Seasonal and Vertical Distribution, Food Web Dynamics and Contaminant Biomagnification of *Cercopagis pengoi* in Lake Ontario

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Abstract

During the early growth season of 1999 to 2001, Cercopagis abundance in offshore waters of Lake Ontario remained low (less than 30 individuals/m^3). From late July, its abundance increased rapidly until it peaked during August. After first appearing in 1998, maximum offshore abundance in Lake Ontario decreased each year since 1999 (1999:1759/m^3; 2000: 679/m^3; 2001: 355/m^3). Cercopagis appears not to migrate below the thermocline and is restricted to the epilimnion. A comparison of pre- and post-invasion average abundance of Daphnia retrocurva, Bosmina longirostris and Diacyclops thomasi suggests that Cercopagis is having a major effect on zooplankton composition and abundance in Lake Ontario. Abundance of all three species has decreased significantly in the offshore waters since the invasion of Cercopagis. Preliminary results also suggest that insertion of Cercopagis pengoi into the Lake Ontario food web will not elevate levels of hydrophobic organic compounds in salmonids through biomagnification.

Key Words

Cercopagis pengoi, invasive species, food web, biomagnification, vertical migration.

Introduction

In July 1998, salmonid fishermen on Lake Ontario complained of an organism fouling fishing lines. Collected specimens were initially believed to be *Bythotrephes*, an invasive species first reported in Lake Ontario in 1988 (Makarewicz and Jones 1990), although closer examination revealed features characteristic of *Cercopagis pengoi* (Figure 1, MacIsaac et al. 1999; Grigorovich et al. 2000). Several independent reports confirmed the establishment of Cercopagis in Lake Ontario (MacIsaac et al. 1999, Makarewicz 1999, Makarewicz et al. 2001, Ojaveer et al. 2001). It is possible that this *Cercopagis* population was founded by a small number of individuals, most likely transported in ballast water whose origin was the Baltic Sea (MacIsaac et al. 1999; Cristescu et al. 2001).

Two closely related forms, *C. pengoi* and *C. ossiani* co-occurred in northwest and southcentral regions of the lake during 1999 and 2000 (Makarewicz et al. 2001; I.A. Grigorovich, unpub. data). Sequencing of the mitochondrial ND5 gene revealed that these forms were characterized by a single haplotype (Makarewicz et al. 2001). Conversely, European populations from the Black Sea, Caspian Sea and Baltic Sea were characterized by 7, 2 and 1 haplotypes, respectively (Cristescu et al. 2001). Lack of haplotype diversity at ND5 strongly suggests that only a single taxon, *Cercopagis pengoi*, is present in the lake (Makarewicz et al. 2001). It is possible that these forms represent two morphologically distinct stages of the *C. pengoi* lifecycle. Available evidence indicates that the *ossiani*-form results from vernal hatching of resting eggs, while later generations (*C. pengoi*-type) are produced parthenogenetically (Makarewicz et al. 2001; Simm and Ojaveer 1999). Similar morphological differences were reported between parthenogenetically- and sexually-produced generations of *Bythotrephes* (Zozulya 1977; Yurista 1992). In this report, we provide an update on seasonal dynamics and abundance, and vertical distribution and migration of *C. pengoi* in Lake Ontario. In addition, we comment on changes in food web dynamics and organic contaminant biomagnification resulting from the insertion of this exotic predator in Lake Ontario.

Methods

Seasonal Sampling

Zooplankton (including *Cercopagis*) of Lake Ontario was sampled from 1999 to 2001 using a double Bongo tow (571 µm nylon mesh net, 50 cm diameter) and a Wisconsin net (63 µm nylon mesh net). Sampling was conducted biweekly due north of Hamlin Beach State Park, N.Y. (43° 25.110′ latitude and 77° 53.986′ longitude). Weekly sampling was conducted during periods of maximum *Cercopagis* abundance until it began to decrease, whereupon the biweekly regime was reinstated. Depth at the sampling site was 100 m, but samples were taken vertically from 20 m to the surface, approximating the epilimnion depth during the thermal stratification period in summer.

Vertical Distribution

Replicated (n=3) zooplankton samples were collected at 1 m intervals from the surface to 20 m between 3:00 pm and 4:30 pm and between 9:00 pm and 11:30 pm on the evening of 27 July 2001. Samples were collected using a submersible water pump; water was pumped at a rate of 1 L/s into filter tubes (0.3 m length and 12 cm diameter, 153 µm mesh net). Samples were counted in entirety for *C. pengoi* and for *Daphnia retrocurva*.

