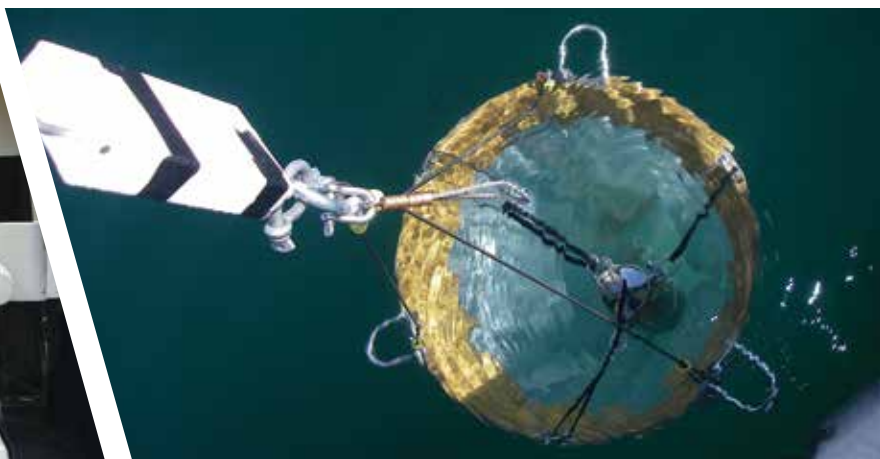


2018

# STATUS ASSESSMENT REPORT





Environment and  
Climate Change Canada

Environnement et  
Changement climatique Canada



Ontario

VIA E-Mail

January 18, 2019

## DISTRIBUTION

**Re: Canadian Niagara River Area of Concern, Status of the Degradation of  
Phytoplankton or Zooplankton Populations beneficial Use**

Since the inception of the Niagara River Area of Concern in the late 1980s, there has been uncertainty about the condition of phytoplankton and zooplankton populations in the Canadian Niagara River Area of Concern. The 1993 Remedial Action Plan Stage 1 report for the Canadian portion of the Niagara River Area of Concern identified the *Degradation of Phytoplankton and Zooplankton Populations* beneficial use as "Requires Further Assessment" because there was no scientific evidence/studies to suggest an impairment or not. The status of the beneficial use did not change in the 2009 Remedial Action Plan Stage 2 Update Report.

In 2014, scientists from the Department of Fisheries and Oceans designed a comprehensive scientific study examining water chemistry and phytoplankton and zooplankton composition at six different monitoring sites along the Niagara River. The sites were sampled monthly (from June to October 2014). The results of the assessment show that there are no issues related to populations of phytoplankton and zooplankton in the Niagara River Area of Concern, and that the status of the *Degradation of Phytoplankton and Zooplankton Populations* beneficial use should be considered as 'Not Impaired'. The results of this assessment are documented in the attached report.

The beneficial use status assessment report was peer reviewed and the reviewing scientists agreed with the soundness of the scientific document and the recommendations within the report. The Remedial Action Plan Team undertook an extensive approach to community outreach and engagement the results of which is summarized in the attached report. As this is a binational Area of Concern, the report was also reviewed by representatives from the New York State Department of Environmental Conservation and the United States Environment Protection Agency. Comments received have been considered in the attached beneficial use status assessment report. None of the reviewers expressed concerns with the conclusions of the studies or recommendation that this beneficial use was "not impaired" for the



Canadian portion of the Niagara River Area of Concern. The beneficial use has never been considered impaired for the U.S. portion of the Area of Concern.

As Annex 4 (Areas of Concern Annex) leads for the Canada Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, we support the "not impaired" designation for this beneficial use and congratulate the Niagara River RAP team, local community and the federal and provincial experts involved in the Niagara River Remedial Action Plan for attaining this important environmental milestone. We look forward to continued progress toward our shared goal of delisting the Niagara River Area of Concern.

Sincerely,



Jon Gee  
COA Annex 4 Lead for Canada  
Manager, Great Lakes Areas of Concern  
Environment and Climate Change Canada



Dawn Walsh  
COA Annex 4 Lead for Ontario  
Great Lakes/COA Divisional Project Manager  
Ontario Ministry of Environment,  
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#### DISTRIBUTION

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Marc Tuchman, U.S. Environmental Protection Agency  
Mark Chambers, Environment and Climate Change Canada  
Cherlene Vieira, Ontario Ministry of Environment, Conservation and Parks  
Susan Humphrey, Environment and Climate Change Canada

# Beneficial Use Status Assessment Report: *Degradation of Phytoplankton and Zooplankton Populations* in the Niagara River (Ontario) Area of Concern Beneficial Use Impairment #13

February 2018

*Revised January 2019*

Prepared by: Natalie Green (RAP Coordinator), Mark Chambers (ECCC), Cheriene Vieira (MECP)  
on behalf of the Niagara River (Ontario) Remedial Action Plan



Suggested citation for the re-designation report:

Green N., M. Chambers, C. Vieira. 2018. Beneficial Use Status Assessment Report: Degradation of Phytoplankton and Zooplankton Populations (BUI #13) in the Niagara River (Ontario) Area of Concern. Niagara River Remedial Action Plan.

