with the three eastern embayment sampling sites (Chaumont Bay, Sandy Pond Bay, and Sodus Bay) were sampled biweekly. Figure 1 shows a map of sampling locations.

Water Chemistry

In 2004, water samples were collected for analysis of chlorophyll *a* (Chl *a*) and two phosphorus fractions: total phosphorus (TP) and soluble reactive phosphorus (SRP). Each sample was obtained by using an integrated water sampler (1.9 cm inside diameter Nalgene

tubing) lowered to a depth of 10m (32.8 m). The tube was then closed off at the surface end and the column of water transferred to 2L Nalgene containers. From each sample a 100mL unfiltered aliquot sample was frozen for later analysis of TP (Menzel and Corwin 1965). We also filtered 1-2L of water through a Whatman 934-AH glass fiber filter that was frozen for later analysis of Chl *a* using the standard acetone extraction method (Strickland and Parsons 1972). A 100mL sample of filtered water was also frozen for later analysis of SRP (Strickland and Parsons 1972).

Quality Assurance - Quality Control

In 2004, Quality Assurance and Quality Control (QAQC) analyses were conducted for TP and SRP. Water samples were collected from embayment and nearshore habitats using the standard sampling methods.

In July, 10 aliquots of raw water were taken from one sample for TP analysis. An additional 10 aliquots of filtered water were taken from the same sample for SRP analysis. One subset of these samples was analyzed at CBFS; another subset was analyzed at the Upstate Freshwater Institute (UFI), an EPA certified laboratory located in Syracuse, NY, for comparison with CBFS results. In the event that significant differences ($p < 0.05$) arose between CBFS and UFI laboratory results, an adjustment equation would have been generated and applied to CBFS results (TP and/or SRP) in order to account for those discrepancies. The adjustment equation is a regression equation that adjusts the CBFS data in relation to the UFI data. In 2004 CBFS and UFI results exhibited no significant difference in TP analysis. Identified contamination issues precluded the use of UFI data for SRP adjustment. As a result, there was no adjustment of the regression equation in either set of data.

In 2004, we also conducted replicate sampling for analyses of TP, SRP, and Chl *a*. Three different samples (triplicates) were collected at each nearshore and embayment location twice in August. From each of the three samples, one aliquot was taken for TP, one for SRP, and one for Chl *a* analysis. The samples were analyzed

at CBFS to determine the amount of variability between samples.

Zooplankton

We measured several zooplankton parameters: total density (#/L), size (mm), and biomass ($\mu\text{g/L}$), as well as *C. pengoi* biomass and total biomass (expressed as proportion of total) of five subgroups of zooplankton. Zooplankton samples were collected with a standard 0.5m diameter, 153 μm mesh nylon net. At most embayment and nearshore sites, we strained a 10m water column. At offshore sites, we sampled a 6-40m (19.7 to 131.2 ft) water column. The samples were anesthetized using antacid tablets, then preserved in the field with 95% ethyl alcohol. Single samples were collected on a biweekly basis at embayment and nearshore sites from May to October, except for July and August when two replicate samples were collected per site on each date.

In the CBFS laboratory, each sample was strained through a 1.02mm mesh cup to separate *C. pengoi* and other larger organisms (>1mm in length) from smaller zooplankton (<1mm). This was done because *C. pengoi* form clumps in the sample, making the usual random subsampling of 1mL samples inappropriate. For each sample that contained clumps of *C. pengoi*, two analyses were performed, one on the smaller zooplankton and one on the larger zooplankton (including *C. pengoi*) that were caught in the 1mm mesh strainer. The larger zooplankton were measured and enumerated by subsampling at least 100 organisms from a gridded, numbered petri dish in which the sample had been homogeneously separated and mixed.

The subsample was examined through a compound microscope at 10-40X magnification. Images from the sample were projected onto a digitizing tablet that was interfaced with a computer. The zooplankton were measured using the digitizing tablet and identified to species, excluding nauplii and copepodites (Pennak 1978, Balcer *et al.* 1984). To calculate the total number of large crustaceans and *C. pengoi* in the clumped part of the sample, we used a ratio of wet weights of the subsample to wet weights of the total sample. Wet weights were determined using a Sartorius balance. For

the smaller sized zooplankton samples, we counted and measured at least 100 organisms from one or more 1mL random subsamples using the same microscope and digitizer technique. [In earlier years of this project an electronic touch screen (1995-1997) and a 20X microprojector (1998-2000) were used for measuring the zooplankton (Hambright and Friedman 1994).]

We used length:dry-weight regression equations (CBFS unpublished data) to estimate zooplankton biomass. Biomass of *C. pengoi* was estimated in two different ways. Nearshore samples were analyzed using a regression based on fresh specimens (which suffered no distortion from preservation). This regression is $\ln W = 1.7164 + 2.3703 \ln L$. Offshore samples were analyzed using a length:dry-weight regression that compensates for biomass loss due to preservation. This regression is based on the original regression used in 1998 but increases the estimated weight by 42% to compensate for biomass loss due to preservation (Giguere *et al.* 1989). This regression is $\ln W = 1.3690 + 2.7686 \ln L$.

Data Analyses

We employed the following analyses to address the above objectives:

(1) Spatial Variability:

For each of the eight embayment and nearshore study parameters (TP, SRP, Chl *a*, water temperature, Secchi depth, zooplankton density, size, and biomass), we compared the biweekly averages between the two habitats using a paired two-sample t-test for means. For the comparisons between offshore, nearshore, and embayment habitats, we examined each of seven study parameters (TP, SRP, Chl *a*, water temperature, zooplankton density, size, and biomass) with two-sample t-tests assuming unequal variances. These pairwise comparisons were made with data that was collected during the same sampling period. Zooplankton density and biomass were log transformed, and each zooplankton relationship was considered significant following the Bonferroni adjusted $\alpha=0.0167$ ($p<0.0167$). Each chemical / physical

relationship was considered significant at $p<0.05$.

(2) East-West Comparisons: Nearshore east-west comparisons were made for the eight study parameters (TP, SRP, Chl *a*, Secchi depth, water temperature, zooplankton density, size, and biomass). Comparisons were made between eastern sites (Galloo Island Lake, Chaumont Bay Lake, Sodus Lake, Sandy Pond Lake) and western sites (Niagara East Lake, Niagara West Lake, Oak Orchard Lake) using the biweekly data from May - October. We employed paired t-tests with untransformed (TP, SRP, Chl *a*, Secchi depth, water temperature, zooplankton size) and log (x+1) transformed (zooplankton density and biomass) mean biweekly values to test for east-west differences. We considered each relationship significant for two-tailed tests at $p<0.05$.