Mirex Analysis

In order to determine whether *Cercopagis* insertion in the food web caused biomagnification of contaminants, we sampled and tested both the plankton and alewife (*Alosa pseudoharengus*), the primary zooplankton predator in the lake. *Cercopagis* samples were placed in solvent-rinsed glass jars, kept in ice and transported back to the lab and immediately frozen until analysis. Alewife were collected monthly from May through November 2000 using gill netting. Floating gill nets were set in 6 m of water east of Hamlin Beach State Park, NY. (43°21.347′ latitude and 77° 55.077′ longitude). Fish length, weight, sex and age were determined by standard procedures (Jearld 1983). Whole fish were frozen in food storage bags. Prior to analysis, fish were thawed, guts were removed and the entire specimen homogenized using a food processor.

Mirex analysis followed Makarewicz et al. (1993), revised from Insalaco et al. (1982). Five grams of homogenized fish sample was weighed and mixed with 20 grams of anhydrous sodium sulfate. Similarly, excess water was removed from *Cercoapgis* samples by blotting with a kimwipe, measured for wet weight and placed overnight in a drying oven at 60°C. Later, the dried sample was mixed with 20 grams of anhydrous sodium sulfate, and extracted overnight (16± 4 hrs) in a Soxhletic extractor (a minimum of 200 cycles) with 75 ml of methylene chloride/hexane (20:80 v/v) solvent mixture. A 30 ml aliquot from the alewife extraction and a 75 ml aliquot from the *Cercopagis* extraction were concentrated to 1 ml under nitrogen gas, and then cleaned by passage through a 5 g florisil column (at a rate of 4 ml/min) to a volume of 50 ml. This eluant was then concentrated under nitrogen gas to a final volume of 1 ml for the salmonid and alewives. Prior to clean-up, percent extractable lipid content of salmonid and alewife was determined by evaporating a known volume of the extract and weighing the residue (Hesselberg et al. 1990).

Mirex and photomirex were quantified by electron capture (^{63}Ni) gas chromatography utilizing a Hewlett Packard Gas Chromatograph model 5890A with a HP7673A auto injector, a HP3396A integrator, and a wall coated open tubular fused silica capillary column (30m x 0.25mm x 0.25 µm) HP-5 (5%-Diphenyl- 95%-dimethylsiloxane) for photomirex and a (12 m x 0.2 mm x .33 µm) Ultra-2 (dimethylpolysiloxane) for mirex. Samples were transported through the column with a 95:5% argon/methane carrier gas and the column flow was set at 0.75 ml/min. The injection port temperature was set at 250°C. The temperature program consisted of an initial temperature of 80°C, holding for one minute, programmed at 5°C/min to 275°C, then held for 11 minutes. A model 7673A autosampler was used to make a 50:1 split injection.

Two separate mirex standard curves were used for low-level *Cercopagis* determination and for higher-level alewife determination. Extraction blanks, replicates, and test recoveries from spiked samples were used for quality control.

Results and Discussion

Offshore Seasonal Abundance

During May and June 1999 to 2001, *Cercopagis* abundance in offshore waters of Lake Ontario was low (less than 30 individuals/m^3); however beginning in July the population increased rapidly and peaked in August (Figure 2). Maximum offshore abundance decreased each year from the initial maximum in 1999 (1759/m^3) to 2000 (679/m^3) to 2001 (355/m^3). Introduced populations of *Cercopagis* in Eastern Europe are also characterized by high density, up to 1000/m^3 (see Krylov et al. 1999). Densities as high as 26 000/m^3 have been reported in its native range in the Dnieper Bug estuary (Polishchuk and Grigoriev 1989). Despite high average *Cercopagis* abundance in Lake Ontario, its biomass is less important relative to those of other invertebrate planktivores. For example, average *Mysis relicta* biomass is 7.2 mg/m^3, while those of *Leptodora* and *Cercopagis* are 7.8 and 5.2 mg/m^3, respectively (Makarewicz et al. 2001).