Correct citation for the technical BUI Assessment:

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick, W.J.S. Currie. 2016. Assessment of the Phytoplankton and Zooplankton Populations in the Niagara River (Canada) Area of Concern in 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3184: 1v + 66p.

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## Overview

Plankton are important indicators of ecosystem health because they form the base of the food chain and they are sensitive to changes in water quality. Phytoplankton are primary producers (i.e., organisms that form the base of the food web and make energy from sunlight) and are an important food source for zooplankton and other organisms. In turn, zooplankton become food for fish and other organisms, some of which are consumed by people. There must be enough phytoplankton in the water to form the base of the food web. If there is not enough phytoplankton, the web is broken and the rest of the organisms in the food web may suffer. According to information on the International Joint Commission's website (IJC), the *Degradation of Phytoplankton and Zooplankton Populations* Beneficial Use Impairment (BUI) applies "when the plankton (microscopic plants and animals) community structure significantly diverges from unaffected comparison sites of similar physical and chemical characteristics". The website also references the original 1991 template of delisting criteria to guide AOCs in developing specific criteria. Locally-developed delisting criteria were never developed for this BUI, because it has never been deemed impaired for the Niagara River Area of Concern (NRRAP, 2009).

Since the inception of the Remedial Action Plan (RAP) initiative in the late 1980s, there has been uncertainty about the condition of phytoplankton and zooplankton populations in the Niagara River Area of Concern (AOC). The Stage 1 RAP Report (NRRAP 1993) identified the *Degradation of Phytoplankton and Zooplankton Populations* BUI as 'Requires Further Assessment' because there was no scientific evidence/studies to suggest an impairment or not. The Stage 2 Update (NRRAP 2009) indicated that monitoring of chlorophyll *a* in the Welland River would be conducted by the Niagara Peninsula Conservation Authority, but that metric and study was better suited to inform on the status of the *Eutrophication or Undesirable Algae* BUI. The *Degradation of Phytoplankton and Zooplankton Populations* BUI on the U.S. side of the Niagara River has never been considered 'Impaired' (NYSDEC 1994; NYSDEC 2012). The 1994 Niagara River (NY) Stage 1 RAP Report notes that no research on phytoplankton and zooplankton populations were conducted specific to the Niagara River; however, data collected in Lake Erie from 1983-1984 compared to historic values indicated that the plankton assemblage shifted from eutrophic toward more mesotrophic community structure (NYSDEC 1994). Furthermore, in 1987/1988 zooplankton bioassays undertaken at Strawberry Island (upper Niagara River, U.S.) and at Fort Niagara (lower Niagara River, U.S.) showed no water column toxicity (NYSDEC 1994).

The Great Lakes Water Quality Agreement (GLWQA) Protocol of 2012 specified that BUIs are to apply to Waters of the Great Lakes, meaning "the waters of Lakes Superior, Huron, Michigan, Erie, and Ontario and the connecting river systems of St. Marys, St. Clair, Detroit, Niagara and St. Lawrence" [...] (GLWQA 2012). In keeping with the intent of the focus of the GLWQA and given the lack of recent, relevant (Niagara River) data available, scientists from the Department of Fisheries and Oceans (DFO) designed a comprehensive scientific study examining water chemistry and phytoplankton and zooplankton composition at six different monitoring sites along the Niagara River (Appendix 1). The sites were sampled monthly (from June to October 2014). **The results of the**

technical assessment show that there are no issues related to populations of phytoplankton and zooplankton in the Niagara River Area of Concern, and that the status of the *Degradation of Phytoplankton and Zooplankton Populations* BUI be changed from 'Requires Further Assessment' to 'Not Impaired'. Key findings of the study are:

- Plankton population levels were low but consistent with expectations for a large river, sourced from a Great Lake with low nutrient levels (oligotrophic) and a high flow rate.
- The most prominent plankton in the Niagara River were rotifers, water fleas, copepods, mussel veligers, and filamentous diatom algae, which tolerates high-flow environments.
- Due to the high flow rates of the river, plankton would only be in the river for a day before exiting into Lake Ontario.
- The amount of zooplankton decreased downstream with the lowest zooplankton levels found in the lower river below Niagara Falls, which was expected because zooplankton experience high mortality when entering high flow river systems.
- A small increase in plankton populations was found downstream of the hydroelectric reservoirs, which likely act as a source of plankton for the river. The reservoirs provide refuge from the fast-flowing river and give plankton time to recover.
- Minor diatom and cyanobacteria peaks occurred in August and September, respectively, but were still very low biomass and not expected to negatively impact the environment.
- Bacteria growth and biomass was elevated in the river compared to Lake Erie, but the highest peaks followed heavy rainfall events.
- Phytoplankton levels were very low—similar to oligotrophic eastern Lake Erie, which is consistent with the findings that the Niagara River is not impaired with respect to eutrophication and algae.
- There were no dramatic changes in zooplankton species composition down river.
- A reduction in zooplankton densities in the upper river (closest to Lake Erie) is most likely due to plankton-eating fishes such as Emerald Shiner and Yellow Perch.

Upon completion of the technical assessment, a scientific peer review of the report was conducted in 2016 as part of DFO's reporting requirements. Based on the results of the assessment, the reviewing scientists agreed with the soundness of the scientific document and the recommendations within the report (Appendix 6). The assessment report and the recommendation to identify the BUI as not impaired was presented to the RAP Team in June 2017. The results, which are consistent with the *Eutrophication or Undesirable Algae* BUI, led to the decision to proceed with the public review of both of the assessments concurrently.