East-west differences between offshore sites were examined for seven study parameters (TP, SRP, Chl *a*, water temperature, zooplankton density, size, and biomass). Offshore sites included all samples taken from sites with water depths of at least 25m (82 ft). The east-west dividing line was 77.8° W longitude (Figure 1). T-tests assuming unequal variance were used to determine the degree of difference of log-transformed (zooplankton density and biomass) and untransformed TP, SRP, Chl *a*, water temperature and zooplankton size data. Water chemistry and zooplankton comparisons were made with mid-July to mid-August data. Each relationship was considered significant for two-tailed tests at $p<0.05$.

(3) Seasonal and Year-to-Year Variability in Embayment and Nearshore Habitats:

We examined eight study parameters (TP, SRP, Chl *a*, Secchi depth, water temperature, zooplankton density, size, and biomass) for seasonal differences in both embayment and nearshore habitats. Year-to-year differences for TP, SRP, Chl *a*, Secchi depth, and water temperature were tested using a paired two sample t-test comparing 2003 and 2004 biweekly average data. We considered each relationship significant for two-tailed t-tests at $p<0.05$.

(4) *Relationships of Variables:*

We investigated several biomonitoring parameters for potential relationships. We examined the influence of TP, SRP, and water temperature on Chl *a* using linear regression analysis (Zar 1984) with untransformed data.

(5) *Zooplankton Community Dynamics:*

We divided zooplankton into the following six groups: daphnids (*Daphnia mendotae*, *D. pulicaria*, *D. retrocurva*, *D. schodleri*); bosminids (*Bosmina longirostris*, *Eubosmina coregoni*); calanoid copepods (*Diaptomus minutus*, *D. oregonensis*, *D. sicilis*, *D. ashlandi*, *D. siciloides*, *Epischura lacustris*, *Eurytemora affinis*, *Limnocalanus macrurus*); cyclopoid copepods (*Acanthocyclops vernalis*, *Diacyclops thomasi*, *Eucyclops sp.*, *Mesocyclops edax*, *Tropocyclops prasinus*); "other" cladocera (*Ceriodaphnia quadrilangula*, *Chydorus sphaericus*, *Leptodora kindtii*, *Diaphanosoma sp.*, *Alona sp.*, *Holopedium gibberum*, *Polyphemus pediculus*, *Bythotrephes longimanus* (formerly *cederstroemi*), *Sida crystallina*); and *Cercopagis pengoi*. We compared average biweekly biomass proportions of each group between embayment and nearshore habitats using a paired t-test to determine differences in community composition between these areas. In addition, we compared the biomass of each group between mid-July and mid-August using t-tests assuming unequal variance on log (x+1) transformed data for embayment, nearshore, and offshore (water depth of 25m or more) areas.

(6) *Cercopagis pengoi:*

The offshore samples collected between mid-July and mid-August by the Kaho and Seth Green provided a comprehensive view of spatial distributions of *C. pengoi* in 2004. For this time period, offshore (water depth of 25m or more) data were analyzed using t-tests assuming unequal variance on log (x+1) transformed *C. pengoi* density and biomass to assess east-west differences in spatial distribution. In addition, log (x+1) transformed mean biweekly values of *C. pengoi* density and biomass were analyzed using paired t-tests to look for an east-west difference among nearshore sites. Comparisons of *C. pengoi* density, average size, and biomass in offshore, nearshore, and embayment habitats

were performed using t-tests assuming unequal variance for the following pairs of sampling periods: August 1998 and August 1999, August 1999 and late July 2000, late July 2000 and August 2001, August 2001 and 2002, August 2002 and July 2003, and July 2003 and mid-July to mid-August 2004. Finally, we compared average densities of *Bosmina longirostris* in the summer sampling period over the nine years of this biomonitoring project (1995-2004) to further assess changes in community structure.

Results

QAQC

In 2004, QAQC analyses were conducted for July TP and SRP samples. In the comparison of QAQC samples analyzed at CBFS with those at Upstate Freshwater Institute (UFI), reported TP values were not significantly different ($p > 0.8$) and thus did not require the use of an adjustment equation. SRP QAQC samples showed significant difference ($p < 0.001$) between those analyzed at CBFS and those from UFI, however, contamination issues identified in the UFI run samples precluded the use of this data for adjusting the regression equation.

The analysis of August TP, SRP, and Chl *a* triplicate samples yielded slightly less than half of the samples as having a coefficient of variance (CV) less than the predetermined acceptance level of 10%. Approximately 50% of the Chl *a* triplicate samples were found to have a CV greater than 10%. The triplicate samples which were found to have a CV greater than 10% were deemed acceptable due to: (1) the low levels of TP, SRP, and Chl *a* detected in Lake Ontario, and (2) the minimal range of resulting values and corresponding standard errors within a given set of triplicate samples. Consequently, we pooled triplicate samples for each August replicate sampling effort and reported an average value for each TP, SRP, and Chl *a*, concluding that a single sample adequately reflects the conditions at the time of sampling throughout the entire field season.

Embayment-Nearshore-Offshore Comparisons:
In 2004 we observed several significant spatial differences between embayment, nearshore, and offshore habitats.

Embayment-Nearshore Comparisons of Secchi depth, Chl a, TP, SRP, and water temperature:

Water clarity measured using a Secchi disc was consistently greater in nearshore areas than in embayment sites, similar to the 2003 trend. The May through October average Secchi depth for embayments (3.5m or 11.5 ft) was significantly shallower ($p < 0.005$) than the nearshore habitat average of 6.5m (Figure 2). Mean biweekly values of SRP ($p < 0.009$) and TP ($p < 0.001$) were significantly higher in embayments than in nearshore habitats. Average embayment Chl a concentrations (7.9 $\mu\text{g/L}$) were approximately four times greater than in the nearshore habitats (1.9 $\mu\text{g/L}$) (Figure 3A). Embayment TP and SRP concentrations averaged 18.5 $\mu\text{g/L}$ and 3.8 $\mu\text{g/L}$, respectively, which were greater than average nearshore values of TP (9.1 $\mu\text{g/L}$) and SRP (2.8 $\mu\text{g/L}$) (Figures 3B&4A). Water temperatures averaged 19.2°C (66.6°F) in embayments and 17.1°C (62.8°F) in nearshore habitats (Figure 4B).