Vertical Distribution and Migration

Little information exists on the vertical distribution and migration of *Cercopagis*. We compared vertical distribution of *Daphnia* and *Cercopagis* over a 24-hour period. At night, *Daphnia* was restricted to the epilimnion, with a maximum abundance at 5 m (Figure 3). By noon, maximum abundance of *Daphnia* was at 12 m, below the thermocline. In contrast, maximum *Cercopagis* abundance was concentrated in the epilimnion over the 24-hour period. Peak abundances at noon and midnight were at 7 and 8 m, respectively. Although peak abundance was in the epilimnion, approximately 14% of the population was observed in the top portion of the metalimnion during the evening. Our temporal survey during August revealed that *Cercopagis* does not appear to migrate below the thermocline, and was generally restricted to the epilimnion. Similarly in Lake Ontario, Ojaveer et al. (2001) suggested that the majority of individuals were found within the warm uppermost 20 m water later during both day and night with no diurnal vertical migration apparent. In the Caspian Sea *C. pengoi* inhabits surface waters, although it is found throughout the top 100 m; in contrast to our study, however, the species exhibits vertical migration in deeper regions of this basin (Rivier 1998).

Food Web

Considering its predatory habit (McPhedran 2001) and high average abundance in the epilimnion of Lake Ontario, *Cercopagis* might have profound impacts on zooplankton abundance and composition. A comparison of zooplankton abundance pre- and post- *Cercopagis* invasion supports this contention. For example, average abundance of *Daphnia retrocurva* ($P<0.001$, Kruskal Wallis one-way AOV,), *Bosmina longirostris* ($P<0.05$, KW) and *Diacyclops thomasi* ($P<0.05$, KW) were significantly different in offshore waters in Lake Ontario since *Cercopagis* invaded the basin (Figure 4). A similar result was observed in the Gulf of Riga (Baltic Sea); the abundance level of *Bosmina coregoni* was significantly lower after the invasion of *C. pengoi* (Ojaveer et al. 2000). Moreover, an inverse relationship exists between the predaceous *Cercopagis* and the herbivorous *Daphnia* in Lake Ontario (Figure 5). Whenever *Cercopagis* abundance was high, *Daphnia* abundance was low, and *Daphnia* was abundant only when *Cercopagis* was not (Figure 6). Similarly with *Bosmina longirostris*, seasonal abundance dropped remarkably when *Cercopagis* abundance increased (Figures 5 and 6). Thus both lab (McPhedran 2001) and field studies (Figure 5) strongly implicate *Cercopagis* as a potent predator of small-bodied zooplankton. Since the microzooplankton community accounts for 70–90% of the consumption of phytoplankton in Lake Ontario (Lampman and Makarewicz 1999), suppression of this group by *Cercopagis* could indirectly result in an increase in abundance of phytoplankton in the lake. Strong predatory effects on small zooplankton have also been noted for confamiliar *Bythotrephes* (Yan et al. 2001).

Contaminant Biomagnification

Lakes with longer food chains tend to have top predators with higher levels of lipophillic contaminants (Cabana and Rasmussen 1994; Kidd et al. 1995; Rasmussen et al. 1990; Van Hoof et al. 1997). If *C. pengoi* represents an additional link in the Lake Ontario pelagic food web, concentrations of these contaminants would be expected to increase in alewife and salmonids as a result of biomagnification (Kiriluk et al. 1995; Rasmussen et al. 1990; Cabana and Rasmussen 1994). To test this hypothesis we examined mirex (dodecachloropentacyclo $[5.3.0.0^{2,6}.0^{3,9}.0^{4,8}]$ decane) concentration in alewife, the major planktivore in the lake. However, no significant differences (P=0.49, ANOVA) were observed in monthly mirex concentrations (range = 0.004 mg/kg to 0.009mg/kg) in the 1998 alewife year class (age two) in 2000. From May to October, the average mirex concentration increased from 0.008 mg/kg in May to 0.009 mg/kg in July but then decreased to 0.006 mg/kg in September (Figure 7). These preliminary results suggest that insertion of a new invasive predator, *C. pengoi*, into the Lake Ontario food web will not elevate levels of lipophilic compounds in Lake Ontario salmonids.