The RAP Team undertook an extensive approach to community outreach and engagement due to the lack of an active Public Advisory Committee (PAC) participating in the Niagara River (Ontario) RAP at the time and based on recommendations and feedback from an externally-conducted stakeholder survey regarding public outreach for the RAP (LURA 2014). These efforts sought to re-connect the public to the RAP process, invite stakeholder participation in the progress of the RAP, update the public with current information on the status of the RAP activities, as well as provide an opportunity to participate in the review of two BUI assessments (*Eutrophication or Undesirable Algae* and



*Degradation of Phytoplankton and Zooplankton Populations*). The RAP Team also hoped that the various outreach opportunities would spark a renewed interest in the RAP process and encourage interest in re-establishing the PAC. The public review period for the two aforementioned BUIs was conducted concurrently from October to November 2017. An overview of public outreach and engagement opportunities are outlined in Table 1 with a detailed account provided in Appendix 2.

**Table 1.** Summary of various public outreach and engagement activities that directly supported the public review of two BUI assessments.

Description of the outreach activity	Timeline
Public-friendly summary document prepared	Aug. 2017
Documents posted online with built-in commenting feature enabled and details of related events included.	Oct. 20 – Nov. 25/17
Hosted an informative bus tour of the Niagara River AOC to highlight recent projects and progress, including the BUI assessments and opportunities for guests to have their say.	Oct. 25/17
Developed a short video to communicate the purpose of the RAP and to inform the public about current activities and projects, as well as the proposed status change for the two BUI assessments.	Oct. 2017
Implemented a public service announcement campaign at various local venues (movie theaters, coffee shops, malls, bus terminals).	Oct. 20 – Nov. 25/17
Hosted a Public Information Open House to share results of two BUI assessments and provide an opportunity for the public to ask questions and have a say on the proposed status change.	Nov. 15/17
Prepared/sent a media release and an advisory to inform the local media and general public on ways to have their say on the proposed status change.	Oct. 23 & Nov. 13/17
Social media campaign to inform public and encourage them to have their say on the status change.	Ongoing

Overall, results from the outreach efforts (event attendance, website analytics and social media engagements) show that many people were aware of the recommendation to change the status of the BUI but did not submit their comments (Appendix 2). A significant effort was made toward community outreach. Many people were reached/engaged through social media and in-person participation at the bus tour and public open house. Four feedback forms were formally submitted. It is unclear if the low number of written responses was due to lack of interest in the RAP process, concurrence or disagreement. The RAP Team carefully considered the feedback that was provided, summarized it and addressed and responded to the key issues submitted, as needed (Appendix 3). Of the four people that provided their feedback, two agreed with the recommendation but noted that there is other work to be done in the AOC to further progress and prevent backsliding (e.g., water quality studies at Queen’s Royal Beach and coastal wetland fish habitat restoration). The key concerns submitted by respondents were related to the geographic scope of the AOC, the RAP process, and water quality concerns in the Welland River and Black Creek (tributaries of the Niagara River). Only one comment was directly related to the *Degradation of Phytoplankton and Zooplankton Populations*

BUI and it was positive. Following the completion of the beneficial use status assessment summary report, the RAP Project Manager contacted each of the respondents to provide them with a copy of the reports to ensure their comments were adequately addressed and to give them an opportunity for further discussion, if required. A copy of the blank feedback form as well as other supporting outreach documents are attached as Appendix 4.

The RAP is in the process of preparing a delisting plan which will identify remaining actions to restore and assess remaining BUIs and outline long-term monitoring needs and/or programs that will continue to monitor water quality in the Niagara River and tributaries that may impact the Niagara River (e.g., ECCC's Upstream/Downstream Program, NPCA's watershed water quality monitoring program, etc.) to ensure the conditions of the Niagara River related to this beneficial use remain healthy.

## Conclusion

The results of the assessment indicate the biomass and productivity of the Niagara River were consistent with the oligotrophic conditions in eastern Lake Erie. The technical experts reported that there is no evidence of impairment of phytoplankton or zooplankton populations and recommended that the BUI status is 'Not Impaired'. No further studies/remedial actions were suggested by the RAP Team. The public was provided with many opportunities to review the assessment and the results. While many people were aware of the recommendation to change the BUI, as indicated through website and social media analytics, a small number (four people) formally submitted written feedback. Comments were mainly related to the boundaries of the AOC, the RAP process, and the condition of the Welland River and Black Creek (tributaries of the Niagara River).

## Literature Cited

*The list of references in this section applies only to the text in the Overview. Individual appendices have their own literature cited sections, if applicable.*

Canada-U.S. Great Lakes Water Quality Agreement (GLWQA). Sept. 7, 2012. Retrieved from <http://ijc.org/files/tinymce/uploaded/GLWQA%202012.pdf>

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LURA Consulting. 2014. Outreach and Engagement Strategy for the Niagara River Area of Concern 2014-2019 Appendix A: Stakeholder Feedback and Key Ideas Report.

New York State Department of Environmental Conservation (NYSDEC). 1994. Remedial Action Plan Stage 1 Report for Niagara River Area of Concern.