Embayment-Nearshore-Offshore Comparisons of July Chl a, TP, SRP and water temperature:

The average Chl a, TP, SRP, and water temperature of the embayment, nearshore, and offshore (collected by R/V Kaho) sites for mid-July to mid-August are noted below and in Table 1. The average Chl a concentration for offshore samples was 1.4 $\mu\text{g/L}$, compared to 8.3 $\mu\text{g/L}$ for the embayment, and 2.6 $\mu\text{g/L}$ for the nearshore sites. Average TP concentrations were 8.4 $\mu\text{g/L}$ (offshore), 16.7 $\mu\text{g/L}$ (embayment), and 10.9 $\mu\text{g/L}$ (nearshore). Offshore and nearshore SRP averaged 2.2 $\mu\text{g/L}$, whereas the average for embayments was 3.3 $\mu\text{g/L}$. Water temperature for the offshore averaged 15.3°C (59.5°F) while the nearshore average water temperature was 19.8°C (67.6°F) compared to 22.3°C (72.1°F) for embayments.

Zooplankton Embayment – Nearshore - Offshore Comparisons: In 2004 we found May through October zooplankton density ($p < 0.001$) and biomass ($p < 0.001$) to be significantly greater in

embayments (95.3/L and 150.1 $\mu\text{g/L}$ respectively) than in nearshore sites (33.1/L and 59.9 $\mu\text{g/L}$ respectively) (Table 2, Figure 5). Average size of zooplankton was not significantly different in embayment sites (0.49mm) than in nearshore sites (0.54mm) (Table 2, Figure 5).

During mid-July to mid-August, the average embayment zooplankton density and biomass (110.7/L and 217.7 $\mu\text{g/L}$, respectively) were not significantly different than the density (53.1/L) and biomass (93.1 $\mu\text{g/L}$) of nearshore samples. The average zooplankton size (0.55mm) in embayment sites was significantly ($p < 0.0004$) less than the average size in offshore samples (0.74mm). The average size of zooplankton in offshore samples was significantly greater ($p < 0.004$) than the average size (0.60mm) in nearshore samples. Zooplankton density and biomass in offshore samples were not significantly different than density and biomass in nearshore samples (Table 3).

East - West Comparisons

In addition to comparing spatial differences between embayment, nearshore, and offshore habitats, we compared biomonitoring variables between the nearshore sites of the eastern and western halves of Lake Ontario. We also compared the eastern vs. western halves of the offshore habitats in Lake Ontario.

East-West Nearshore Comparisons of Secchi depth, Chl a, TP, SRP and water temperature:

East-West nearshore comparisons were made using data from May through mid-October. Mean Secchi depth was found to differ significantly ($p < 0.001$) between eastern and western sampling sites in 2004. Western nearshore Secchi depths averaged 4.4m, while eastern nearshore Secchi depths averaged 7.4m (Figure 6D). No significant differences were observed in Chl a, TP, SRP, or water temperature from east to west. This pattern is similar to that seen in 2003 (Table 4). The average Chl a concentrations were 2.0 $\mu\text{g/L}$ in the east nearshore sites and 1.9 $\mu\text{g/L}$ in the western nearshore sites. Average TP concentrations were 10.3 $\mu\text{g/L}$ in the east and 8.0 $\mu\text{g/L}$ in the west. Eastern nearshore SRP

concentrations averaged 2.7µg/L and western sites averaged 2.8 µg/L. Mean water temperature for the eastern nearshore was 17.0°C (62.6°C) and 18.7°C (65.7°F) for the western sites.

East-West, North-South Offshore Comparisons of Chl a, TP, SRP, and water temperature:

The comparisons of the offshore biomonitoring study parameters from north to south and east to west yielded no significant differences.

East-West Nearshore Zooplankton Comparisons:

No significant differences were found between eastern and western halves of Lake Ontario for average size, density, and biomass of zooplankton, or for the density and biomass of *Cercopagis pengoi*. Although there were no significant differences found between the east and west, each zooplankton parameter was to some degree greater in the west than the east of Lake Ontario, and *Cercopagis* density and biomass were generally greater in the east than the west (Table 5). Each of these trends runs opposite to those observed in 2003.

East-West Offshore Zooplankton Comparisons:

In the mid-July to mid-August east-west comparison for offshore sampling stations, average size was significantly greater in western samples. Mean density was similar at eastern and western sites. Mean biomass was generally greater in the west than the east, although the difference was statistically insignificant (Table 6). *Cercopagis pengoi* density was insignificantly higher in the east than in the west, and *C. pengoi* biomass was insignificantly higher in the east (Table 6, Figures 7, 8 & 9).

Seasonal and Year-to-Year Variability in Embayment, Nearshore and Offshore Habitats

In 2004, we observed seasonal differences in Secchi depth, Chl a, TP, SRP, water temperature, and all three zooplankton parameters in embayment, nearshore and offshore habitats.

Secchi depth, Chl a, TP, SRP, and water temperature: Water clarity of nearshore habitats

in 2004 was generally consistent from May through September, followed by an increase in October. The sharpest increase in clarity came in Niagara River West, which went from a minimum depth of 1.0m (3.3 ft) in late May to a maximum of 8.5m (27.9 ft) by late June (Figure 2). Nearshore Secchi depths ranged from a minimum of 1.0m (3.3 ft) (Niagara River East and Niagara River West, late-May) to a maximum of 12.0m (39.4 ft)(Sodus Bay, mid-July). Embayment Secchi depths were shallowest in August and October and deepest in May. Embayment Secchi depths ranged from 0.7m (2.3 ft)(Sandy Pond Bay, early September) to 7.0m (23 ft)(Chaumont Bay, late September).

Chl a concentrations were higher in embayments than in nearshore areas, exhibiting an increasing trend from May to September, then decreasing slightly in October. Nearshore concentrations remained fairly constant throughout the sampling season, (Figure 3A). Both embayment and nearshore Chl a concentrations peaked in September at 16.7µg/L, and 2.2µg/L respectively. Embayment Chl a concentrations varied from 1.2µg/L in Chaumont Bay (late June) to 45µg/L in Sandy Pond Bay (early September). Nearshore Chl a ranged from less than 0.3µg/L (Niagara River East, late-September) to more than 49µg/L (Sandy Pond Lake, late May). Offshore Chl a averaged 1.1µg/L (Figure 3A), ranging from 0.5µg/L to 2.1µg/L.