Acknowledgements

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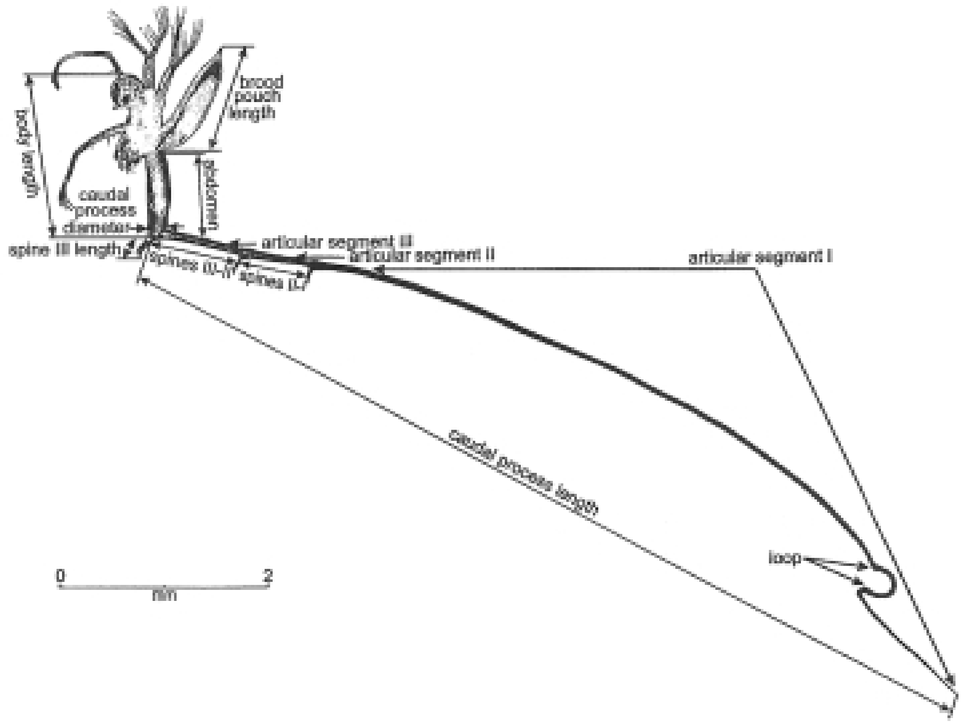

Figure 1. Diagram of *Cercopagis pengoi* (Ostroumov) (Crustacea, Cladocera).