New York State Department of Environmental Conservation (NYSDEC). 2012. Remedial Action Plan Stage 2 Addendum for the Niagara River Area of Concern.

Niagara River Remedial Action Plan (NRRAP). 2009. Niagara River Remedial Action Plan Stage 2 Update.

Niagara River Remedial Action Plan (NRRAP). 1993. The Niagara River (Ontario) Area of Concern: Environmental Conditions and Problem Definitions, Remedial Action Plan Stage 1.

**APPENDIX 1:**  
**Statement by Fisheries and Oceans Canada**



Dec. 5, 2017

**Statement by Fisheries and Oceans Canada on the status of Degradation of Phytoplankton and Zooplankton Populations (BUI 13) in the Niagara River Area of Concern.**

Fisheries and Oceans Canada conducted monthly monitoring of six stations along the length of Niagara River (three in the upper river and three in the lower river) from May to October, 2014. Samples for water chemistry, phytoplankton, zooplankton and microbes were collected and analysed to determine if there was any evidence of impairment, and if plankton populations in the river were consistent with expectations for a large connecting channel between two of the Great Lakes.

Overall, the biomass and productivity of the system for both phytoplankton and zooplankton were consistent with the oligotrophic conditions in eastern Lake Erie. Biomass and productivity of bacteria and other microbes were found to be elevated throughout the river compared to the lakes, though the peaks in productivity always followed large precipitation events. This is not unexpected in an urbanized environment with cities on both sides of the river.

Phytoplankton and zooplankton biomass decreased exponentially with distance downstream, as expected within a high flow lotic environment. The loss of zooplankton biomass is most likely due to predation by large populations of planktivorous fishes in the river (especially Emerald Shiner). Although the biomass of plankton in the river was very low relative to Lakes Erie and Ontario, the well-documented relationship between increased river flow and decreased plankton abundance suggests that the low plankton biomass in the river is expected due to riverine flow conditions and not of concern.

The plankton communities of the Niagara River were dominated by species common in the source waterbody, but are also more resilient to the highly turbulent conditions of the river. These species included siliceous diatoms, filamentous algae, small zooplankters, dreissenid veligers and loricated rotifers. Furthermore, the seasonality of species composition in the Niagara River is the same as its source water body, suggesting no impact from the river on succession within the plankton communities.

Niagara Falls and the two hydroelectric plants were not found to be a significant cause of plankton mortality down river, rather there is some evidence that entrainment time in the hydroelectric reservoirs may be promoting a slight enhancement to phytoplankton and zooplankton densities, thus contributing to the downriver populations. The high flow means that plankton are resident in the connecting channel for only about 24 hours, so an opportunity for refuge in the reservoirs appears to be an important aspect of Niagara River plankton ecology. This effect is inferred from station sampling above and below the plant outfalls since the reservoirs were not sampled directly as part of this monitoring survey.

The Niagara River is a unique system, particularly within the Great Lakes, so by examining plankton studies of other large river system and relating the plankton community structure of the Niagara River AOC to those of the adjacent lakes, we determined that any reductions in biomass and changes in species compositions are consistent with expectations for a large connecting channel, indicating there is no evidence of impairment of phytoplankton or zooplankton populations in the Niagara River. It is therefore recommended that the status of BUI #13 be changed from "Requires Further Assessment" to "No Impairment" for Niagara River AOC.

Warren Currie

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Kelly Bowen

Mark Fitzpatrick

Heather Niblock

Mohi Munawar

Marten Koops



## **APPENDIX 2:**

### **Public Review and Engagement Opportunities**

## Introduction

Engaging and obtaining input from the broad range of partners involved in the RAP initiative (public, Indigenous Peoples, municipalities, industry, etc.) is vital to the success of restoring the Niagara River AOC. There was significant involvement and engagement from the community through a Public Advisory Committee (PAC) since the Niagara River RAP's inception in 1987 until 2009. The PAC was involved in the development and review of all major RAP documents (e.g., Stage 1, Stage 2, and Stage 2 Update Reports) as well as important decisions regarding the review of BUI status and delisting criteria. However, the PAC did not exist at the time of these BUI reviews and had not been actively engaged since 2009.

In 2014, the RAP's Coordinating Committee (which oversees Governance) hired an external consultant to develop a strategic outreach and engagement framework to support the delisting process by reviewing existing outreach mechanisms and interviewing past and present RAP participants, including six representatives from government agencies and twelve from the local community (LURA, 2014). The report found that many stakeholders expressed disappointment that the Public Advisory Committee no longer existed and offered advice and potential tools for successful and engaging opportunities in the RAP process. Some of the principles and ideas from the LURA (2014) report were used to guide the outreach and engagement process for the RAP with stakeholders, as well as the BUI assessment review.

The RAP Team is presently working diligently to re-establish the PAC to better engage with the community and provide a forum through which the public and stakeholders can share concerns, views and opinions on Niagara River issues, and become involved in the activities and studies of the RAP initiative. The RAP Team undertook an extensive approach to community outreach and engagement. Part of these efforts included facilitating the review of the two BUI assessments (*Eutrophication and Undesirable Algae & Degradation of Phytoplankton and Zooplankton Populations*). The public review period for these two BUIs was conducted concurrently from October 20 to November 25, 2017. One of the main goals of the outreach and engagement activities was to provide ample opportunity for review, discussion, and comment on the proposed status change for the two BUIs. The RAP Team also hoped that the outreach events would spark a renewed interest in the RAP process and help to re-establish the PAC and Implementation Committee, as well as enhance the information exchange and involvement with RAP activities.