TP concentrations were higher in embayments than nearshore habitats, similar to 2003 (Figure 3B). Monthly average embayment TP concentrations increased from May to September, while nearshore TP concentrations remained relatively constant during the same period. Both embayment and nearshore TP decreased slightly in October. Average embayment TP values peaked in September at 27.3µg/L and nearshore concentrations reached 11.6µg/L in May. Embayment TP ranged from 4.4µg/L at Sodus Bay (mid-July), to 44µg/L at Sandy Pond Bay (late September). Nearshore TP ranged from 3.3µg/L at Oak Orchard Lake (late August) to 31.3µg/L at Sodus Bay Lake (late May). The average offshore TP concentration

for mid-July through mid-August was 8.8µg/L (Figure 3B), ranging from 4.1µg/L to 14.2µg/L.

Mean monthly embayment and nearshore SRP concentrations exhibited a relatively similar monthly pattern throughout 2004 (Figure 4A). Nearshore SRP concentrations had both a minimum of 1.4µg/L and a maximum of 6.0µg/L at Galloo Island Lake (late June, late May respectively). Embayment SRP ranged from 1.7µg/L (early June) to 12.9µg/L (mid-October) at Chaumont Bay. In embayment, nearshore, and offshore sites, monthly SRP concentrations peaked late in the season, with the embayment maximum reaching 6.7µg/L and the nearshore reaching its maximum value of 3.9µg/L, both in October. Offshore TP monthly average had a maximum of 3.4µg/L in September.

Water temperatures for both embayment and nearshore habitats exhibited a similar seasonal pattern: warming into August, and cooling into fall (Figure 4B). Monthly average temperatures peaked during August at 22.9°C (73.2°F) (embayments) and 21.0°C (69.8°F) (nearshore). Embayment temperatures ranged from minimum of 12.0°C (53.6°F) in (late September) to a maximum of 26.3°C (79.3°F) (mid-August), both in Sandy Pond Bay. Nearshore temperatures ranged from 8.0°C (46.4°F) in mid-May at Sodus Bay Lake to 24.3°C (75.7°F) at Chaumont Bay Lake during early August. Offshore temperature data were insufficient to calculate a mean.

We also compared 2003 and 2004 annual means derived from biweekly data (secchi depth, Chl *a*, TP, SRP, and water temperature) in both embayment and nearshore habitats (Figure 2, 3&4). 2003 and 2004 biweekly secchi readings did not differ significantly in either embayment or nearshore annual comparisons. Embayment biweekly secchi values averaged 3.1m in 2003 compared to 4.0m in 2004 ($p>0.11$). Nearshore secchi values averaged 6.1m in 2003 and 6.4m in 2004 ($p>0.62$).

Mean biweekly Chl *a* concentrations were found to be significantly lower ($p<0.002$) in 2004 than in 2003 for the embayment data but not so in the nearshore sites. Average embayment Chl *a* in

2004 was 8.0µg/L, approximately half its 2003 value of 14.8µg/L. Nearshore biweekly Chl *a* concentrations were 1.8µg/L and 1.9µg/L, in 2003 and 2004, respectively (insignificantly different, $p>0.71$)

The average biweekly TP value for embayments in 2004 was less (18.4µg/L) than the corresponding average in 2003 (23.9µg/L). The nearshore TP values were slightly higher in 2004 (9.3µg/L) than in 2003 (8.6µg/L). These annual TP differences, both in embayment and nearshore comparisons, were insignificant ($p>0.07$, $p>0.37$ respectively).

Embayment and nearshore annual means for SRP were not significantly different in 2004 than their 2003 values. Embayment biweekly SRP mean value in 2003 was 4.1µg/L compared to 3.6µg/L in 2004 ($p>0.13$). Nearshore annual mean was approximately 2.7µg/L in both 2003 and 2004 ($p>0.82$).

Water temperature also did not differ significantly between 2003 and 2004 in either embayment or nearshore habitats. Embayment temperature average was insignificantly ($p>0.47$) higher in 2004 (19.7°C or 67.5°F) than in 2003 19.4 °C or 66.9°F). 2004 nearshore average temperature (17.3 °C or 63.1°F) was also insignificantly ($p>0.15$) higher than in 2003 (16.3°C or 61.3°F).

Zooplankton: Zooplankton densities were highest in late August at embayment sites, and were generally higher in embayments during the entire 2004 sampling season (Figure 5A). The lowest zooplankton densities occurred at offshore sites in May. For individual dates and habitats, the lowest nearshore zooplankton density was 0.41/L at the Galloo Island (GIL) site in mid-May and the lowest embayment density was 10.9/L at Sandy Pond Bay (SPB) in late September. The highest densities were 335.5/L at Niagara River West Lake (NWL) in late August and 451.0/L at Sandy Pond Bay in mid-August. At offshore sites, the lowest density was seen in early May (0.225/L) and the highest was observed in mid-July (121.2/L).

Zooplankton average size at embayment sites was highest in mid-May (0.58mm) and lowest in mid-October (0.35mm). At nearshore sites, average size was highest in early August (0.64mm) and lowest in early July (0.38mm). Offshore mean zooplankton size was highest in mid-May (0.92mm) and lowest in early July (0.52mm) (Figure 5B). Figure 10 shows mean monthly zooplankton size for each habitat in 2003 and 2004. Offshore average size was greater than both embayment and nearshore average size for each time period data were available. Offshore and nearshore seasonal trends in zooplankton lengths in 2004 were generally similar to the trends in 2003. However, average zooplankton sizes in embayment sites were less variable in 2004 than 2003. In 2004, average sizes were consistently near 0.52mm during May through August before declining in September and October (Figure 10).

