Appendix F-1

Assessing Community Structure of Lower Trophic Levels in Onondaga Lake, New York in 2013

2013 Annual Report

June 2014

Prepared by

Lars G. Rudstam and Christopher Hotaling

Department of Natural Resources
Cornell Biological Field Station
900 Shackelton Point Rd.
Bridgeport, NY 13030

Introduction

This report summarizes the information collected by Onondaga County and processed by Cornell Biological Field Station. To efficiently visualize this information, we provide a series of tables and graphs with the 2013 data including some interpretation of the observed patterns. We also provide a series of graphs that put the year 2013 in a longer term perspective by comparing 2013 with previous years of AMP data from Onondaga Lake. This information is incorporated in the annual report for the Onondaga Lake Ambient Monitoring Program (AMP) and we refer the reader to that report for a broader view of the connections between nutrient loading, water chemistry, and the biology of the lake. This section deals specifically with the phytoplankton and zooplankton data. A series of significant findings for the year 2013 are at the end of the report.

A section is also provided that documents the methods used in 2013. There were two changes in 2013 compared to previous years. First, sampling was discontinued at the North Station. This station seldom showed different results from the South station in data collected from 1998 to 2012. Zooplankton and phytoplankton biomass were highly correlated when comparing zooplankton data collected from 1995 to 2012 at both stations on the same day (R^2=0.69, p<.0001, N=104) and when comparing phytoplankton data collected at both stations on the same day from 2002 to 2012 (R^2=0.82, p<.0001, N=50). Further, paired t-tests of the $\log_{10}$ transformed zooplankton biomass showed no significant differences between the north and south stations for the integrated whole water column samples (p=0.077, N=59) or for the upper mixed layer samples (p=0.276, N=45). The same paired t-test comparing the $\log_{10}$ transformed phytoplankton biomass from the north and south stations did reveal significant difference between the two stations (p<0.022, N=50) although the mean differences were not large (mean north station 1.07 mg/L, mean south station 0.92 mg/L). Second, flowmeter measures were used to calculate the volume filtered by the zooplankton net in 2013. In previous years, we had used tow depth and an assumption of 100% efficiency of the plankton net because flowmeters were not available or appeared to malfunction for years 1995-1999, part of 2003, 2004, 2007, and part of 2009. However, using a flowmeter will give a better measure of volume filtered and therefore of zooplankton biomass density. Because a sufficient number of years with flowmeter data is now available, we now will use these measures when available. For the years with no flowmeter readings, we used the average efficiency calculated from the years with flowmeter readings (83.6%). This will change the time trend graphs slightly compared to previous years reports but should give a more accurate estimate of biomass and density in the lake.

Methods

Samples for zooplankton and phytoplankton were collected approximately biweekly from April (4/4) through November (11/26) in 2013 with one additional samples from January 8, 2013. Total number of sampling occasions was 18. All samples were taken at the South Deep station in 2013.

Phytoplankton samples were preserved in Lugol's iodine solution. The phytoplankton sample for each date and sampling site is an integrated sample of the upper mixed layer (UML) of the water column or the top 6 m of water when the lake was not stratified. In 2013, all samples were from 6 m depth to the surface. All integrated water samples for phytoplankton analysis were collected using a 2 cm inner diameter Tygon tube.

Phytoplankton samples were processed by PhycoTech, Inc. (Owner Dr. Ann St Amand, 620 Broad St., Ste. 100, St. Joseph, MI 49085). Raw water samples were run through filtration towers, and the filters from these towers were then made into slides. The method used in counting the phytoplankton depended on the relative importance of soft algae and diatoms in the samples as well as algal size. Phytoplankton cells were identified to species when possible and cells were measured to determine species-specific greatest axial length dimension (GALD) and individual biovolume. Species with GALD>50µm were classified as net-plankton and species with GALD<50µm were classified as nano-plankton. Total biovolume for each species was calculated by multiplying cell concentration by individual biovolume. PhycoTech reported total biovolume in $\mu m^3/mL$, which we converted to cm^3/m^3 (a unit more commonly used in the literature) by dividing by 1,000,000 or to µg/L by dividing by 1000. We assume the density of algal cells was equal to that of water (1 g/cm^3) to convert biovolume to biomass. A compendium of algal cell sizes including the data from Onondaga Lake is in Kremer et al. (2014).

Zooplankton samples were collected with vertical hauls using a 0.50 m diameter net with 80 µm nylon mesh. Vertical tows were taken from the upper mixed layer from a depth of 15 meters on all sampling occasions. A tow from six meters was added during part of the year when the lake was thermally stratified (from 6/25 to 9/18 in 2013). Samples were preserved using 95% ethyl alcohol; this preservative comprised at least 70% of each final sample volume. Flow meter readings were taken on the zooplankton net tows to determine the volume of water strained in each haul. In 2013, calculated efficiency of the net varied between 47 and 119%, with an average of 80.3% (N=25, SE 3.3%).

Flow meters have been used consistently since 2010 but are not available for all years. Therefore, we calculated the average efficiency of this net for all samples taken from 2010 through 2013 (83.6%, N = 188, SE 1.3%). Efficiencies varied some between years (87% in 2010, 87% in 2011, 79% in 2012 and 81% in 2013). For years with samples collected without a flowmeter (1995-1999, 2007, part of 2009), the densities are calculated using the tow depth and assuming the average 83.6% efficiency of the net. For some years with flowmeter data, we noticed some unrealistically low values, likely due to malfunctioning flowmeters. Therefore, we replaced any efficiencies calculated to be less than 40.3% with 83.6% (40.3% represents the average of 83.6% minus 2.5 times the standard deviation for years 2010-2013). We also assumed efficiency higher than 200% to be in error but no such values were present in the data set. "Efficiencies" larger than 100% can occur when the boat is drifting during sampling. Because unrealistically low efficiencies were common from August 2003 through 2004, all efficiencies from that time period were also replaced by the 83.6% average. It is likely that the flowmeter did not work properly from August 2003 through 2004. Efficiencies in 2000-2002, 2005-

2006 and 2008-2013) were accepted if larger than 40.3%. Average efficiencies for those years were 68% (2000, N=56), 70% (2001, N=48), 68% (2002, N=59), 69% (2003 through July, N=20), 82% (2005, N=63), 66% (2006, N=64), 95% (2008, N=38), and 102% (2009, N=22). The higher efficiencies in 2008 and 2009 are reasonable given that water clarity was substantially higher in those two years than in surrounding years.

For time trends, we used the integrated samples in spring and fall and the upper mixed layer samples during the summer (6/25 through 9/18 in 2013). These depths were sampled all years in summer. Integrated samples from 15 m were not always collected in the summer. Only South Deep station data are included in the time trends. These restrictions are necessary to allow for comparisons of the same type of data over all years.

A compound microscope (40X-200X magnification) was used to identify zooplankton to species when possible. For each sample, one to three 1-mL subsamples were withdrawn with a pipette from a known volume of sample, until at least 100 individual zooplankton were counted and measured. Zooplankton length was measured using a compound scope equipped with a drawing tube and a digitizing pad interfaced with a computer. Dry mass was estimated for each measured animal from standard species-specific length-weight regressions compiled by Watkins et al. (2011, CBFS standard equations).

Results and Discussion

Data analyzed are from 1996 to 2013 and result and discussions of each data set are included in the table and figure headings when appropriate. A summary of significant findings is provided at the end of the document.

<u>Tables for 2013 data:</u>

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Table 2. Comparison of zooplankton abundance in 15 and 6 m tows from June through September.
Table 3. Phytoplankton abundance and biovolume for the major divisions.
Table 4. Major genera of phytoplankton.

<u>Figures for 2013 data:</u>

Figure 1 Biovolume and proportional composition of phytoplankton of 7 algal division.
Figure 2 Seasonal trend in phytoplankton in Onondaga Lake divided in net-plankton (GALD>50 µm) and nano-plankton (GALD<50 µm).
Figure 3. Composition by genera of cyanophytes (bluegreens).
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Figure 8. Average length of crustacean zooplankton in Onondaga.
Figure 9. Seasonal development of phytoplankton and zooplankton biomass in Onondaga Lake.

Figures for time trends:
Figure 10. Time trend in annual average phytoplankton biomass in Onondaga Lake, 1998 – 2013.
Figure 11. Time trend of annual average phytoplankton biomass divided in 7 divisions, 1998-2013. Second panel shows the proportions of the 7 divisions over time.
Figure 12. Time trend of cyanophytes by major genera, 1998-2013
Figure 13. Average crustacean zooplankton biomass 1996-2013, and time trends for selected major groups.
Figure 14. Time trend of the biomass of different *Daphnia* species in Onondaga Lake, 1996-2013.
Figure 15. Time trend of the biomass of *Cercopagis pengoi* in Onondaga Lake 1996 to 2013.
Figure 16 Time trend of average length of crustacean zooplankton in Onondaga Lake, 1996-2013.
Figure 17. Comparison of time trends in zooplankton and phytoplankton biomass.

Onondaga Lake in 2013

Table 1. Biomass (µg/L, dwt) of the major zooplankton groups in Onondaga Lake in 2013. Groups are Calanoid copepods (*Skistodiaptomus oregonensis, Epischura lacustris* and *Eurytemora affinis*), Cyclopoid copepods (mostly *Diacyclops thomasi*, a few *Mesocyclops edax*, *Acanthocyclops vernalis* and *Tropocyclops prasinus*), copepod nauplii, Bosminids (*Bosmina longirostris*, a few *Eubosmina coregoni*), Daphniids (*Daphnia mendotae* and *Daphnia retrocurva*), Other cladocerans (*Ceriodaphnia*, *Diaphanosoma*, *Chydorus*), Predatory cladocerans (*Cercopagis pengoi*). Standard samples are the South Deep integrated samples from 1/8 through 6/11 and from 10/1 to 11/26; South Deep upper mixed layer samples from 6/25 to 9/18. S-Int: integrated water column samples taken from 15 m depth. S-UML: upper mixed layer samples taken from 6 m depth.

Total zooplankton biomass density was between 9 and 426 µg/L. Cyclopoid copepods (mainly *Diacyclops thomasi)* were most abundant in April through June. Bosminids were abundant from June 13 to July 23, with a second peak in October. Daphniids and calanoid copepods were rare. The low abundances of both daphniids and calanoids indicate high alewife planktivory in 2013.