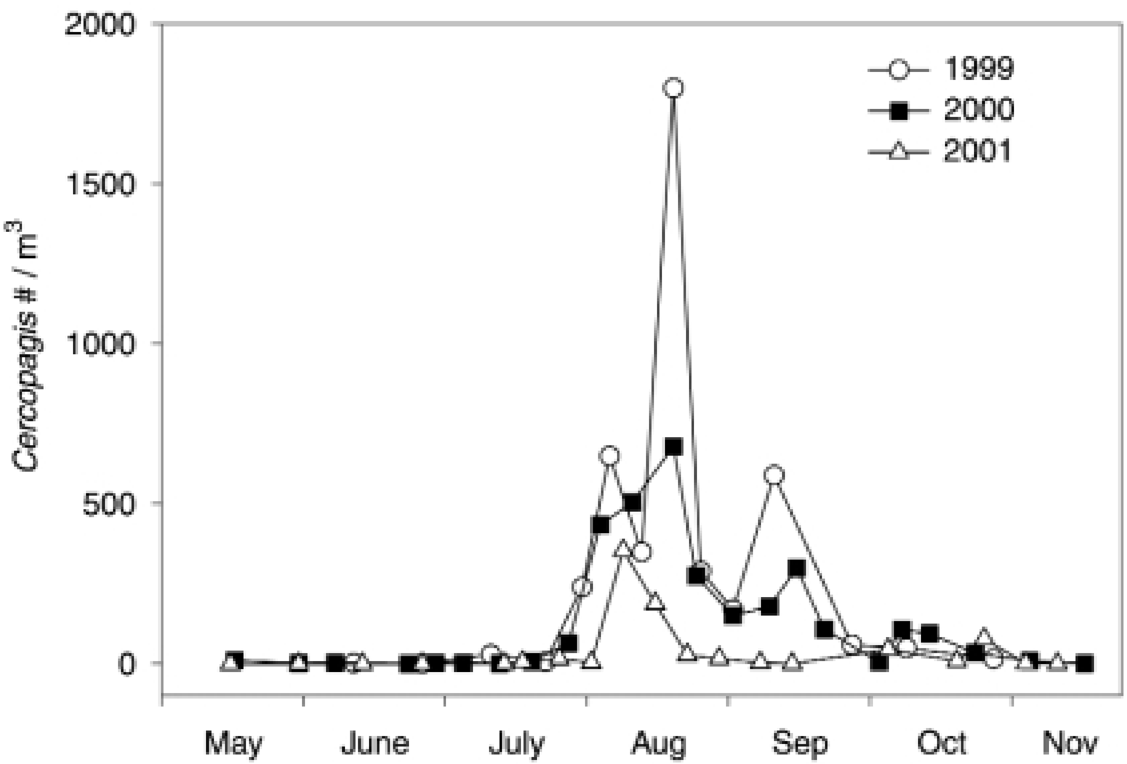

Figure 2. Seasonal distribution of *Cercopagis pengoi* in the offshore of Lake Ontario due north of Hamlin Beach State Park, New York. Samples were taken with a double Bongo net hauled from 20 m to the surface.

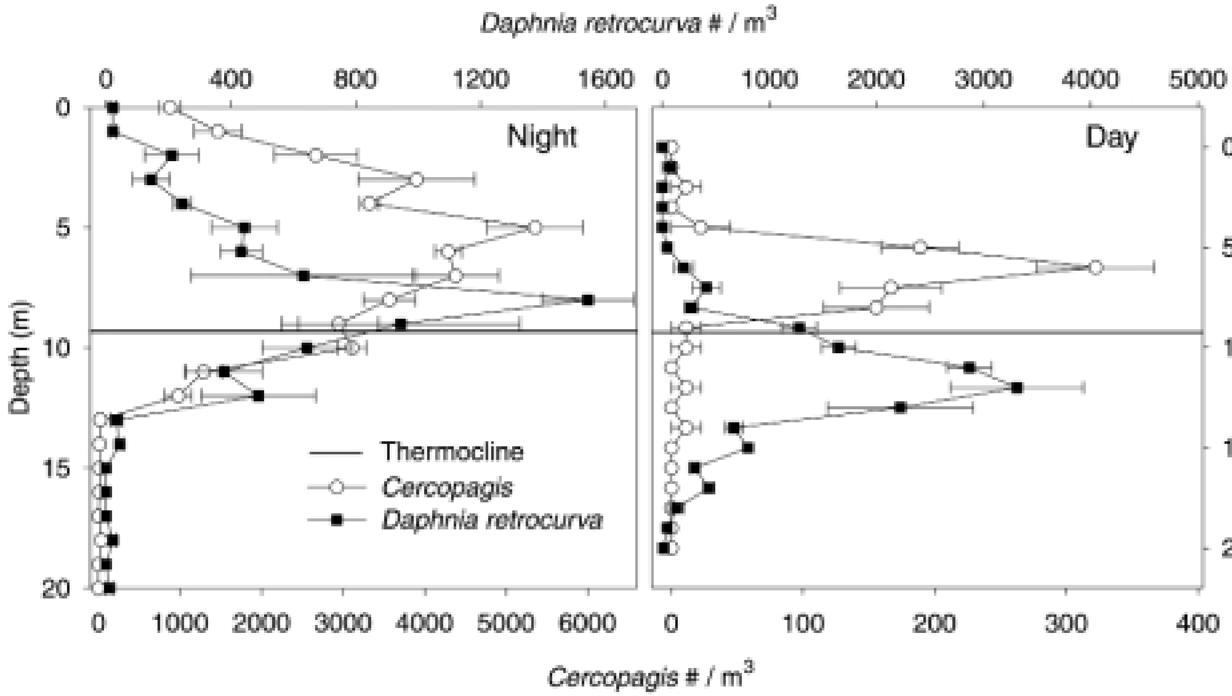

Figure 3. Vertical distribution of *Daphnia retrocurva* and *Cercopagis pengoi* in Lake Ontario over a 24-hour sampling period. Values are the mean ± the S.E. of the replicated count.