Mean biomass from May through October was highest at the embayment sites in mid-August (343.5µg/L). The lowest mean biomass occurred at the nearshore sites in mid-May (2.1µg/L). Mean biomass of the zooplankton community in embayment areas remained greater than in nearshore and offshore habitats for nearly the entire sampling season, with September being the only exception. The maximum zooplankton biomass at a single site on a sampling date in embayment and nearshore habitats was 686.2µg/L in mid-August at Sandy Pond Bay, and 799.4µg/L in late August at Niagara River West Lake. The minimum biomass at an individual site on a single date for embayments was 13.5µg/L at Chaumont Bay in mid-September, while it was 1.6µg/L for nearshore sites at Chaumont Bay Lake in mid-May. Offshore mean biomass values were generally low throughout the season, but exceeded nearshore average biomass values in mid-May, both sampling weeks in July, and mid-October (Figure 5C).

Relationships Among Variables

We examined the relationships of TP, water temperature, and SRP with Chl *a* using a linear regression analysis for embayment and nearshore sites (Figure 11). Both the biweekly water temperature-Chl *a*-relationship and the

TP-Chl *a* relationship were positively correlated in both embayment and nearshore habitats. Biweekly SRP-Chl *a* relationships were positively correlated in embayment habitats but negatively correlated in nearshore habitats. When Chl *a* was regressed against water temperature, temperature explained 17% of the variability in embayment Chl *a* (insignificant at $p>0.19$), and 5% of the variability in nearshore habitats (insignificant at $p>0.49$) (Figure 11A). When Chl *a* was regressed against TP, we found that TP significantly explained ($p<0.001$) 80% of the Chl *a* variability in embayments, and significantly ($p<0.05$) explained 34% of Chl *a* variability in nearshore areas (Figure 11B). The regression of Chl *a* against SRP insignificantly explained 12% of the variability in embayment Chl *a* ($p<0.27$). The regression of nearshore Chl *a* against SRP yielded a negative relationship, where SRP insignificantly explained 22% of the variability of Chl *a* ($p>0.12$) (Figure 11C).

Zooplankton Community Dynamics

Embayment - Nearshore: In 2004, none of the six zooplankton taxa significantly differed in proportion of their total biomass between embayments and nearshore sites (Table 2). The proportion of *C. pengoi* biomass was not significantly greater in the nearshore sites than embayment sites, but with a p -value of 0.066, the trend was stronger than that of the other zooplankton groups (Table 2).

The bosminid proportion of total biomass in nearshore habitats peaked in early July, and interestingly declined in late July as nearshore *Cercopagis pengoi* reached its greatest values (Figures 13A & 13E). A similar shift was not seen in embayment sites, however; while bosminid proportion of biomass also increased in embayments during early July, embayment *Cercopagis pengoi* biomass proportion remained relatively constant (Figures 13A & 13E). Embayment bosminid biomass proportion was highest in late September and October, while embayment *Cercopagis pengoi* biomass proportion increased only slightly in late September (Figures 13A & 13E). Daphnids peaked in percent biomass in early August in the nearshore and in late June for embayment sites, with a secondary peak in mid-August (Figure

12B). Calanoid copepod contribution to total zooplankton biomass remained relatively low May through September for both sites, but rapidly increased to a peak of 0.79 for nearshore sites in October (Figure 12C). Cyclopoid copepod proportions were greatest in nearshore habitats during early June of 2004, and in embayments during mid-May, composing 81 and 58 percent of total zooplankton biomass during those periods, respectively. Cyclopoid proportion of biomass reached a low for embayments in late June, and a low for nearshore sites in early August (Figure 12D). *C. pengoi* increased in biomass in late July and comprised nearly 27% of total zooplankton biomass in nearshore areas. In embayment habitats, *C. pengoi* accounted for only 4% of total biomass at its first peak in early July and 6% at its second peak in late September (Figure 12E). During times other than these peaks, *C. pengoi* contributed less than 2% of the total zooplankton biomass at embayment sites and less than 9% at nearshore sites. "Other" cladocera peaked in embayments at 20% of the total zooplankton biomass in late May, while nearshore proportions peaked at 41% in mid-August (Figure 12F).

Offshore: Cyclopoid copepods and daphnids dominated the offshore community for most of the sampling period, accounting for an average of 40% and 20% of total biomass, respectively. Other important contributors to offshore biomass were *Holopedium gibberum* during late August (29%), *Bosminia longirostris* during early September (25%), and calanoid copepods during mid-October (53%). Of these species, all except *B. longirostris* contributed to an overall large offshore zooplankton average size. In offshore habitats, the dominant cyclopoid copepod *D. thomasi* annual average size was 0.82mm, *D. retrocurva* annual average size was 0.77mm, *H. gibberum* annual average size was 0.59mm, and calanoid copepod annual average size was 1.19mm. Other less frequently detected species that contributed to large zooplankton average size when present in offshore habitats were *C. pengoi*, *B. longimanus*, and *L. kindtii*.

Embayment - Nearshore - Offshore: In mid-July to mid-August, there were several notable differences between the components of the zooplankton community in the different habitats

(Table 3). Bosminid biomass values at offshore sites (3.4µg/L) were significantly lower than Bosminid embayment biomass (32.6µg/L) ($p < 0.0167$) (Table 3, Figure 13). Cyclopoid biomass was significantly lower at offshore sites (38.2µg/L) than embayment sites (143.2µg/L) ($p < 0.0167$) (Table 3). The embayment *Cercopagis* biomass of 0.8µg/L was significantly less than *Cercopagis* biomass at nearshore (3.97µg/L) sites ($p < 0.0167$) (Table 3, Figure 13).

Cercopagis pengoi

Offshore and nearshore biomass and density of *C. pengoi* in late July are presented in Figures 7 and 8, respectively. During mid-July to mid-August of 2004, average densities of *C. pengoi* at offshore, nearshore, and embayment sites were 0.37/L, 0.51/L, and 0.10/L, respectively (Figure 14). There were no statistically detectable differences in east-west nearshore data during the entire sampling season for *C. pengoi* biomass (Table 5). Likewise, there were no statistically detectable differences in the offshore east-west comparisons of *C. pengoi* density and biomass (Table 6). Longitude did not explain an appreciable amount of the variation in *C. pengoi* distribution in Lake Ontario during mid-July to mid-August 2004 (Figure 9).