Starting October 2, 2017, the RAP Coordinator contacted over 50 past and new stakeholder organizations/participants to invite them to attend an informative bus tour event and to get involved in the RAP (to re-establish the Implementation and Public Advisory Committee) (see pg. 16). In addition to contacting people individually, the RAP Team put out a general call for participation in the RAP initiative and/or the Bus Tour on the RAP's social media accounts, which resulted in views but no active engagement. Responses from those contacted personally were received from 24 individuals spanning various sectors (municipalities, government, environmental groups, Indigenous Peoples, industry, scientists, and citizens) that expressed an interest in re-engaging in the RAP process. These

representatives will be contacted in early 2018 to begin re-establishing the Implementation and/or Public Advisory Committees.

### **Outreach Event: Bus Tour**

The “Rolling by the River” Bus Tour event was hosted on October 25, 2017 and was attended by 32 people, including past and present RAP participants, academic researchers, students, and interested citizens. The tour was the Niagara River RAP’s first outreach event since a public information meeting hosted in May 2015. Participants met at the Niagara-on-the-Lake Community Centre and boarded a coach bus to learn about recent progress and work in the Niagara River in a unique and interactive way. There were six stops and three additional topics along the tour route that were designed to tell the Niagara River story. Invited experts from various partnering organizations spoke about their work and provided hands-on experiences for participants along the tour.

The group learned about the purpose of the RAP initiative, the revisions to the Niagara River AOC boundary as a result of the 2012 Great Lakes Water Quality Agreement, historical sediment contamination in the watershed, ongoing watershed water quality monitoring, assessment and condition of plankton populations, monitoring of fish populations, coastal wetland habitat and prairie habitat restoration projects, binational water quality monitoring, and recent beach contamination investigations. At various stops, attendees had the opportunity to get off the bus and interact with researchers, examine water samples containing live plankton, witness electrofishing sampling efforts, get up close with live Niagara River fish, view habitat restoration sites, and ask a lot of questions (Figure 1). Each participant received a summary of the BUI assessment, Open House Poster, a feedback form, and other relevant, informative materials. Participants were informed about the review process and ways to provide input. Overall, the bus tour was a great success! A lot of positive feedback was received from those in attendance and several participants expressed their renewed interest in the RAP initiative and were encouraged by the recent progress. Thanks are owed to Ontario Ministry of Environment and Climate Change, Environment and Climate Change Canada, Fisheries and Oceans Canada, Niagara Peninsula Conservation Authority, Ontario Ministry of Natural Resources and Forestry, Niagara Parks Commission, and the Town of Niagara-on-the-Lake for their involvement in delivering the event.

### **Digital Engagement: Website**

A page on the RAP’s website ([ourniagarariver.ca/bui-review-2017](http://ourniagarariver.ca/bui-review-2017)) dedicated to the proposed BUI status changes was enabled on October 20, 2017 to allow the public to easily access relevant information and provide their feedback on the changes. The page was linked to various places on the website so that it could be found easily by the end-user (under ‘Track Our Progress’, ‘Latest News’ and through its own link). The webpage included a brief overview of the two BUIs undergoing review and provided easy access to the relevant technical and summary documents (Appendix 4). A “Have Your Say” section outlined the ways in which individuals could learn about the research and BUI assessments and submit their comments on the proposed status changes. There were several ways to submit written comments to accommodate as many people as possible: online (RAP website), by mail,

in-person at the bus tour or open house events, and email. A copy of the feedback form is provided in Appendix 3. Despite receiving only 4 feedback forms (2 online, one by email, one by mail), there was a lot of activity on the website during the review period. Three days prior to the review period (when the analytics tool was enabled), there were 61 users that visited the website with a total of 167 total page visits. During the review period (Oct. 20 – Nov. 25), there were 295 users to the website and 724 total page visits, including 97 unique to the BUI Review page. The reach of our digital engagement was multi-national with 67% of users accessing the site from Canada, 23% from the United States and 10% from other countries.



**Figure 1.** An assortment of photos from the “Rolling by the River” Bus Tour hosted by the RAP Team on October 25, 2017.

Part of the growth to website visits can be attributed to our other outreach efforts including connecting with past RAP partners over the phone and email, hosting events, video ad campaign, and connecting to people through social media and an E-newsletter. A short video was created and released on the same day as the other BUI documents to inform the public about the Niagara River RAP and the recent research on the two indicators. The 36-second [video](#) was used in several ways through different media outlets during the review period. It was broadcast in its entirety at the Cineplex movie theaters in Welland, Ontario and Niagara Falls, Ontario. A shorter 15 second version was shown at Landmark Cinemas in St. Catharine’s and that truncated version with captions (and no sound) was also broadcast on television monitors at over 90 different Tim Horton’s locations in the Niagara Region, at the Seaway Mall in Welland, and two bus stations in St. Catharine’s and Niagara

Falls. The video was also shared on the Niagara River RAP’s social media channels and in the monthly E-newsletter. There were 44 views of the video on YouTube, and over 5000 on Facebook and Twitter (Table 1). Although the RAP does not have quantitative data on the number of views or the reach resulting from the ad campaigns at the local theaters, mall and bus stops, it is reasonable to presume that many people saw the ads which resulted in more visits to the website and more people learning about the RAP.