Date	StationID	Calanoid copepods	Cycl.. copepods	Nauplii	Bosminids	Daphniids	Other cladocerans	Predatory cladocerans
1/8/2013	S-Int	0.00	20.15	5.51	3.91	0.00	0.00	0.00
4/4/2013	S-Int	0.00	101.66	4.66	0.74	0.00	0.00	0.00
4/15/2013	S-Int	0.00	8.59	1.02	0.30	0.00	0.00	0.00
4/29/2013	S-Int	0.00	11.03	2.22	0.67	0.00	0.00	0.00
5/14/2013	S-Int	0.00	26.72	3.94	0.48	0.00	0.00	0.00
6/11/2013	S-Int	0.94	24.73	2.47	23.71	0.00	0.00	0.00
6/25/2013	S-Int	6.54	41.99	2.17	123.57	0.16	0.00	0.00
6/25/2013	S-UML	6.45	21.55	3.93	276.88	0.70	0.00	0.00
7/9/2013	S-Int	4.76	23.74	0.85	172.87	1.74	0.00	0.55
7/9/2013	S-UML	7.88	8.70	0.78	405.35	2.94	0.00	0.04
7/23/2013	S-Int	1.26	6.47	1.55	16.59	4.01	0.68	0.74
7/23/2013	S-UML	3.52	4.68	1.72	48.46	4.11	0.80	1.71
8/6/2013	S-Int	1.26	2.28	0.21	3.01	0.97	3.01	1.10
8/6/2013	S-UML	0.00	0.00	0.33	10.71	1.22	2.24	6.56
8/20/2013	S-Int	0.00	9.02	1.48	4.88	0.94	5.26	0.30
8/20/2013	S-UML	0.00	12.15	0.22	12.20	1.00	11.51	1.24
9/4/2013	S-Int	0.00	0.42	0.35	6.03	0.00	0.80	2.05
9/4/2013	S-UML	0.00	2.21	0.73	12.77	3.23	6.34	5.65
9/18/2013	S-Int	0.00	3.09	0.31	3.79	0.10	0.81	0.55
9/18/2013	S-UML	0.00	2.27	0.00	7.08	0.68	0.34	1.82
10/1/2013	S-Int	0.00	0.65	0.32	14.24	0.53	0.50	0.00
10/15/2013	S-Int	0.29	4.45	0.99	20.64	0.67	1.26	0.00
10/30/2013	S-Int	0.36	2.07	0.69	45.53	0.34	0.33	0.00
11/13/2013	S-Int	3.11	1.74	1.20	48.55	0.32	0.00	0.00
11/26/2013	S-Int	0.00	1.95	2.05	11.04	0.00	0.00	0.00

Table 2. Comparison of biomass (volumetric in mg/m^3 (=µg/L) and areal in mg/m^2, both in dry wt) obtained with integrated (S-Int, 15 m) and upper mixed layer (S-UML, 6 m) tows. The proportion of the total zooplankton biomass found in the UML is calculated as the ratio of the areal density in the upper mixed layer divided by the total areal density in the integrated tow. For all dates, the biomass per unit volume was higher in the UML and with the exception of 9/18, more than 2/3 of the zooplankton biomass was found in the UML. On 9/4, more zooplankton biomass was found in the upper mixed layer than in the whole water column, which results in over 100% of the zooplankton in the epilimnion with these calculations. We attribute this to patchy distributions. There was no indication of an aggregation of metalimnetic zooplankton in 2013. Such aggregations occur in lakes with high abundance of planktivorous fish and an oxygenated metalimnion (e.g. Klumb et al. 2004, Holeck et al. 2013).

Date	**StationID**	**Volumetric Total Biomass (mg/m^3)**	**Areal Total Biomass (mg/m^2)**	**Proportion in the UML (%)**
6/25/2013	S-Int	174.43	2616	
6/25/2013	S-UML	309.51	1857	71
7/9/2013	S-Int	204.52	3068	
7/9/2013	S-UML	425.69	2554	83
7/23/2013	S-Int	31.30	469	
7/23/2013	S-UML	65.01	390	83
8/6/2013	S-Int	11.85	178	
8/6/2013	S-UML	21.06	126	71
8/20/2013	S-Int	21.88	328	
8/20/2013	S-UML	38.32	230	70
9/4/2013	S-Int	9.65	145	
9/4/2013	S-UML	30.92	186	128
9/18/2013	S-Int	8.66	130	
9/18/2013	S-UML	12.19	73	56

Table 3. Biomass (µg/L) of phytoplankton in Onondaga Lake in 2013 in the upper mixed layer or top 6 m of the water column. The phytoplankton community of Onondaga Lake consisted of, in order of importance, Bacillariophyta, Chrysophyta, Chlorophyta, Cryptophyta, Cyanophyta, Pyrrhophyta, Haptophyta and Euglenophyta.

Date	**Bacillario phyta**	**Chlorop hyta**	**Chrysop hyta**	**Cryptop hyta**	**Cyanop hyta**	**Euglenop hyta**	**Haptop hyta**	**Pyrrhop hyta**
1/8	95.03	20.89	0.75	431.89	2.48	0.00	0.00	0.00
4/4	956.23	12.50	347.83	120.53	2.36	0.00	0.00	6.65
4/16	1470.74	10.59	172.85	33.17	3.59	0.00	0.00	8.51
4/29	1334.46	26.25	137.40	71.73	3.59	6.17	0.00	0.00
5/14	2595.81	3.96	414.08	113.17	3.26	0.00	0.00	4.73
6/11	293.59	22.25	207.85	190.35	36.65	0.00	0.00	4.73
6/25	6.14	42.36	532.13	57.50	0.19	0.00	0.00	36.30
7/9	22.96	150.90	22.37	183.63	4.50	0.00	0.00	0.00
7/23	5082.23	264.93	115.26	270.77	1.99	0.00	0.00	74.85
8/6	431.29	285.09	940.53	80.46	16.63	0.00	0.00	0.00
8/19	1911.46	454.26	382.13	253.04	120.41	0.00	0.00	0.00
9/3	1003.76	572.27	207.83	46.64	38.40	0.00	0.00	9.27
9/18	531.34	209.95	127.87	213.14	194.86	0.00	0.00	0.00
9/30	148.84	923.29	154.25	153.67	584.99	0.00	21.58	0.00
10/14	13.17	247.22	21.77	253.39	108.34	0.00	0.00	52.50
10/29	15.06	66.04	13.03	266.07	10.78	0.00	0.00	0.00
11/13	13.63	23.27	0.00	179.22	16.13	0.00	0.00	0.00
11/25	15.52	21.63	0.00	183.78	20.99	0.00	0.00	0.00

Table 4. The major algal genera in Onondaga Lake in 2013 at the South Station contributing more than 1% of the total average biovolume (16 genera in 2013). Number of species identified were 24 diatoms, 36 chlorophytes, 11 chrysophytes, 3 cryptophytes, 12 cyanophytes, 6 pyrrophytes, 1 euglenophyte, and 1 haptophyte. The most abundant genera in 2013 were five diatoms, five chlorophytes, two cryptophytes, three chrysophytes, and one cyanophyte. In 2013 the dominant algal genus changed through the season with *Asterionella*, *Ochromonas* and *Synedra* in April-May, *Cyclotella* and *Cryptomonas* in June, *Urosolenia* and *Erkenia* in July, *Cryptomonas* and *Synedra* in August-November. *Urosolenia* is a diatom that was not identified in 2012 but has been observed in previous years in the lake (2007 and 2011). It was abundant during a peak phytoplankton period in July. Values given are the mean of all south samples during the year. Relative biomass is in proportion to the sum of all measured biomass in the 2013.

Genus	Division	Mean Biomass (ug/L)	Relative biomass (% of total)	2012 Biomass/Rank
Urosolenia	**Bacillariophyta**	28.6	18.0	Not found
Synedra	**Bacillariophyta**	25.7	16.2	166.2/2
Erkenia	**Chrysophyta**	15.1	9.5	78.2/5
Asterionella	**Bacillariophyta**	14.9	9.4	61.5/6
Cyclotella	**Bacillariophyta**	12.2	7.6	169.3/1
Diatoma	**Bacillariophyta**	10.2	6.4	41.9/10
Cryptomonas	**Cryptophyta**	10.2	6.4	146.3/3
Rhodomonas	**Cryptophyta**	5.6	3.5	34.1/11
Chlamydomonas	**Chlorophyta**	5.2	3.2	25.1/12
Ochromonas	**Chrysophyta**	4.3	2.7	49.4/7
Closterium	**Chlorophyta**	4.0	2.5	8.9/25
Pseudanabaena	**Cyanophyta**	3.1	2.0	5.5/29
Chlorococcales[1]	**Chlorophyta**	2.3	1.5	46.9/8
Mougeotia	**Chlorophyta**	2.2	1.4	1.4/44
Dinobryon	**Chrysophyta**	1.84	1.2	20.6/15
Tetraedron	**Chlorophyta**	1.82	1.1	4.7/30

1) The genus of the Chlorococcales was not determined.

Figure 1. Temporal trends in biovolume (panel A) and proportional biovolume (panel B) of phytoplankton divisions in Onondaga Lake in 2013. Phytoplankton biomass peaked in May during the diatom-dominated spring bloom and again in July and August (diatom = Bacillariophyta). Biomass was low from the end of June through the beginning of August. The summer phytoplankton consisted of diverse assemblage including diatoms, chlorophytes, chrysophytes, and cryptophytes although the peak in July and August were again dominated by diatoms. A small peak in cyanophytes occurred in the end of September. The first sample was collected on 1/8 and the last on 11/25. Sample dates are in Table 3.