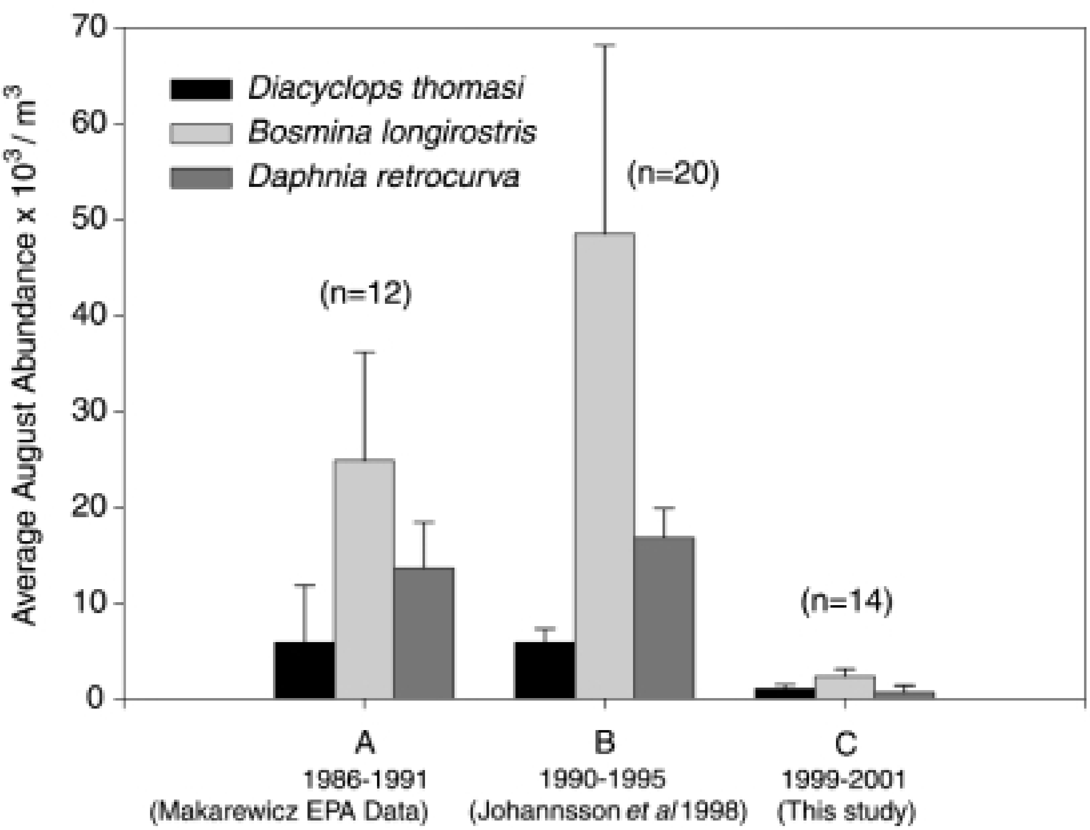

Figure 4. Average August abundance of dominant zooplankton before and after the appearance of *Cercopagis pengoi* in Lake Ontario. Values are the mean ± the S.E.