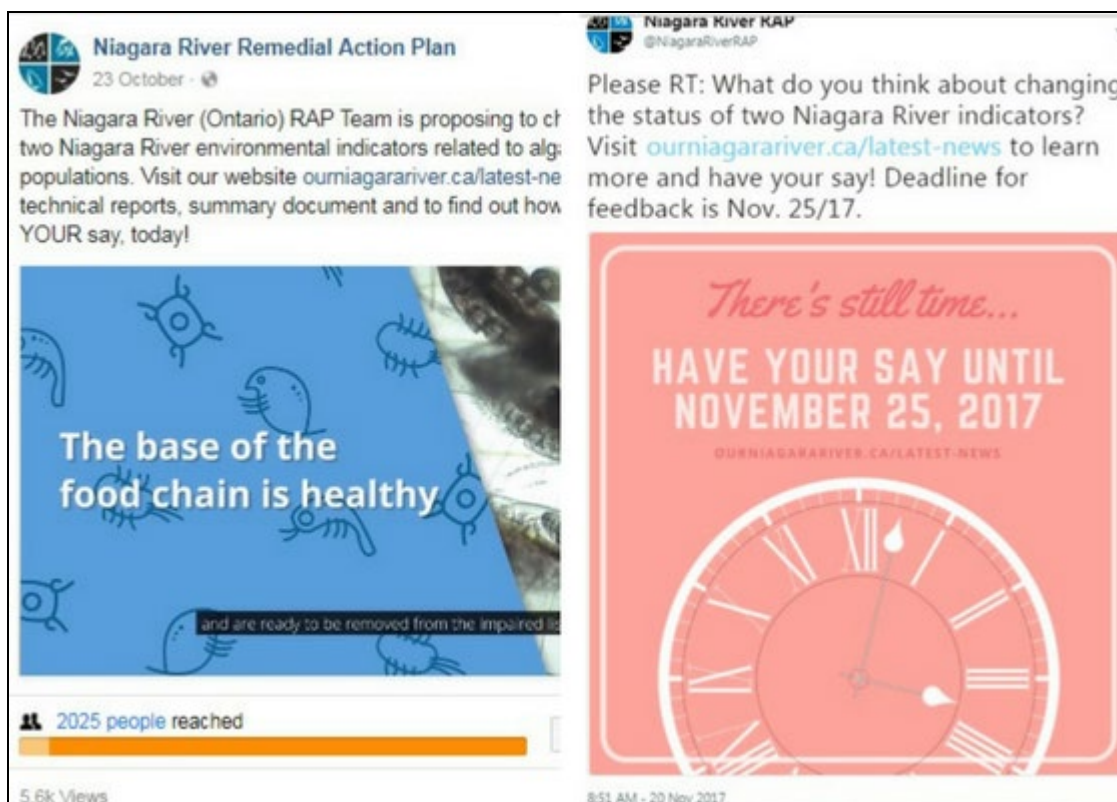
### Digital Engagement: Social Media

In April 2017, the RAP Team created its own social media accounts (i.e., Facebook, Twitter, YouTube), managed by the RAP Coordinator, to communicate relevant information about the Niagara River and to share related Great Lakes news, science, and issues. During the review period, the RAP gained 23 followers on Twitter and 7 followers on Facebook. Many posts/tweets about the proposed status was shared on both platforms—some relating directly to the BUI review and others were more general (Figure 2). Existing analytics information collected by each social media platform and extracted data related to three key metrics (plus one specific to the video) were used to gauge the overall reach during the review period. The total followers, number of users that saw two key posts/tweets (referred to as an impression), and the number of interactions with the post/tweet (e.g., click, like, share/retweet) (referred to as engagement) as well as the number of 3 sec. video views are summarized in Table 1. The results indicate that while many people were aware of the information and the proposed BUI status change, they chose not to provide written feedback. Commenting directly on a post/tweet is an easy way for an end-user to share their opinion about a given topic. During the review period, there were no comments provided on any of the posts and tweets shared on the RAP social media pages.

**Table 1.** Summary of social media metrics to gauge the interaction or reach during the review period. The asterisk indicates a result that was paid to be “boosted” to reach a larger number of people in a given area.

Post or Tweet Topic	Metric	Facebook	Twitter	YouTube
N/A	Total page followers (as of Dec. 1)	19	55	N/A
Video	Video Views (number of times it was watched at least 3 sec.)	5,517*	160	48
	Number of people that saw the post/tweet with video at least once	1,922*	1,070	N/A
	Number of interactions (clicks, likes, shares, retweets)	8*	22	N/A
There’s still time to have your say	Number of people that saw the post/tweet at least once	662*	83	N/A
	Number of interactions (clicks, likes, shares, retweets)	34*	5	N/A





**Figure 2.** Two sample posts shared on the Niagara River RAP’s social media accounts to support the BUI review from Oct. 20 to Nov. 25, 2017. A Facebook post with the video is shown on the left and a Tweet to encourage people to have their say is on the right.