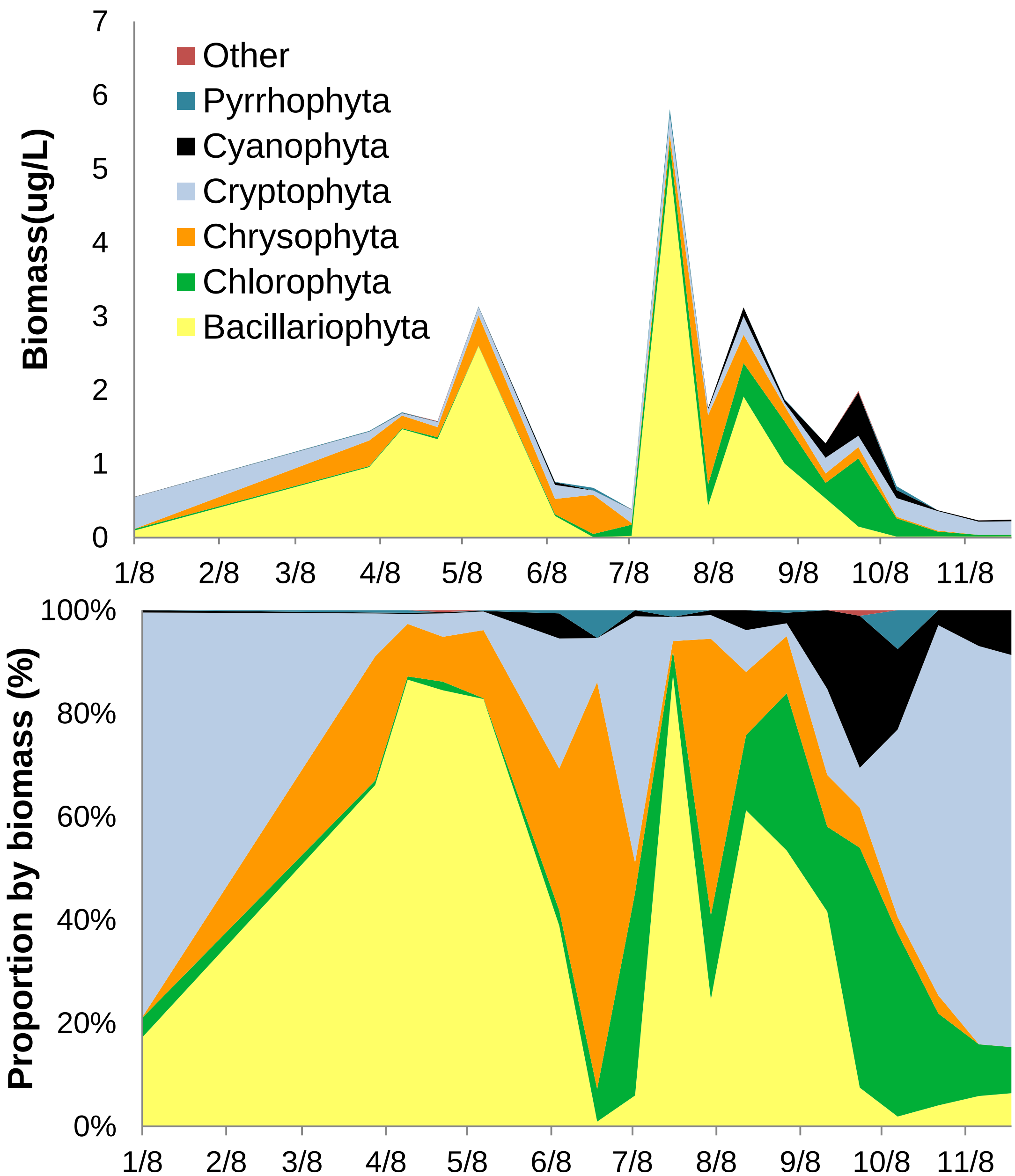


Figure 2. Temporal trends in phytoplankton in Onondaga Lake in 2013 divided in net phytoplankton (GALD>50 µm) and smaller phytoplankton (GALD<50 µm). With the exception of June and July, both large and small phytoplankton were present in 2013. .

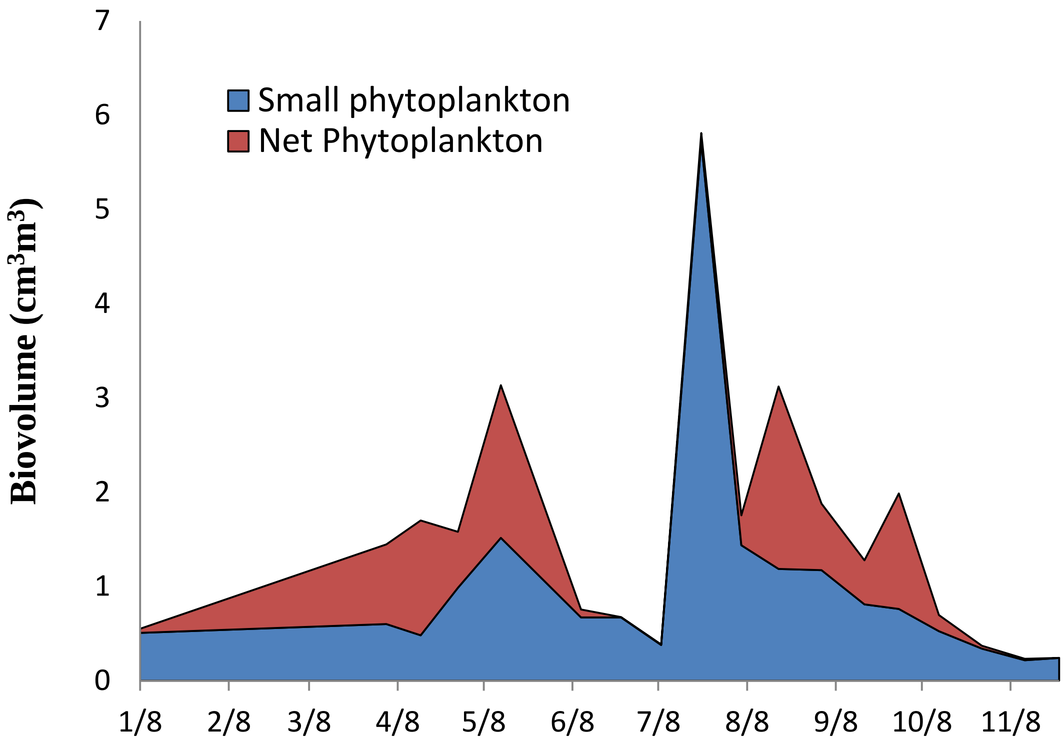


Figure 3. Temporal trend of biovolume of cyanobacteria genera in Onondaga Lake (South station) in 2013. Cyanobacteria biovolume was low throughout most of the year, except in September, when *Pseudanabaena limnetica* was present. *Cuspidothrix* is a filamentous bluegreen. Of the large nitrogen fixing bluegreens, only *Anabaena* was present in low numbers. The other group includes the genera *Aphanizomenon, Aphanocapsa*, *Aphanothece*, *Merismopedia*, *Planktothrix*, *Synechocystis* and *Synechococcus*.

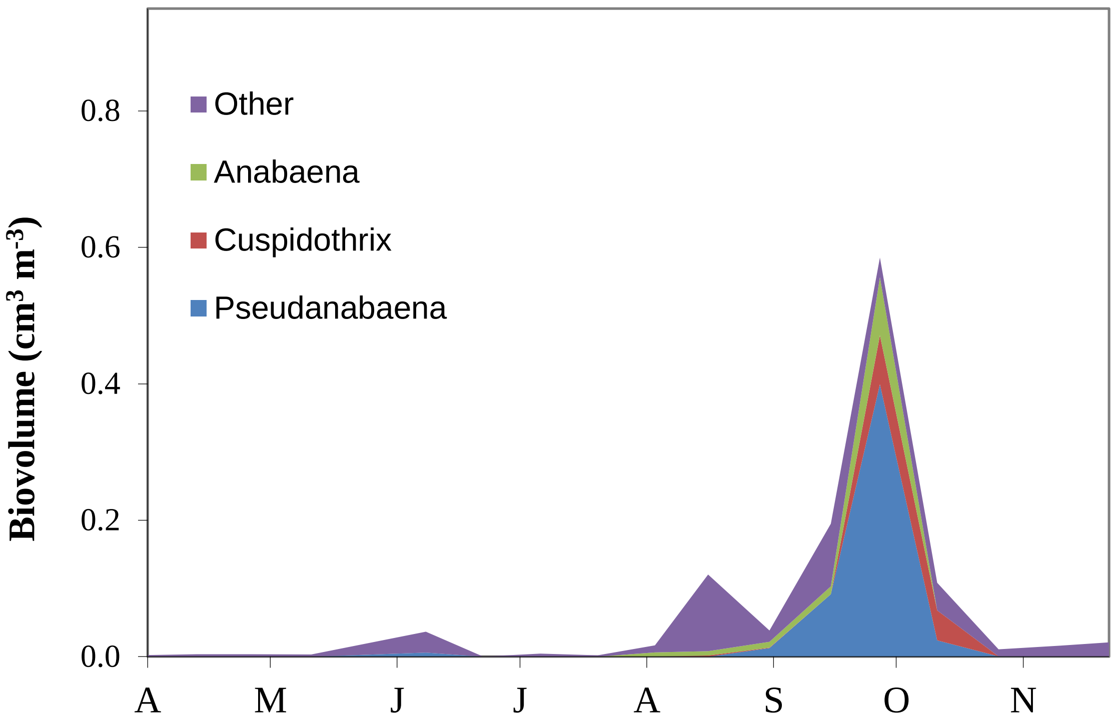


Figure 4. Total density (#/L) and biomass (ug/L) of crustacean zooplankton in Onondaga Lake in 2013 from South Deep integrated samples (1/18 from upper mixed layer). Density and biomass was highest in mid-June through mid-July and consisted mostly of *Bosmina*. The increase in the fall is also mainly *Bosmina* whereas the early April biomass is dominated by *Diacyclops*.

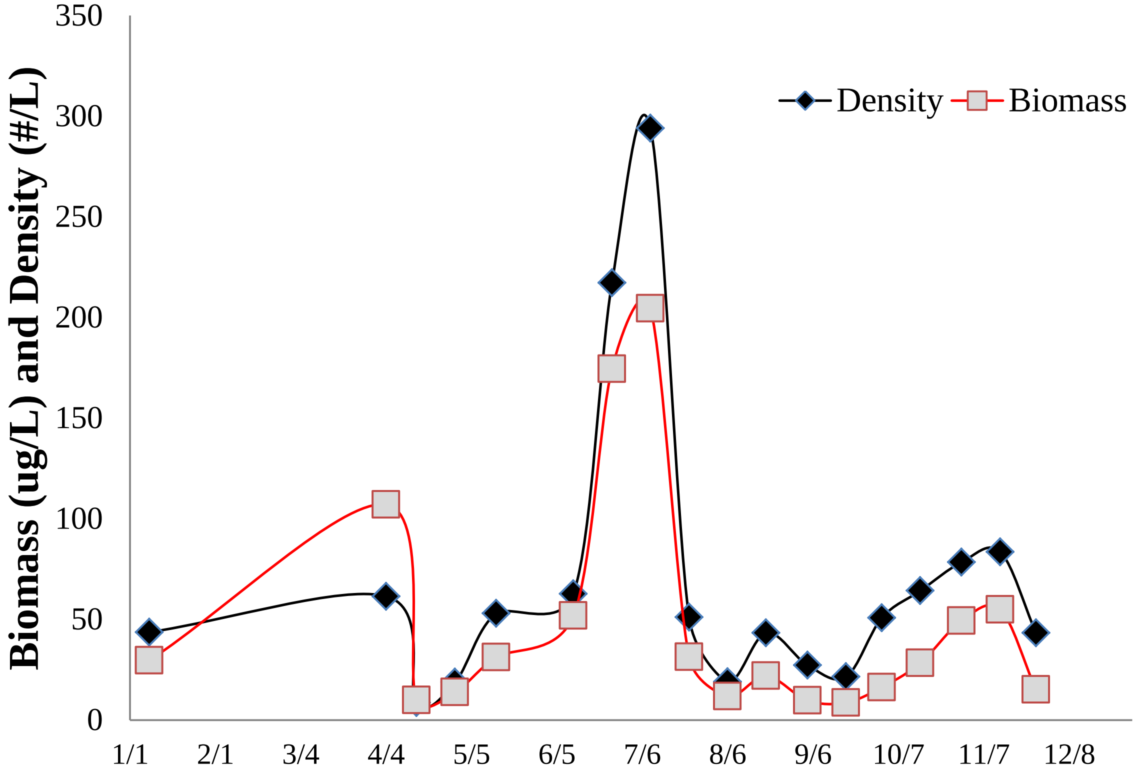


Figure 5. Total zooplankton biomass (dry mass) divided into copepods and cladocerans in Onondaga Lake, 2013. Samples represent integrated tows from 15 m depth to the surface at South Deep.