Statistical differences were detected in *C. pengoi* density, average size, and biomass when offshore samples from July 1999 and August, 2000 were compared. *C. pengoi* density, average size, and biomass in offshore habitats during late July 2000 were all significantly lower ($p < 0.005$, 0.005, 0.00005 respectively) than in offshore habitats in August 1999 (Table 7). However, *C. pengoi* density, average size, and biomass significantly increased again in offshore habitats in August 2001 (all $p < 0.05$) (Table 7). In July 2003 offshore *Cercopagis* samples, significant decreases were found in density ($p < 0.02$), average size ($p < 0.001$), and biomass ($p < 0.02$) when compared to August 2002 data (Table 7). Statistical differences were detected in all three offshore *C. pengoi* parameters between July 2003 and mid-July to mid-August 2004. Mean density, average size, and biomass each

increased ($p < 0.002$, $p < 0.0002$, and $p < 0.0006$, respectively) (Table 7). No significant changes occurred in *C. pengoi* density, average size, or biomass between any pair of consecutive years sampled at either nearshore or embayment habitats.

Trends in the mean densities of bosminids during the July/August offshore sampling efforts over the past eight years of this biomonitoring project were examined to see if the arrival of *C. pengoi* in Lake Ontario was associated with a change in zooplankton community structure. After more than a 20-fold increase in bosminid density from 1995 to 1996 and 1997, values plummeted in 1998 when *C. pengoi* first arrived (Figure 15). Even though the density remained low in 1999, it increased to almost 19 bosminids per liter in 2000 as *C. pengoi* densities simultaneously decreased. However, in 2001 bosminid density once again declined dramatically to six bosminids per liter, and appeared to be associated with an increase of offshore *C. pengoi* density. *C. pengoi* offshore density increased from 0.53/L in 2001 to 0.64/L in 2002 and was associated with a decline in offshore bosminid density to 1.6/L, again suggesting a relationship with increased *C. pengoi* density. July of 2003 saw offshore bosminid densities increase to 6.7/L while *C. pengoi* offshore density (0.05/L) was considerably lower than in August 2002 (0.64/L). During mid-July to mid-August 2004, offshore bosminid density decreased to 3.2/L and *C. pengoi* densities increased to 0.37/L. It should be noted, however, that the magnitude of *C. pengoi* density increase far exceeded the magnitude of bosminid density decrease in 2004.

Bythotrephes longimanus

After not being detected in 2002 or 2003, *B. longimanus* was detected in three fall samples from the eastern end of Lake Ontario during 2004: one from mid-September at the Galloo Island (GIL) nearshore site and two from October at the Smokey Point offshore site. *B. longimanus* density and biomass were highest at the Galloo Island site (0.051/L and 7.2 $\mu\text{g/L}$, respectively) and lowest at the early October Smokey Point site (0.009/L and 1.0 $\mu\text{g/L}$, respectively), with an intermediate density and biomass of 0.027/L and 3.5 $\mu\text{g/L}$ at the mid-

October Smokey Point site. *B. longimanus* body length averaged 2.47mm at the Galloo Island site, 2.55mm at the early October Smokey Point site, and 2.81mm at the mid-October Smokey Point site.

Significant Research Findings

Embayment-Nearshore-Offshore Comparisons

In 2004 embayments continued to be very productive habitats in comparison to nearshore and offshore areas of Lake Ontario. In embayments, TP concentrations from May to October were slightly more than 2.0 times higher than those in nearshore habitats. Embayment TP concentrations in mid-July to mid-August were 1.5 times higher than offshore concentrations (Figure 3B). TP concentrations in less than an eighth of the offshore sites (4 of 34) exceeded the target value (10 $\mu\text{g/L}$) set for the offshore pelagia by the Great Lakes Water Quality Agreement (GLWQA).

Chl *a* concentrations (May through October, 2004) for embayments were 4.3 times greater than for nearshore habitats (Figure 3A). Embayment Chl *a* during mid-July through mid-August was also 6.1 times greater than the offshore Chl *a*.

May through October 2004 SRP concentrations for embayments were 1.4 times higher than for nearshore habitats. Embayment SRP concentrations in mid-July to mid-August were 1.7 times greater than offshore SRP (Figure 4A).

Annual secchi depths were found to be 1.9 times deeper at nearshore sites than embayments, corresponding with the elevated Chl *a* concentrations of embayment habitats.

In 2004, embayment sites had nearly three times the zooplankton density and 2.5 times the biomass of nearshore sites, and only a moderately lower average zooplankton size than nearshore sites (Table 2). For mid-July to mid-August of 2004, embayment density was over two times greater than nearshore density and over four times greater than offshore density. Embayment biomass was over two times greater than nearshore biomass, and over three times the

offshore biomass. Embayment average size was similar to nearshore average size, but was significantly smaller than offshore average size (Table 3).

East-West / North-South Comparisons

The east-west comparisons of bi-weekly study variables for nearshore sites yielded a significantly greater ($p < 0.001$) Secchi depth (1.7 times greater) in the eastern half of Lake Ontario. This is attributed to the seasonal mean of 9.5m for Sodus Bay Lake in the east, which was at least 1.4 times greater than any of the other eastern nearshore stations, and at least 1.9 times greater than any other western nearshore station (Figure 6D).

For the east-west comparison of nearshore data including total zooplankton density, average size, biomass, and *C. pengoi* density and biomass, no significant differences were found. In the comparison of east-west offshore samples, the only difference found was significantly greater total zooplankton average size in western samples.

Sodus Bay – Sandy Pond Bay

As in 2003, Sodus Bay and Sandy Pond Bay were found to be the most productive sites in 2004 (Figure 6A-C, 6E-F). Seasonal Chl *a* averages of 5.9µg/L (Sodus Bay) and 18.5µg/L (Sandy Pond); and zooplankton biomasses of 176.2µg/L (Sodus Bay) and 238.2µg/L (Sandy Pond) exceeded all other sites. The seasonal mean Secchi depths found at Sodus Bay (4.0m) and Sandy Pond Bay (1.7m) were the shallowest of all sampled habitats (Figure 6D), and corresponded with the elevated Chl *a* values.

Seasonal Variability in Embayment and Nearshore Habitats

Several water quality parameters exhibited seasonal trends. Mean monthly Chl *a* and TP concentrations in embayments steadily increased through the sampling season, peaking in late August - early September, and only decreasing slightly in October (Figure 3A & B). Nearshore Chl *a* and TP remained fairly constant May through October. Both embayment and nearshore SRP also peaked at the end of the

season, both reaching their peak in October (Figure 4A).