### **Outreach Event: Public Information Open House**

Twenty people attended the Public Information Open House on November 15, 2017 (6:30 pm to 8:30 pm) at the Niagara Parks School of Horticulture in Niagara Falls—centrally located within a short drive for most residents in the Niagara River area. The Open House was an opportunity for interested citizens to learn about the recent research and to provide feedback in-person. Attendees were provided with supporting documents (hard copy and electronic copies on a USB stick), feedback forms with a comment submission box, a RAP overview brochure, E-newsletter sign-up, and some promotional items. There was a meet-and-greet with light refreshments before the presentations were set to begin so that guests could mingle, peruse the supporting documents, read the poster boards (AOC boundary, BUI status, habitat restoration), and ask questions.

The two lead scientists that were involved in leading the technical assessments (Dr. Warren Currie and Tanya Long) provided short presentations summarizing the results and proposed recommendation to change the status of each BUI (Appendix 6). There was ample opportunity after the presentations to ask questions about the research (Figure 3). Overall, the event went very well. The group was engaged and interested in the research. Most of the questions were directed toward Lake Erie (e.g., algal blooms, fisheries), one related to flow of the Upper Niagara River and secchi depth sampling in plankton assessment, and one question about the geographic scope of the AOC and

the importance of efforts in the Welland River watershed (which ultimately drains in to the Niagara River). All of the questions were addressed by the scientists and the RAP Team, as appropriate.



**Figure 3.** Photos of the Public Information Open House event on Nov. 15, 2017: (Top) Dr. Warren Currie takes questions from the group; (bottom left) information table with supporting documents; (bottom right) Tanya Long begins her presentation on the *Eutrophication or Undesirable Algae* BUI assessment.

While no media representatives attended the event, the information was highlighted in the local newspaper and three attendees noted that they heard about the event through the newspaper. The invitation to the open house was shared as broadly as possible using the social media platforms noted previously, advertised on our website, E-newsletter, shared directly with RAP partners (via email), and during the bus tour. In addition, the RAP Coordinator posted the event details on the community event section of each local newspaper (St. Catharine's Standard, Niagara Falls Review, Welland Tribune, Fort Erie Times) and the local TV channel. Furthermore, a media release was sent to local media outlets on October 23, 2017 and a media advisory on November 13, 2017. Refer to Appendix 4 for a copy of the Open House poster, agenda, media release and advisory, and news article.

**List of groups/organizations that participated in related outreach opportunities (i.e., bus tour or public information open house)**

Brock University	Mississaugas of the New Credit First Nation
Buffalo-Niagara Waterkeepers	Niagara College
Citizens-at-large	Niagara River (ON) Remedial Action Plan
Environment and Climate Change Canada	Niagara River (NY) Remedial Advisory Committee
Fisheries and Oceans Canada	Niagara Parks Commission
Friends of One Mile Creek	Niagara Peninsula Conservation Authority
Hamilton Harbour Remedial Action Plan	Niagara Regional Native Centre
Lorraine Bay Water Quality Group	Ontario Federation of Anglers and Hunters
Ministry of Natural Resources and Forestry	Town of Niagara-on-the-Lake
Ministry of the Environment and Climate Change	Welland Riverkeepers

**List of groups/organizations contacted to participate in the RAP or related outreach opportunities**

Atlas Steels	Niagara College
Bert Miller Nature Club	Niagara Community Awareness & Emergency Response Group
Brock University	Niagara Falls Nature Club
Buffalo-Niagara Waterkeeper	Niagara Parks Commission
Citizens-at-large	Niagara Regional Native Centre
City of Niagara Falls	Niagara Restoration Council
City of Welland	Niagara River (NY) Remedial Advisory Committee
Cytec	Niagara Sustainability Initiative
Ducks Unlimited Canada	Niagara Peninsula Conservation Authority
Environment and Climate Change Canada	OMAFRA / Environmental Farm Plan
Fort Erie Conservation Club	Ontario Federation of Anglers and Hunters
Fort Erie Friendship Centre	Ontario Power Generation
Friend of One Mile Creek	Oxy Vinyls Canada
Friends of Fort Erie's Creeks	Peninsula Field Naturalists Club
Greening Niagara	Region of Niagara
Hamilton Regional Native Centre	Town of Fort Erie
Land Care Niagara	Town of Niagara-on-the-Lake
Lubrizol Canada Ltd.	Welland Riverkeepers
Metis Council	
Mississaugas of the New Credit First Nation	
Ministry of Natural Resources and Forestry	
Ministry of the Environment and Climate Change	

## **APPENDIX 3:**

### **Results of Written Feedback**

## Results of Written Feedback

Four feedback forms were submitted. Two people expressed concerns with the recommendation to identify the BUI as 'Not Impaired'. Feedback that included one or more concerns were grouped into specific topics or issues (summarized below). The main concerns noted were related to water quality issues in the Welland River and to the boundaries of the Niagara River AOC. Those that submitted written feedback indicated they had read the supporting documents (i.e., the technical report or the summary) and had attended either the Bus Tour and/or the Public Information Open House. To maintain privacy, names and other identifying text are not included (e.g., organization, contact information).