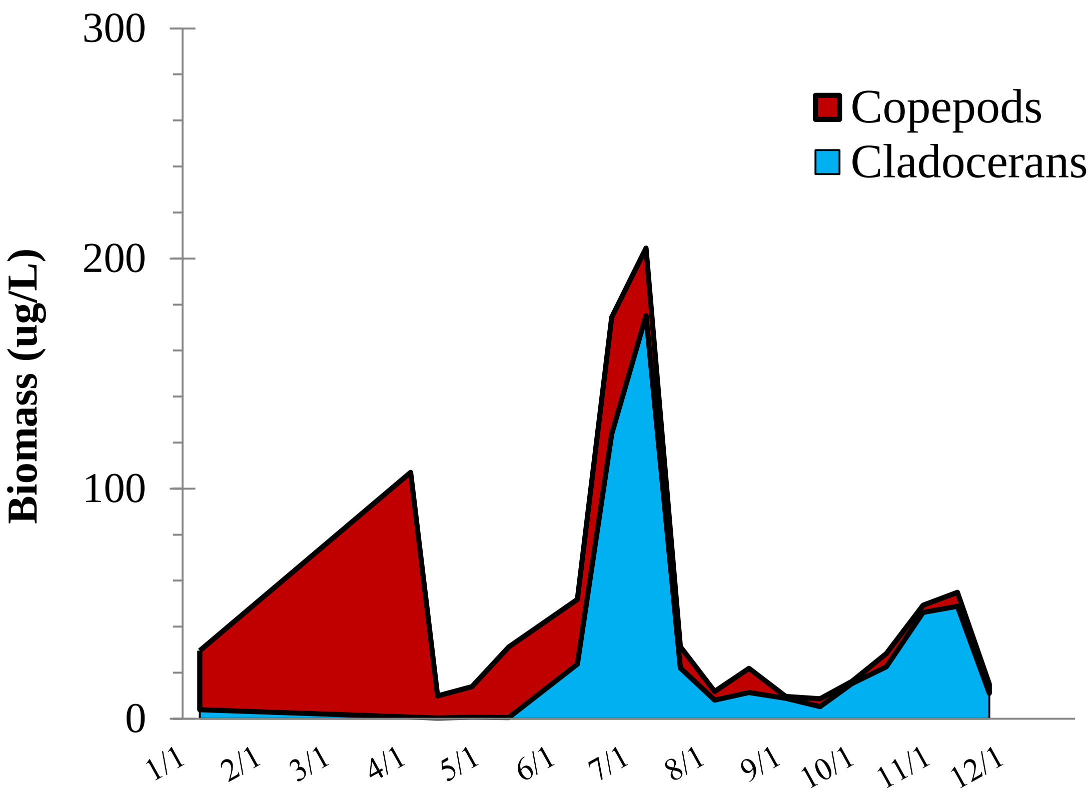
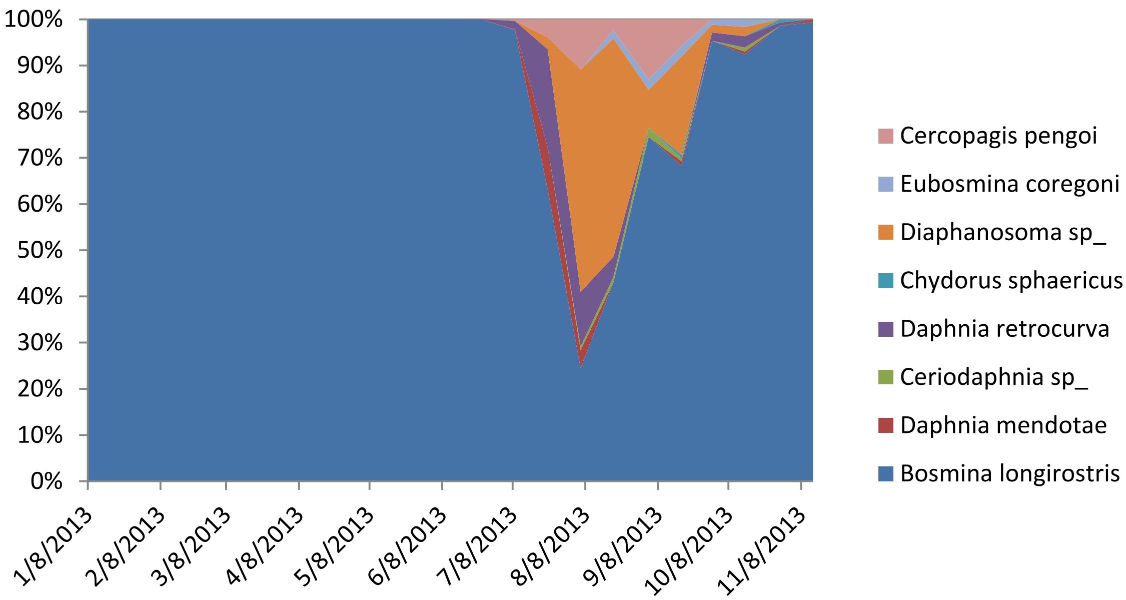


Figure 6. Composition of the cladoceran and copepod community in Onondaga Lake in 2013 in integrated samples. A total of 14 species, as well as nauplii and calanoids, cyclopoids and harpacticoid copepodites, were identified in 2013. *Bosmina longirostris* dominated the cladoceran group with other species rare. *Diacyclops thomasi* was the most common copepod species in the spring and early summer with higher diversity in the summer and fall. Nauplii and copepodites are not identified to species.



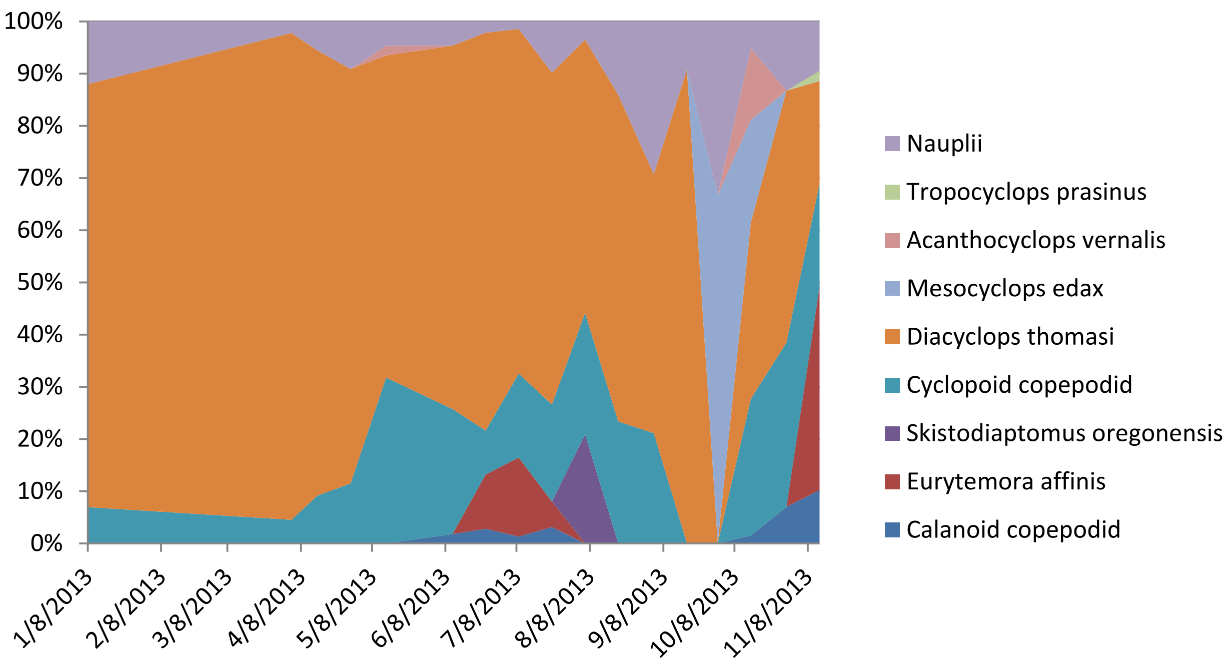


Figure 7. Biomass of predatory cladocerans in Onondaga Lake in 2013 and comparisons with recent years. The only species present in this group in 2013 was the exotic fish hook flea *Cercopagis pengoi*. *C. pengoi* was also observed in 1999, 2000, 2002- 2008, and 2010-2012. It was found in samples collected on 6 dates (7/9 to 9/18) and the seasonal pattern and abundance in 2013 was similar to 2010-2012. This graph is based on the 15-m tows (integrated water column samples).