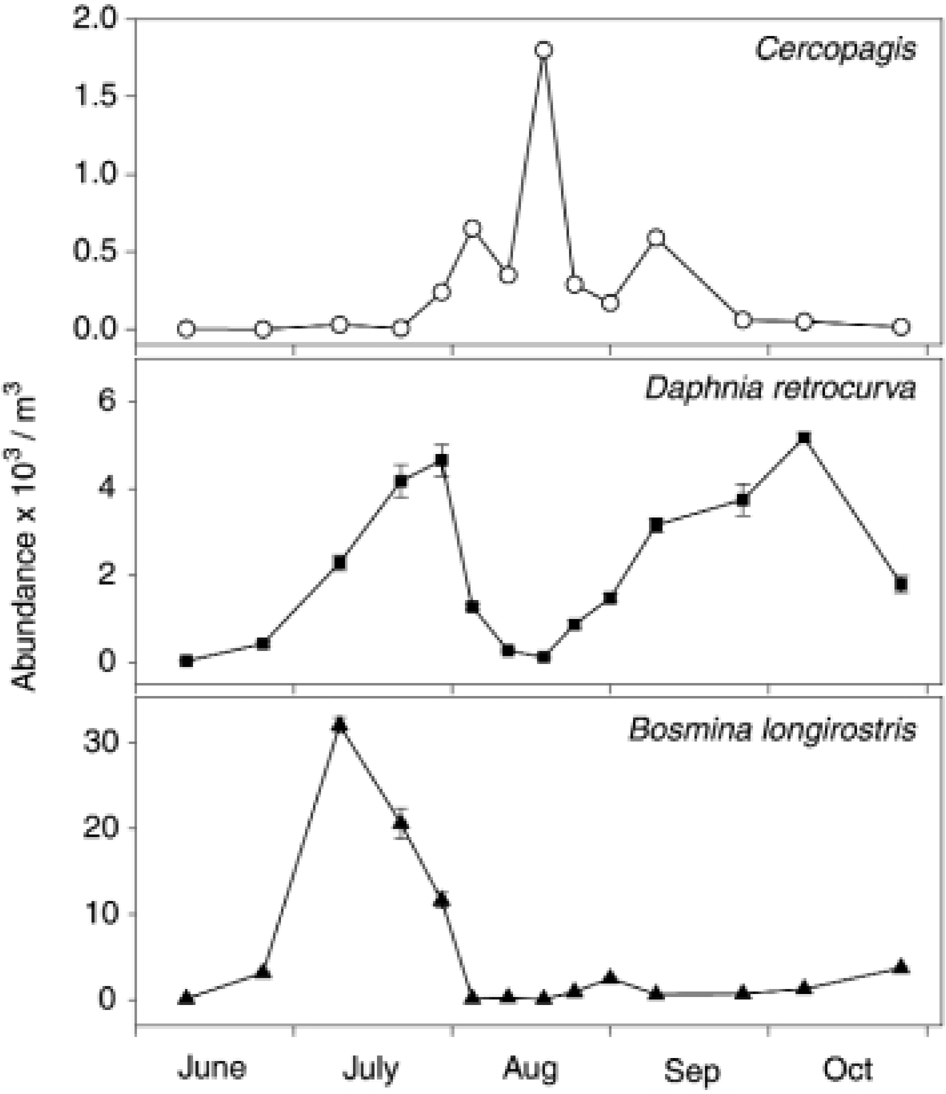

Figure 5. Seasonal distribution of *Daphnia retrocurva*, *Bosmina longirostris*, and *Cercopagis pengoi* in Lake Ontario, 1999. Values are the mean + S.E. of the replicated count.