For zooplankton, embayments had the highest biomass and density for most of the entire May through October season, both peaking in mid-August. Nearshore densities were slightly higher than embayment densities in early and late September, and nearshore biomass was higher than embayment biomass during the entire month of September (Figure 5). Zooplankton average size was quite similar in nearshore and embayment sites, with nearshore average size the larger of the two in eight of the 12 sample weeks. Offshore average size was greater than both nearshore and embayment habitats whenever it was available (mid-May, early June, July – mid-September, mid-October). The average size of crustacean zooplankton peaked in early May for offshore and embayment habitats, and in early August for embayment sites (Figure 5). Density and biomass values peaked in mid-August for embayment sites and early September for nearshore sites. Offshore density and biomass peaked in early July (Figure 5). Biomass and density were at their lowest values in all three habitats in mid-May (Figure 5).

Zooplankton Community Dynamics

In 2004, cyclopoid copepods were the largest contributors to biomass in nearshore habitats. In embayments, bosminids had the largest contribution to total biomass (Table 2). There were no significant differences in community composition between embayments and nearshore sites throughout the 2004 season, although there was a trend toward higher *C. pengoi* proportions of biomass in nearshore sites. Cyclopoid copepods were prominent at both embayment and nearshore habitats, especially in the early season in nearshore habitats (Figure 13). As in 2003, 2004 offshore cyclopoid copepod biomass was higher than the biomass of any other offshore taxa (Table 3). *Cercopagis pengoi* proportion biomass had a moderate increase in nearshore habitats in mid-July (Figure 13).

Zooplankton average size in embayment habitats was low (0.4-0.6mm) from spring through fall

due to high densities of Bosminids and other small cladocerans, such as *Chydorus sphaericus* and *Ceriodaphnia quadrangula*. Cyclopoid copepods were an important contributor to embayment biomass, but cyclopoid average size in embayments was 0.58mm, as compared to 0.81mm in offshore habitats. Similar conditions existed in nearshore habitats, with high densities of Bosminids throughout the sampling period and cyclopoid copepods averaging 0.57mm in length. Offshore habitats had consistently large zooplankton average sizes due to an abundance of large cyclopoid copepods and daphnids from the spring through fall, as well as large seasonal biomass contributions from calanoid copepods and *H. gibberum*. *C. pengoi*, *B. longimanus*, and *L. kindtii* were detected less frequently, but also increased offshore zooplankton average size when present.

Cercopagis pengoi

In 2004, *C. pengoi* was first observed in mid-June in nearshore and embayment samples. *C. pengoi* biomass peaked in mid-July in nearshore sites, and in late September in embayments. The highest biomass observed in Lake Ontario was 12.4µg/L at the Nine Mile Point offshore site in mid-July. No spatial differences in biomass or density were found between east-west offshore or nearshore comparisons (Tables 5 and 6). *C. pengoi* densities in the eastern and western basins of Lake Ontario were similar; longitude did not account for any east-west difference in density. Figures 14 and 15 reflect comparisons of *C. pengoi* biomass and density for the month of mid-July to mid-August. While *C. pengoi* is typically greatest in biomass and density at offshore sites, in 2004 these parameters were both higher in nearshore habitats.

C. pengoi was detected in 45.3% of all the samples in May through October in 2004, an increase from the detection rates of 31.8% in 2003 and 31.6% in 2002, yet lower than the rates of 50.0% in 2001 and 62.3% of the samples in 2000. Since its appearance in 1998, *C. pengoi* density appears to be inversely related to bosminid density (Table 7, Figure 5).

Bythotrephes longimanus

B. longimanus was detected in three samples from 2004 after not being detected in 2002 or 2003. *B. longimanus* was detected on three dates late in the season (late September and October) at two sampling locations (Galloo Island and Smokey Point) at the east end of Lake Ontario. *B. longimanus* densities ranged from 0.009/L to 0.051/L, biomass ranged from 1.0µg/L to 7.2µg/L, and average size ranged from 2.47mm to 2.81mm.

Linkages between Lake Ontario Zooplankton and Alewife Populations.

Lake managers recognize the importance of ecological indicators, especially their utility in assessing management and restoration efforts. Zooplankton are positioned in the food chain of freshwater lakes to reflect ecological balance between algae and zooplankton and fish and zooplankton. In fact, mean zooplankton length can be used as an indicator of the balance between plankton eating fish and fish predators (Mills and Schiavone 1982). A common symptom of degraded ecosystems is distortion of the expected relationship between the biomass of organisms and body size. The virtual absence of large-bodied zooplankton like *Daphnia* in freshwater lakes in response to intense planktivory by fish, for example, is a deviation from an expected size distribution. In lakes with a diverse population of quality-sized piscivores that are in sufficient numbers to control populations of small plankton-eating fish, larger-bodied zooplankton are usually abundant. In lakes where plankton eating fish growth is slow and quality-sized planktivores are scarce, the density of predators is most likely low. Conditions where predation is successfully controlling planktivore density mean body lengths of crustacean zooplankton are greater than 0.8-1.0 mm. The dominance of small crustacean zooplankton, on the other hand, points to the absence of sufficient number of predators to suppress planktivore density.

Alewife (*Alosa pseudoharengus*) is the dominant planktivore in Lake Ontario. Intense planktivory by these fish has historically structured the zooplankton community toward small species like *Bosmina*. Zooplankton are the principal food of juvenile and adult alewife and these fish

can account for more than 96% of predation on zooplankton (Rand et al. 1995). Alewife abundance declined 42% from the early 1980s to the early 1990s (O’Gorman et al. 2000) and changes in the zooplankton community were observed in response to this decline. Among the more significant changes during this period was a shift to larger zooplankton species and increased abundance of summer cyclopoid copepods.

In Lake Ontario, the impact of planktivory by alewife may be greater at one time of the year than another. For instance, adult alewife in this large lake migrate inshore in the springtime and return to the offshore through July. Consequently, one would expect that the impact on offshore zooplankton by adult alewife would be highest in epilimnetic waters sometime mid-summer through early fall. For the period mid-July through mid-September 2004, we found that offshore mean zooplankton size was 0.74mm, suggesting that piscivores are either in balance with their alewife prey or are greatly suppressing populations of adult alewife. In 2004, populations of adult and juvenile alewife were not sufficiently abundant to suppress larger sized zooplankton species like *Cercopagis*, *D. retrocurva*, *D. thomasi*, *H. gibberum*, *L. macrurus*, and *E. lacustris*. Like the period from the early 1980s to the early 1990s when alewife densities were declining, offshore cyclopoid copepod biomass in Lake Ontario in 2004 was higher than any other offshore taxa. Finally, lakes with large populations of alewife typically have zooplankton that are very small (0.3 to 0.4 mm, CBFS unpublished data), whereas offshore crustacean zooplankton in Lake Ontario during mid summer to early fall were considerably larger, averaging 0.74mm in length.