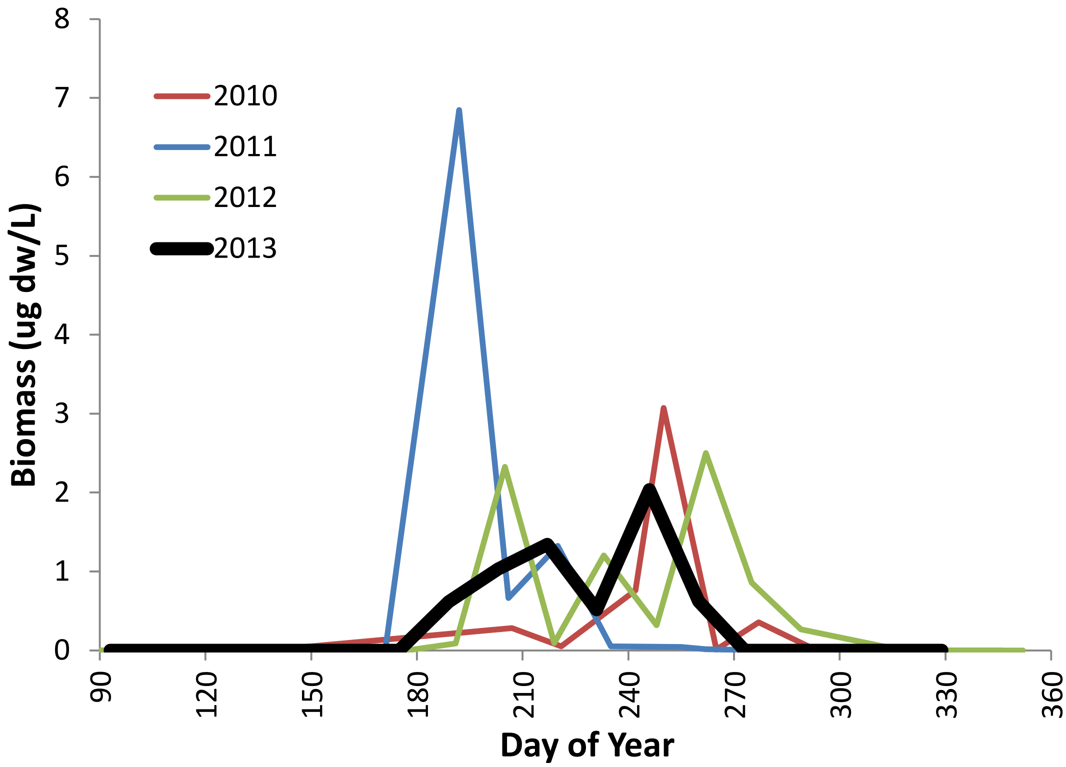


Figure 8. Average crustacean zooplankton length (mm) in Onondaga Lake in 2013. The largest mean size of zooplankton (0.69 mm) was observed in an early spring (4/4) sample when the copepod *Diacyclops* was common. The decline in length through June is due to increasing number of *Bosmina*. Lengths were slightly greater through the season than in recent years (2010-2012) but still indicative of a zooplankton community was dominated by *Bosmina* and cyclopoid copepods. Lengths were larger in 2009 when *Daphnia* was abundant June-August.

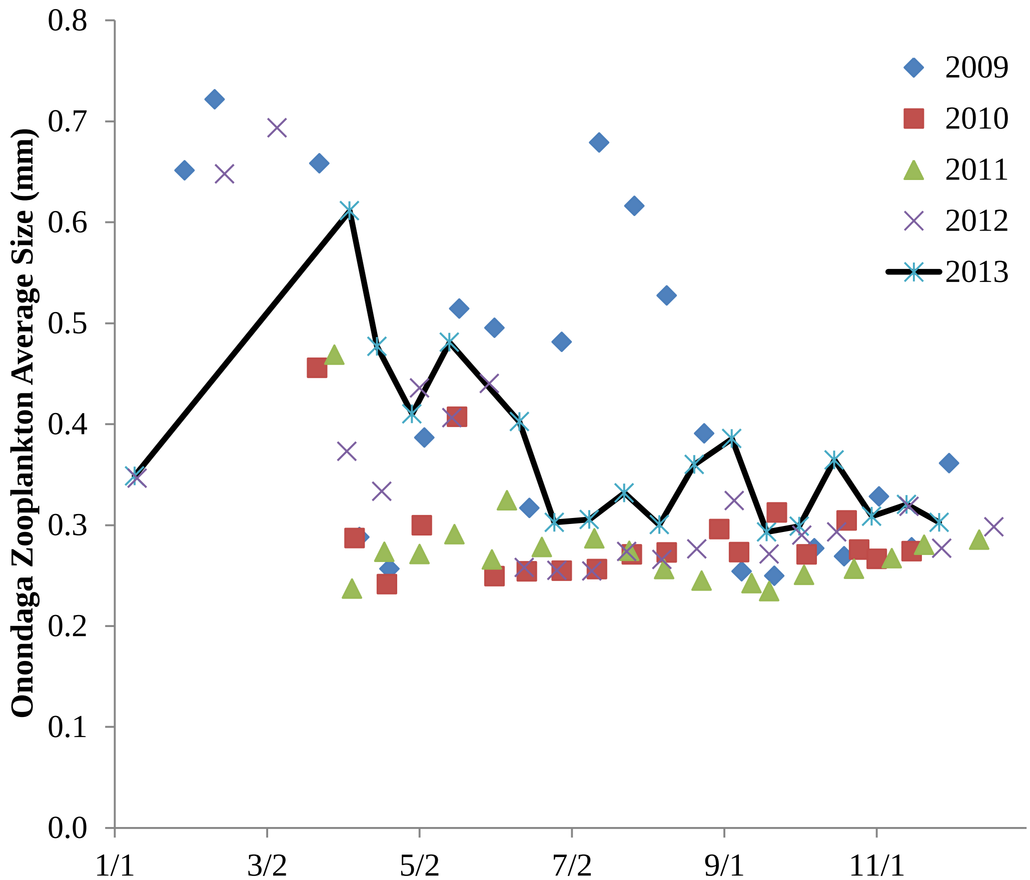
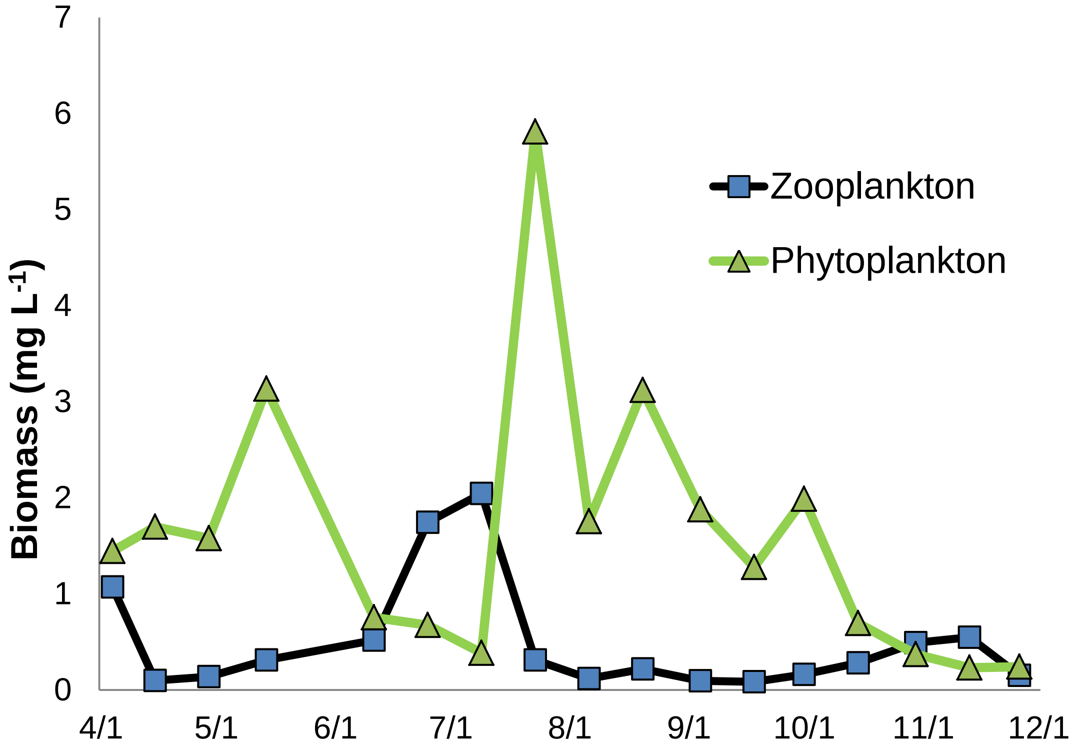


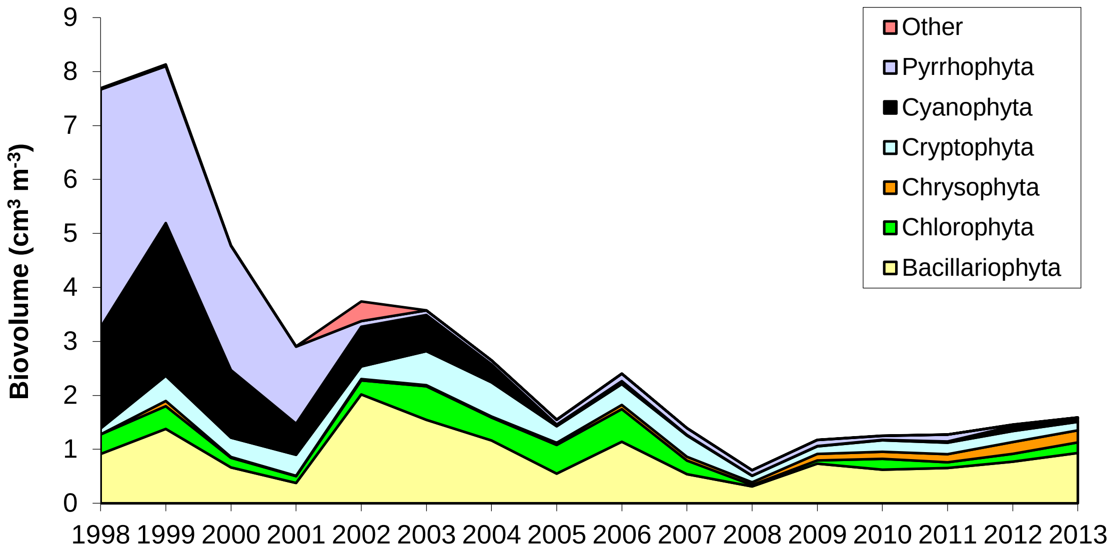
Figure 9. Temporal trend of zooplankton and phytoplankton biomass (wet mass) in Onondaga Lake in 2013. Zooplankton biomass was dominated by bosminids through most of the year. The decline in phytoplankton biomass after the middle of May is associated with declines in diatoms. Zooplankton biomass increased at that time but the decline could also be due to silica depletion as the decline was mainly in diatoms. Diatoms returned at the end of July and dominated through the year. There were very few *Daphnia* in 2013. Zooplankton wet weight is calculated from a dry/wet weight ratio of 10% commonly used for zooplankton. Other graphs in this report present zooplankton biomass is µg dry weight/ unit volume or unit area.