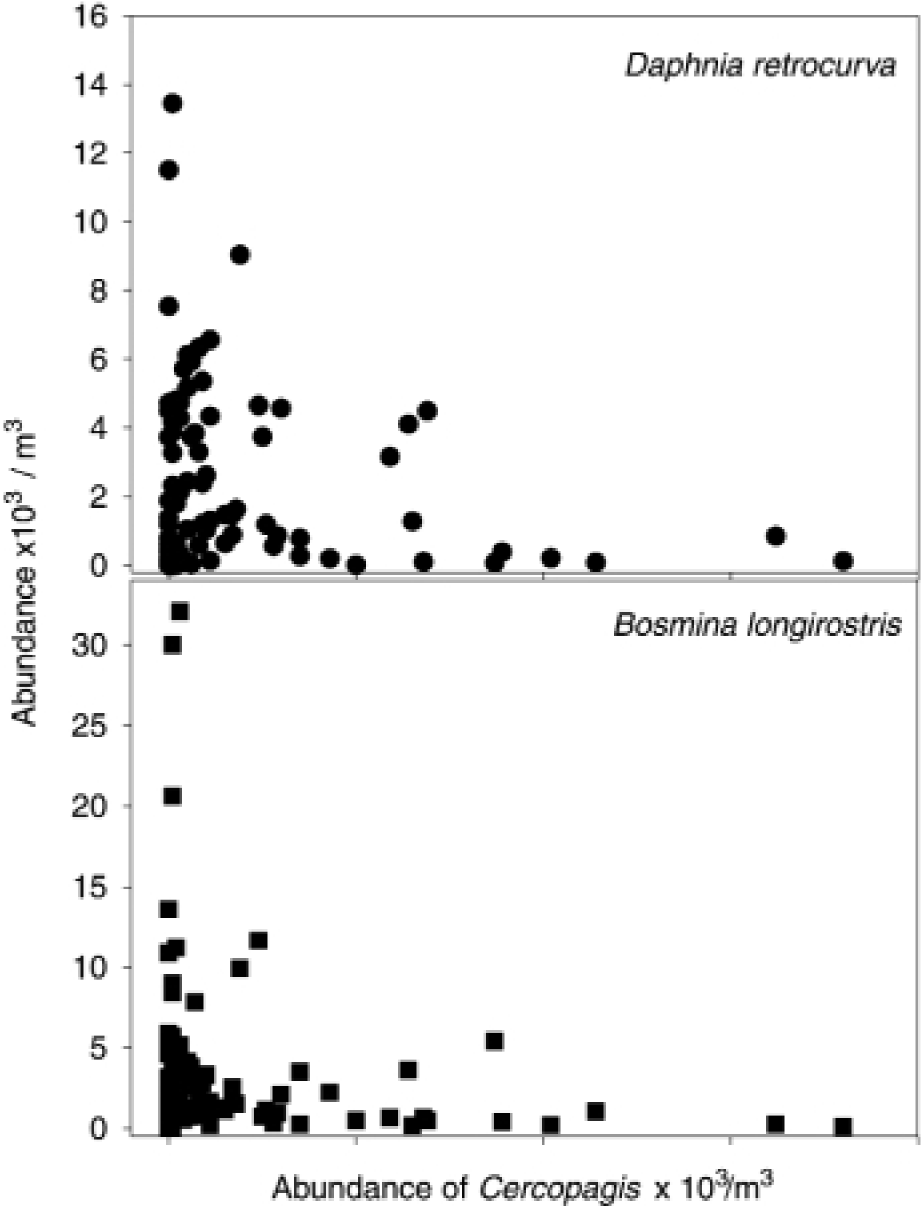

Figure 6. Simultaneous abundances of *Cercopagis pengoi* and other cladoceran species from 1999 to 2001 (n=111).

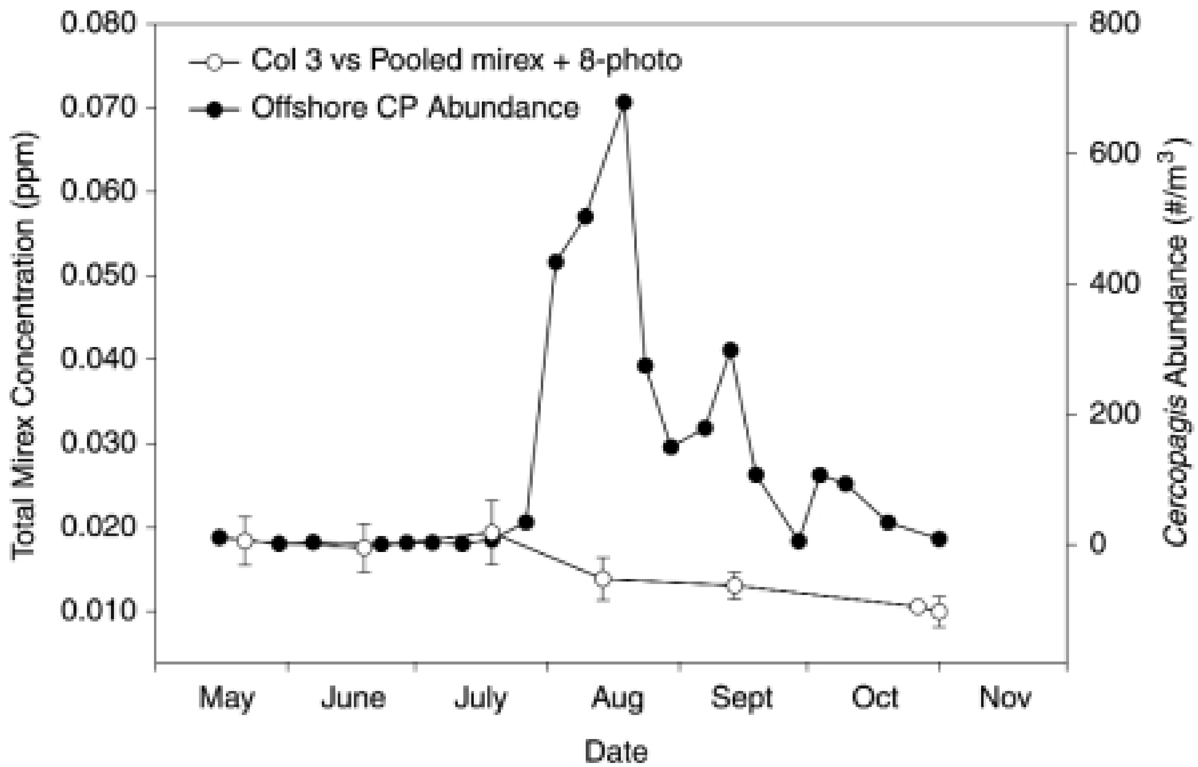

Figure 7. Seasonal *Cercopagis* abundance and total mirex concentration in *Alosa psedoharengus* (age 2+), Lake Ontario, 2000. Values are the mean ±S.D.