The relationship between zooplankton average size and alewife abundance is complicated by the presence of the predatory exotic zooplankter, *Cercopagis pengoi*. *C. pengoi* possesses a tail spine several times its body length, preventing young-of-the-year planktivores from preying upon it until their gape is large enough to accommodate the spine (Bushnoe et al. 2003). In Lake Ontario, *Cercopagis* abundance is inversely related to bosminid density so declines in *Bosmina* could contribute to a shift in the

mean size of zooplankton toward larger organisms. However, *C. pengoi* is a moderately large sized cladoceran and adult alewife are known to feed on this organism. *C. pengoi* was present in nearly half of Lake Ontario zooplankton samples collected in 2004. Consequently, the high occurrence rate of *C. pengoi* observed in Lake Ontario samples in 2004 provides some additional circumstantial evidence that adult alewife numbers were likely low and were not sufficiently abundant to suppress *Cercopagis* abundance.

The exotic predatory macrozooplankton *Bythotrephes longimanus* is a large spiny zooplankton that was observed in Lake Ontario in September and October 2004. *B. longimanus* was not detected in Lake Ontario in 2002 and 2003. Alewife feed on *B. longimanus* in Lake Ontario, and when they feed heavily on this organism, body condition improves. The emergence of the large cladoceran *Bythotrephes* in 2004 provides yet one more line of evidence that adult alewife abundance is currently suppressed in Lake Ontario.

Given the dependence of Lake Ontario adult alewife on microzooplankton for food, and that high mean body size of zooplankton is inversely related to alewife abundance, we conclude that current densities of adult alewife in Lake Ontario are low. The supportive evidence for this conclusion is based on the facts that 1) a high mean body size of offshore crustacean zooplankton (0.74 mm) in mid summer to early fall, 2) the observance of the large cladoceran *C. pengoi* in nearly 50% of all samples collected in Lake Ontario in 2004 April through mid-October, and 3) the emergence of the macrozooplankton *B. longimanus* in fall 2004.

References

- Balcer, M.D., N.L. Korda, and S.I. Dodson. 1984. Zooplankton of the Great Lakes. The University of Wisconsin Press, Madison, Wisconsin.
- Bushnoe, T. M., D. M. Warner, L. G. Rudstam, and E. L. Mills. 2003. Cercopagis pengoi as a New Prey Item for Alewife (*Alosa pseudoharengus*) and Rainbow Smelt (*Osmerus mordax*) in Lake Ontario. *J. Great Lakes Res.* 29: 205-212.
- Christie, W.J., K.A. Scott, P.G. Sly, and R.H. Stus. 1987. Recent changes in the aquatic food web of eastern Lake Ontario. *Can. J. Fish. Aquat. Sci.* 44(Suppl. 2):37-52.
- EPA. 1993. Lake Ontario: An ecosystem in transition. Report of the Lake Ontario pelagic community health indicator committee. U.S. Environmental Protection Agency. Contract No. 68-W9-0003. 65p.
- Giguere, L.A., J.F. St-Pierre, B. Bernier, A. Vezina, and J.G. Rondeau. 1989. Can we estimate the true weight of zooplankton samples after chemical preservation? *Can. J. Fish. Aquat. Sci.* 46: 522-527.
- Hambright, K.D. and S. Friedman. 1994. CAPAS: A computer-assisted plankton analysis system for the MacIntosh. *Fisheries* 19:6-8.
- International Joint Commission. 1988. Great Lakes Water Quality Agreement of 1978 (Revised) Ottawa, Ontario, and Washington, DC. 130 pp.
- Menzel, D., and N. Corwin. 1965. The measurement of total phosphorus on the liberation of the organically bound fraction of persulfate oxidation. *Limnol. Oceanogr.* 10:280-282.
- Mills, E.L., and A. Schiavone. 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. *N. American J. of Fisheries Management.*
- Mills, E. L., J. M. Casselman, R. Dermott, J. D. Fitzsimmons, G. Gal, K. T. Holeck, J. A. Hoyle, O. E. Johannsson, B. F. Lantry, J. C. Makarewicz, E. S. Millard, I. F. Munawar, M. Munawar, R. O’Gorman, R. W. Owens, L. G. Rudstam, T. Schaner, and T. J. Stewart. 2003. Lake Ontario: food web dynamics in a changing ecosystem (1970-2000). *Can. J. Fish. Aquat. Sci.* 60: 471-490.
- Mills, E.L., R.A. Keats, T.L. Negley, L.G. Rudstam, C.P. Schneider, B. Lantry, R. McCullough, D. Bishop, W. Pearsall, J. Norris, D. Busch, C. Knauf, G. Brown. 1998. 1998 Status of the Lake Ontario Ecosystem: A Biomonitoring Approach.
- O’Gorman, R., J. H. Elrod, R. W. Owens, C. P. Schneider, T. H. Eckert, and B. F. Lantry. 2000. Shifts in depth distributions of alewives, rainbow smelt, and age-2 lake trout in southern Lake Ontario following establishment of dreissenids. *Trans. Am. Fish. Soc.* 129: 1096-1106.
- Pennak, R.W. 1978. Fresh-water invertebrates of the United States. John Wiley and Sons, New York. 803 pp.
- Rand, P. S., D. J. Stewart, B. F. Lantry, L. G. Rudstam, O. E. Johannsson, A. P. Goyke, S. B. Brandt, R. O’Gorman, and G. W. Eck. 1995. Effect of lake-wide planktivory by the pelagic community in Lakes Michigan and Ontario. *Can. J. Fish. Aquat. Sci.* 52: 1546-1563.
- Strickland, J.D.H., and T.R. Parsons. 1972. A practical handbook of seawater analysis. *Bull. Fish. Res. Board Can.* 167: 310 p.
- Zar, J.H. 1984. Biostatistical analysis. Second Edition. Prentice Hall. Englewood Cliffs, New