Time series 1996 – 2013 for Onondaga Lake

Figure 10. Temporal trend of average annual phytoplankton biovolume (April – October) in Onondaga Lake from 1998-2013. Annual biovolume decreased substantially during this period (linear regression, $R^2 = 0.68$, $p<0.0001$). However, there has been no decline in biovolume since the low values recorded in 2008.

Figure 11. Temporal trend of average annual biovolume (April-October) of phytoplankton divisions in Onondaga Lake from 1998-2013. The phytoplankton community of Onondaga Lake consists of mainly of Bacillariophyta, Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, and Pyrrhophyta. Chrysophytes are the only group that has increased over time (P<0.0001). All other groups declined; cyanobacteria and dinoflagellates declined significantly (p<0.001). The lower panel shows the proportional distribution of the 7 divisions. Chrysophytes and diatoms increased signficantly in proportional biovolume over this period (P<0.001), while dinoflagellates (Pyrrhophyta) and cyanophytes decreased (P<0.002). There were no significant changes in proportional biovolume for chlorophytes and cryptophytes.



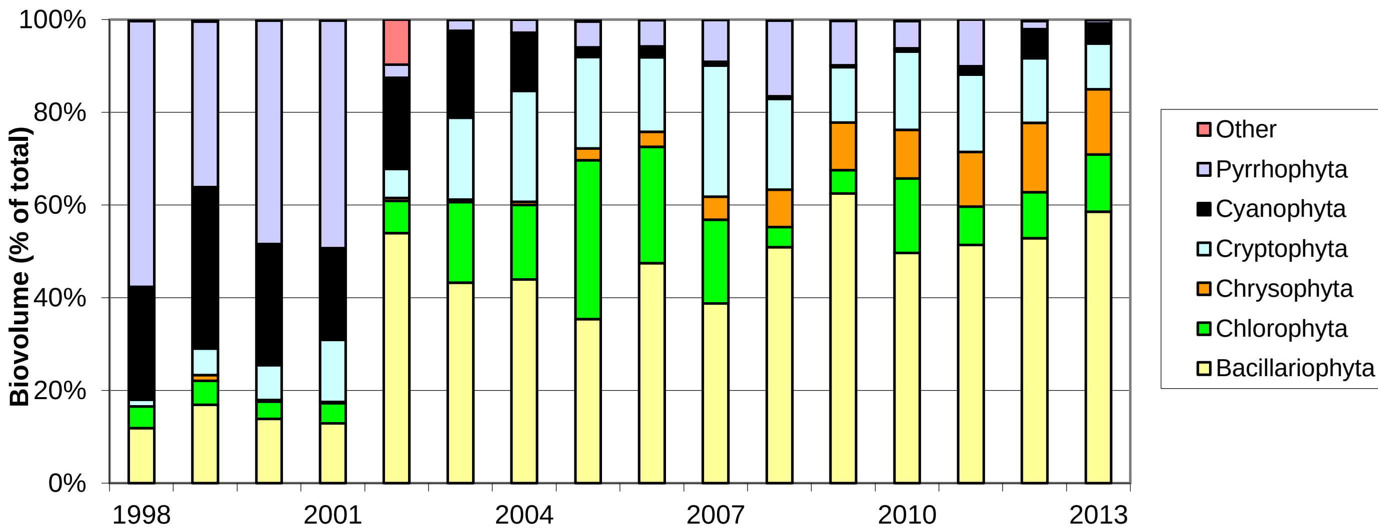


Figure 12. Time trend of mean annual biovolume of cyanobacteria genera in Onondaga Lake from 1998 to 2013, all dates sampled. Cyanobacteria biovolume in 2013 was higher than most recent years due to *Pseudanabaena* and *Cuspidothrix* in mid-August through mid-October. Both these species are moderate size net plankton (GALD 70- 250 um). Large bluegreens have been virtually absent from the lake since 2005.

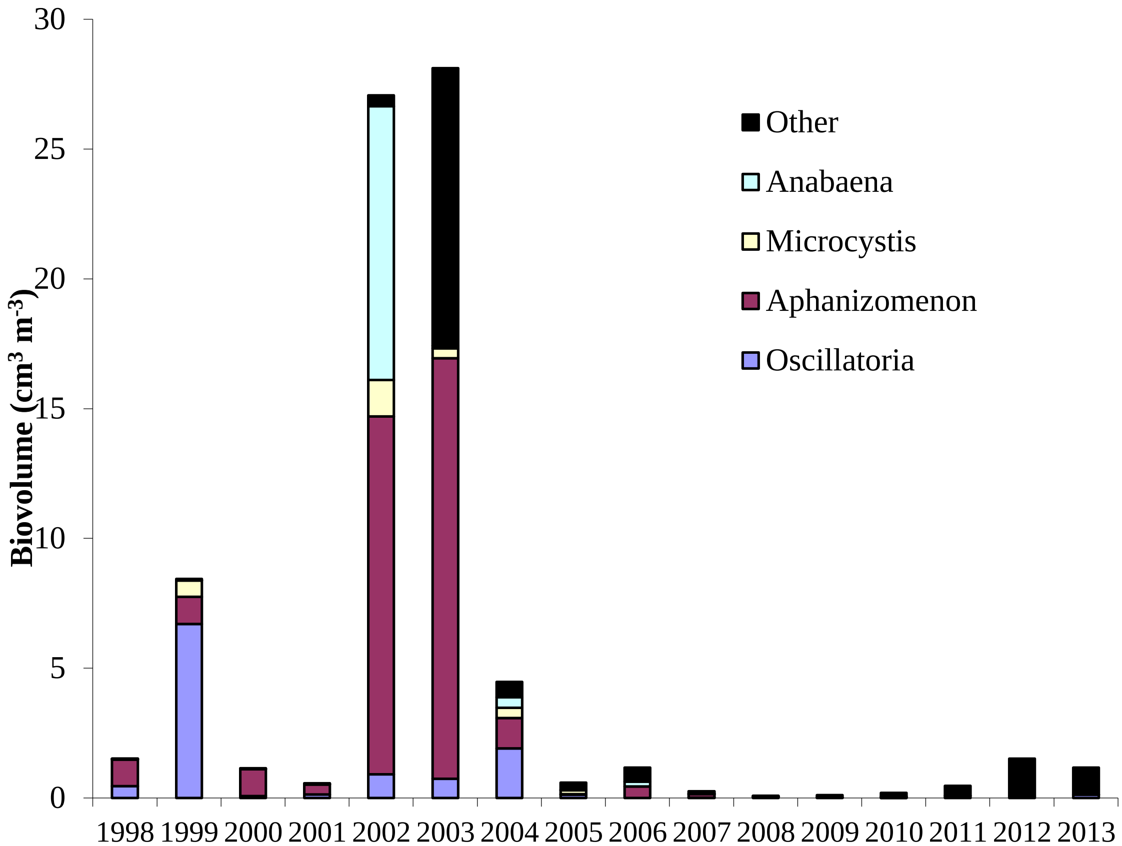
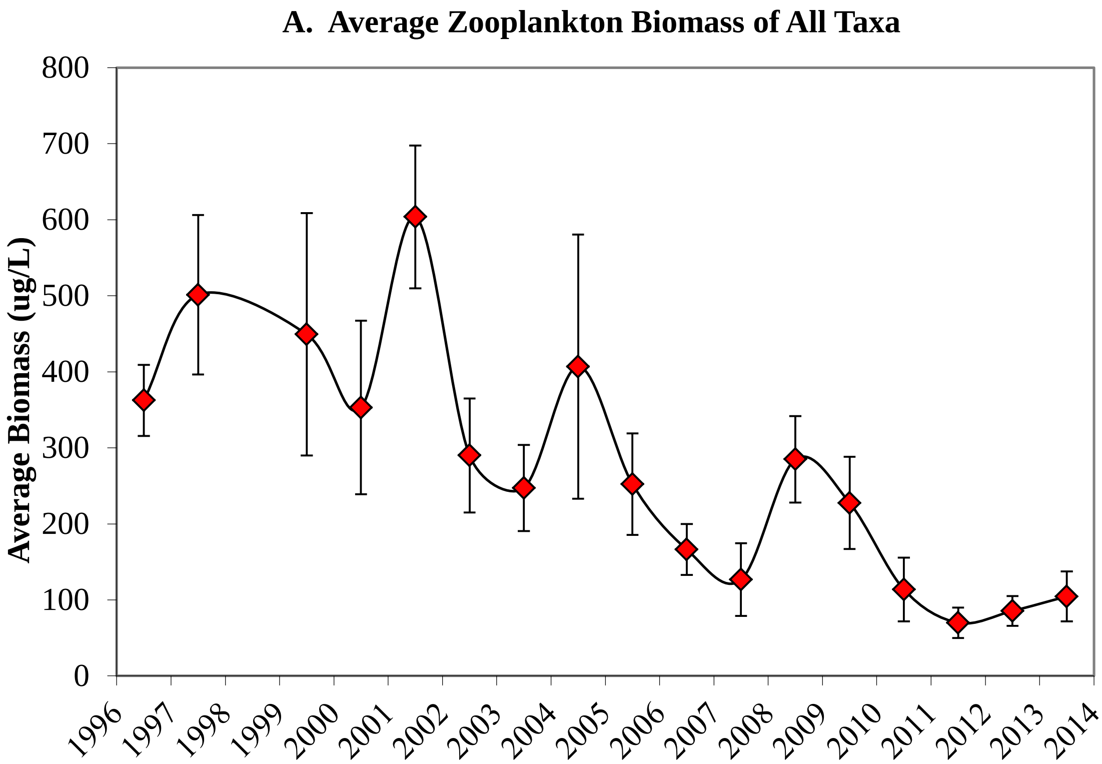


Figure 13. Average biomass of zooplankton (all taxa combined) and the proportion of major taxa in Onondaga Lake from April through October in 1996-1997 and 1999-2013. For consistency across time, all densities are based on the 2008 sampling schedule (integrated samples during the mixed period, and upper mixed layer during the stratified period, and South Deep only, with volume strained calculated using field tow depth). The community composition changed dramatically in the late summer of 2002 as alewife increased in abundance, in the summer of 2008 following alewife declines and again in the summer of 2009 and continuing through 2013 when alewife abundance was again high. Data from 1998 are only available for proportions due to an error in recording sample volume that year and is therefore not included in panel A. Porportions are still valid so the 1998 data is included in panel B. Bars in panel A are 1 SE based on weekly samples.


A. Average Zooplankton Biomass of All Taxa
Average Biomass (ug/L)
800
700
600
500
400
300
200
100
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

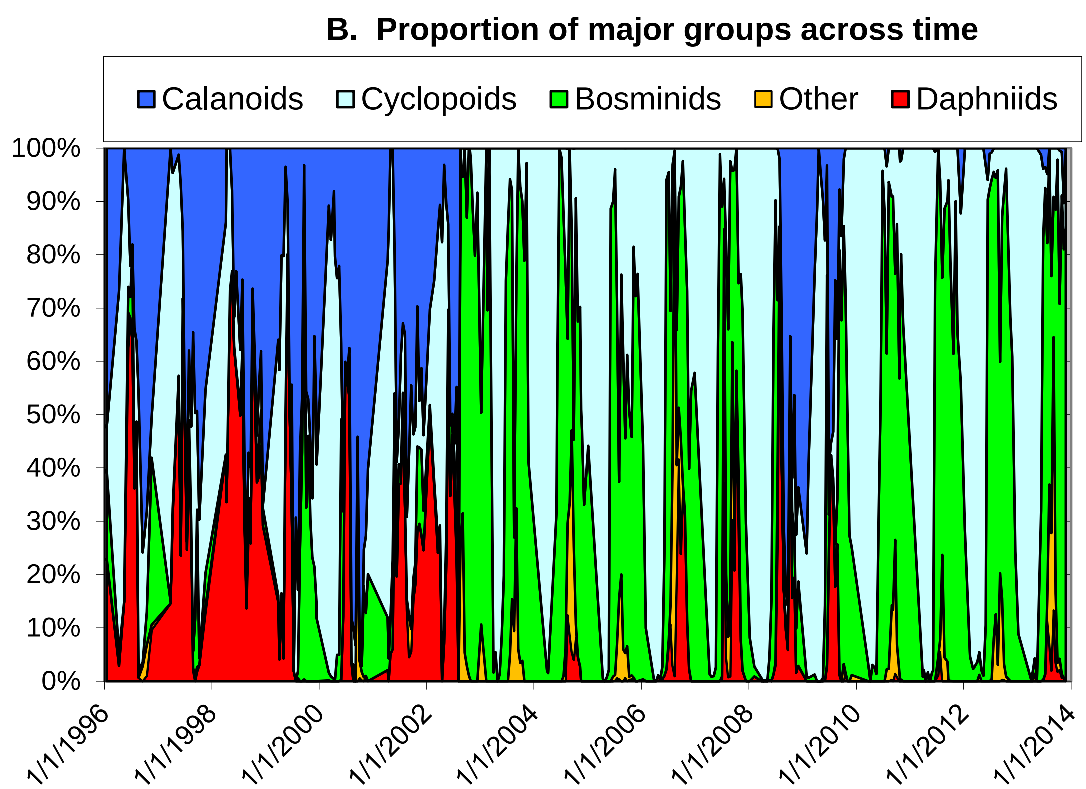
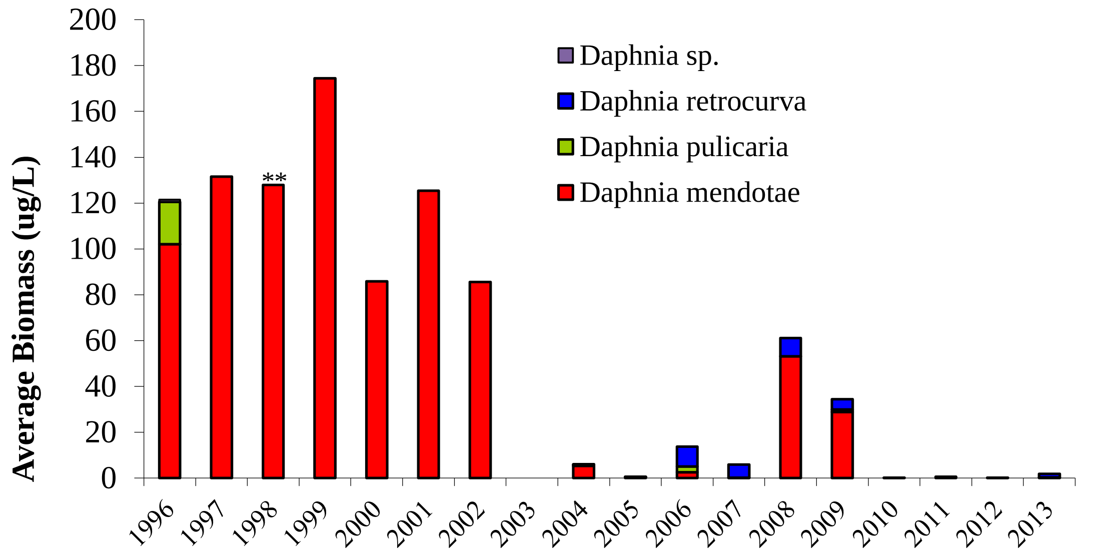

B. Proportion of major groups across time
Calanoids
Cyclopoids
Bosminids
Other
Daphniids
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006
1/1/2008
1/1/2010
1/1/2012
1/1/2014

Fig 14. Biomass of different *Daphnia* species in Onondaga Lake. There is no data available on biomass for 1998, but the *Daphnia* population that year was dominated by *D. mendotae*. *Daphnia* species composition is a sensitive indicator of fish zooplanktivory rate. Data are average of standard South Deep samples collected from April to October. Most samples are from the upper mixed layer. In 2008 and 2009, April and October samples are from integrated water column samples. The low biomass of *Daphnia* in the years between 2003 and 2007 and then again in 2010-2013 is attributed to the presence of abundant alewife during these time periods. *Daphni*a was abundant in 2008 and 2009, and mostly consisted of *D. mendotae* and limited biomass of *D. retrocurva*. *D. mendotae* was present from mid-July to early December in 2008, and from mid-June through August in 2009. We interpret the change in August 2009 to be the result of both individual and population growth of the large 2009 alewife year class. All *Daphnia* species have been virtually absent in the lake since fall of 2009. Also shown is a more detailed time series for all *Daphnia* combined. (Note: ND = No Data for 1998, ** average biomass for 1998 is chosen as 125 µg/L only to show the species composition for that year.



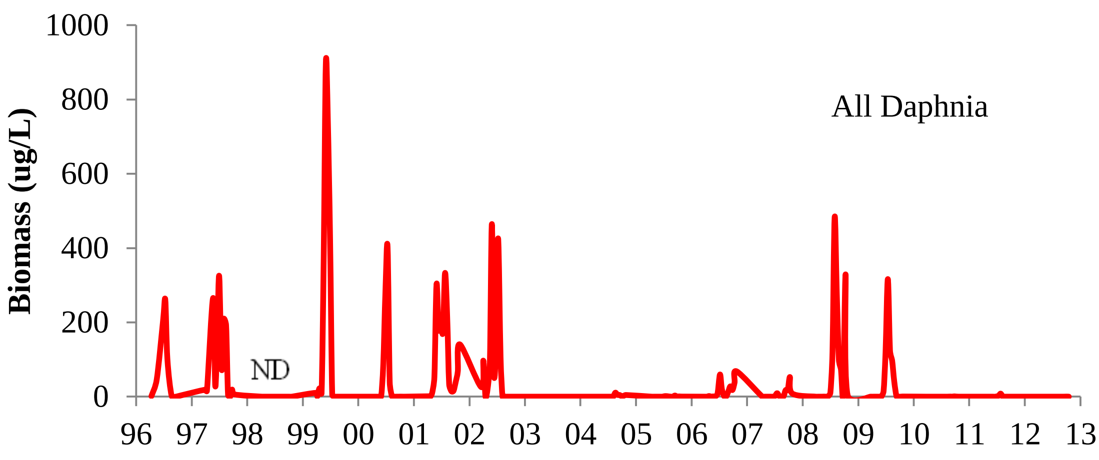


Figure 15. Time series of *Cercopagis pengoi* in Onondaga Lake, 1996 to 2013. Data represent average biomass from standard samples collected at South Deep station from April through October. Bars represent one SE. Values for 2006 corrected for a database error and are not identical to last year's report.

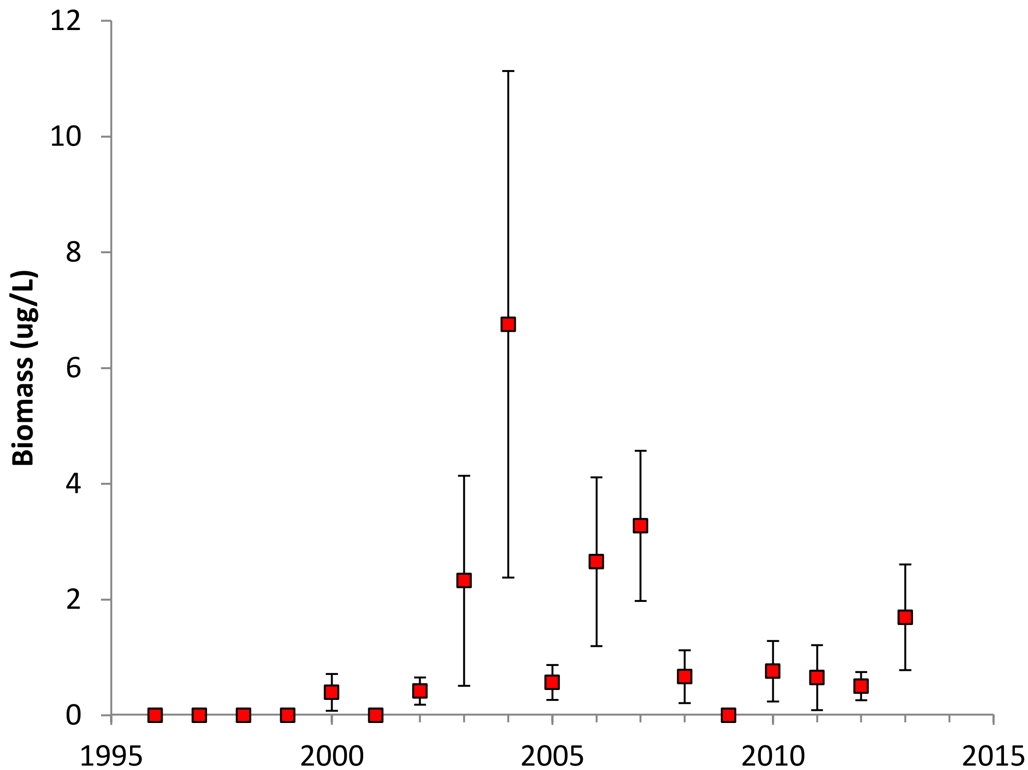


Figure 16. Time trends in average size of all crustaceans from 1996 to 2013 in Onondaga Lake. These lengths include nauplii. Based on the average of weekly average zooplankton lengths in the South Deep station from samples collected April – October using the sampling regime established in 2008-2012. *Cercopagis pengoi* is not included. Bars are one SE based on weekly values.

Larger average size in 2008 and 2009 is associated with return of a daphniid-calanoid community and the small sizes in 2003 to 2007 and in 2010-2013 are associated with a bosminids-cyclopoid community. Note the increase in average length in 2013 which was due to larger abundance of *Diaphanosoma* in the summer and cyclopoids in the spring than in 2010-2012. Details on the 2013 size and species structure are in Figures 6, 7 and 8.

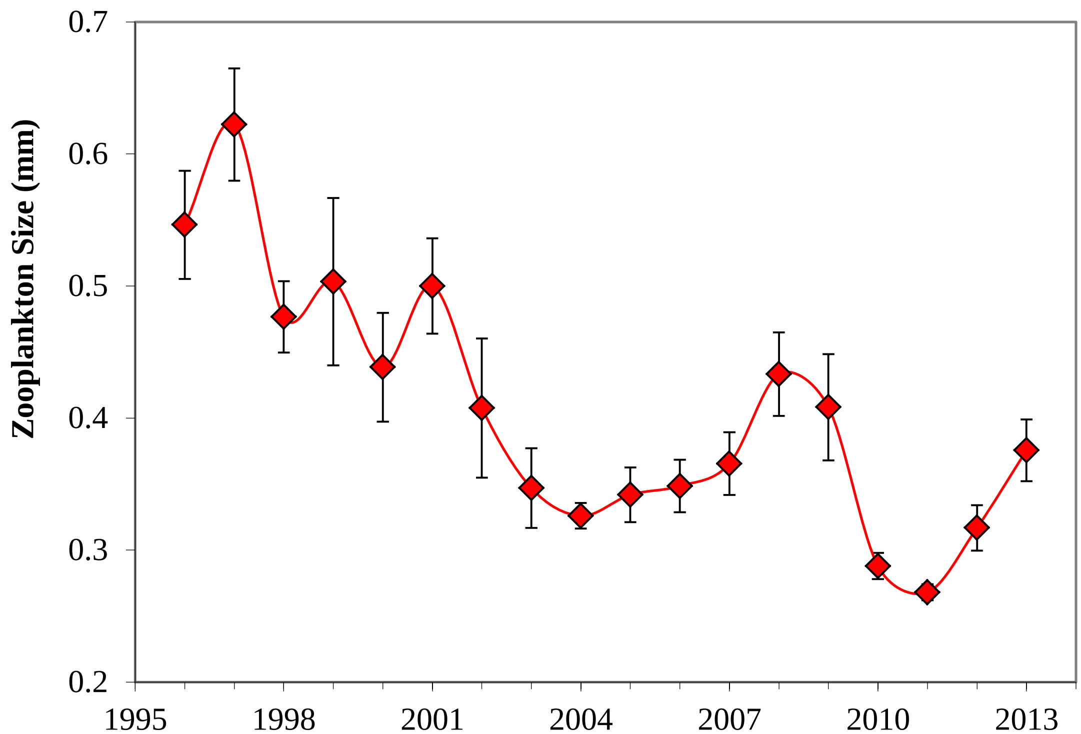
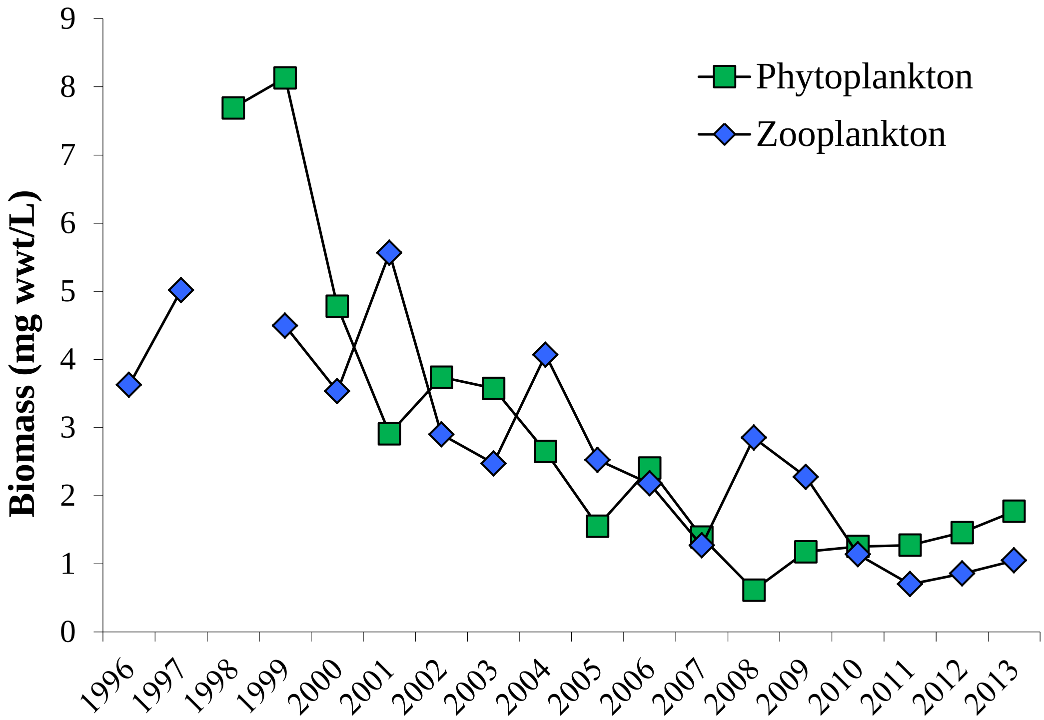


Figure 17. Time trend of zooplankton and phytoplankton biomass in Onondaga Lake 1996 to 2013 (April-October). Zooplankton biomass was converted to wet weight assuming a dry to weight ratio of 10%. For zooplankton biomass in dry weight, see Figure 13. Both zooplankton and phytoplankton biomass has been increasing slightly since 2011 and phytoplankton biomass in 2013 was the highest since 2006.



Significant Findings

The algal biomass in Onondaga Lake since 2007 have been below 2 mg/L (April through October averages), values lower than expected from meso-eutrophic systems (3-5 mg/L, Wetzel 2001). However, average biomass in 2013 was slightly higher than in 2012 and about three times the values from 2008 (Fig 17). Peak biomass exceeded 5 mg/L, as it did in 2012. Peak biomass did not exceed 4.1 mg/L from 2007 to 2011. An unusually wet June and early July may have contributed to increased nutrient levels in the lake and higher phytoplankton biomass compared to recent years. In nearby Oneida Lake, bluegreen blooms started earlier in 2013 than typical for that lake and this was associated with high nutrient input from the tributaries. The dominant alga in July in Onondaga Lake was the diatom *Uroselenia sp*. This genus had only been observed two previous years, in 2007 and 2011.

The longer term time trend shows a continuous decline in algal biomass since 1998 that is highly significant. However, algal biomass has not declined further since low values in 2008. We attribute the low algal biomass to lower phosphorus loading since implementation of enhanced phosphorus removal at the Metro water treatment plant. In 2008 and 2009, algal biovolume was also affected by grazing from large zooplankton. Large zooplankton were rare in 2013.

Large bluegreens (cyanobacteria) have almost disappeared from the lake (Fig 12). The main species in the past was *Aphanizomenon flos-aquae*. This species historically occurred July through October but blooms decreased in duration to July – August in 1997-2000. In 2013, there were a small peak in bluegreens (*Pseudanabaena limnetica*) in the end of September and a bluegreen genus was therefore one of the common genera in the lake for the first time since at least 2006. Peak cyanobacteria abundance was 0.6 mg/L in 2013, still a low value.

Diatoms had the highest biovolume of all algal groups and showed a prolonged but moderate spring peak in May through early June dominated by *Asterionella* and *Synedra* in May and *Cyclotella* in June, *Urosolenia* and *Erkenia* in July, and *Cyclotellas* and *Synedra* in August-November.

Average total zooplankton biomass (Apr-Oct, dry wt) was 104 μg/L in Onondaga Lake; an increase from 2011 and 2012. Zooplankton biomass has been low since 2010 and there is an overall long-term decline. Variability among years, such as the increase in 2008 and 2009, is due to the low abundance of planktivorous alewife in those two years. The change over time indicated that the decline in nutrient concentrations can cause a 3-5 fold decline in zooplankton and an increase in planktivory can cause a 2-3 fold decline. The average size of the total zooplankton community in Onondaga Lake in 2013 was higher than in 2010-2012, but still indicative of high planktivory rates. The species and size composition is similar to 2003-2007 and 2010-2012 and quite different from what was observed in 2008 and 2009 when the alewife population was low (Figure 13B).

The temporal changes in the zooplankton community are linked to changes in predation by the dominant fish planktivore in the lake, the alewife (*Alosa pseudoharengus*) (Wang et al. 2010). Alewife density in spring of 2008 and 2009 were below 100 fish/ha, but density rebounded in the spring of 2010 due to a strong 2009 year class. The acoustic estimate of the alewife population was slightly lower in spring of 2013 than in spring of 2012 (although net catches were higher, Rudstam et al. 2014), which is consistent with the occurrence of some larger zooplankton in 2013 (*Diaphanosoma* sp.). The data from Onondaga Lake support the strong structuring effect of fish planktivory, especially alewife, on the species composition and size structure of zooplankton (Brooks and Dodson 1965, Post et al. 2008, Wang et al. 2010). *Cercopagis pengoi* were observed in 2013 and at higher abundance than in 2010-2012, but lower than in some earlier years in the 2000s (Fig 7 and 15). This species is more likely to negatively affect *Bosmina* than *Daphnia* (Warner et al. 2006) and is not likely to contribute much to the total predation on zooplankton in high alewife years.

Populations of *Daphnia* can exert strong influence on the phytoplankton community (Sommer et al. 1986, 2012, Mills and Forney 1988). High water clarity and low phytoplankton biovolume was observed in 2008 and 2009 associated with the combination of high grazing from large zooplankton, decreased phosphorus loading, and possible increased grazing by dreissenids. Although algal biovolume increased compared to 2008, the algal biovolume remained low in 2010 to 2013 even though the zooplankton biomass declined compared to 2008-09 and was dominated by small grazers (bosminids). Algal biovolume is about three times the values observed in 2008 a year with both low TP loading and high *Daphnia* populations. Declines in phosphorus loading and top down effects of alewife interact in Onondaga Lake.

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