Summary of Feedback	Response
<i>Submission #1</i>	
Concern over the change of the AOC boundary from encompassing the entire watershed to a focus on the Niagara River proper. The watershed was the true (original) focus of the International Joint Commission and those that framed the AOC concept.	<p>Prior to 2012, the Niagara River Remedial Action Plan included the Welland River as part of the Area of Concern, as requested by the Public Advisory Committee in 1989.</p> <p>The 2012 Canada-U.S. Great Lakes Water Quality Agreement (<a href="http://ijc.org/files/tinymce/uploaded/GLWQA%202012.pdf">http://ijc.org/files/tinymce/uploaded/GLWQA%202012.pdf</a>), clarified that the <b>Waters of the Great Lakes</b> as the waters of "Lakes Superior, Huron, Michigan, Erie and Ontario and the connecting river systems of St. Marys, St. Clair including Lake St. Clair, Detroit, Niagara and St. Lawrence at the international boundary or upstream from the point at which this river becomes the international boundary between Canada and the United States, including all open and nearshore waters". The International Joint Commission provides advice and input to Canada and the United States on Great Lakes issues and continues to assess progress on restoring Areas of Concern.</p> <p>Taking into account this clarification, the Niagara River (Ontario) Area of Concern is now defined as the waters of the connecting channel flowing from the mouth of Lake Erie to Lake Ontario from the international boundary to the Canadian shoreline. Where issues within the watershed contribute to beneficial use impairments in the Niagara River, actions will be undertaken as appropriate.</p>



Summary of Feedback	Response
<i>Submission #1 (continued)</i>	
<p>Concern about uncoupling the Niagara River AOC from its watershed in determining delisting criteria. Would be disappointed if instead of remediating excess nutrients in the Welland River, the RAP Coordinating Team simply redefined the delisting criteria so that Niagara River watershed rivers would fall under the delisting radar as long as some agency agreed to monitor them.</p>	<p>This concern relates to the Area of Concern boundary (see response above), the delisting criteria process as well as addressing nutrient issues in the Welland River. Delisting criteria were never specifically developed for the <i>Eutrophication or Undesirable Algae</i> Beneficial Use Impairment. This prompted the use of a transparent, science-based assessment framework for examining Beneficial Use Impairments established by the Toronto Region Area of Concern and used by other Areas of Concern.</p> <p>While it is recognized that the condition of the Welland River continues to be a local community concern, sources or issues which occur outside the geographic scope of the Remedial Action Plan program and do not contribute to issues in the Niagara River are captured through other local, provincial/state, federal processes, and legislated programs. Where it affects the waters of the Great Lakes, the issue of excessive nutrients is being addressed through a dedicated annex under the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health. Both the federal and provincial governments have committed to developing programs and tools for the agri-food sector to raise awareness and increase adoption of environmental farm planning and beneficial management practices through education, technical advice and funding.</p>
<p>The Welland River, which drains a large area into the Niagara River, suffers from high nutrient loads. Most of the NPCA's Welland River monitoring sites are classified as "impaired". Cleaning up the Welland River so that the majority of the NPCA sample sites were no longer "impaired" would mean that the entire Niagara River watershed had been improved.</p> <p>The RAP's rationale that the Welland River would not negatively impact the Niagara River because the nutrients are diluted to harmless levels suggests that "dilution is the answer to pollution". Disagree that impairments in the Welland River should not impede the goal of delisting the Niagara River as an AOC.</p>	<p>The Welland River is the Niagara River's largest tributary. Improvements within the watershed would certainly contribute to better conditions in the Welland River.</p> <p>There are many other factors (not just the condition of tributaries or incoming waters of eastern Lake Erie) to consider when examining potential algal blooms or eutrophication in the Niagara River. For this reason, this comprehensive assessment was undertaken using five different water quality metrics at key locations along the Niagara River. The assessment indicates that nutrients in the Welland River do not result in eutrophication or undesirable algae impairments in the Niagara River. Specifically, the assessment examined the potential impact of the Chippawa Creek/Niagara Power Canal where the flow of the Welland River mixes with Niagara River water (the Welland River does not discharge directly into the Niagara River due the flow reversal for power generation).</p>

Summary of Feedback	Response
<i>Submission #2 (continued)</i>	
<p>Agree with the recommendation to change the status of eutrophication to not impaired. Understand that further remediation along the Fort Erie shorefront, Niagara-on-the-Lake <i>E. coli</i>, is part and parcel of this recommendation.</p>	<p>The comment refers to elevated levels of <i>E. coli</i> at Queen's Royal Beach in Niagara-on-the-Lake. The matter is being addressed by Remedial Action Plan partners through efforts related to the <i>Beach Closings</i> Beneficial Use Impairment.</p> <p>Other work through the Lake Erie LAMP and the Nearshore framework addresses issues along the Lake Erie shoreline (including Fort Erie). These issues are the focus of the Niagara Coastal Community Collaborative.</p>
<p>Appreciate the reasons for recommending changing the Plankton Population BUI to unimpaired given the fresh monitoring evidence and DFO's scientific evaluation. The predation on this reportedly normal /expected forage downstream (fast flowing mixing) is reassuring to the higher level forage species (emerald shiners in the upper section and gizzard shad in the lower). More assessment of the Hydro reservoirs was also mentioned. The effects of the increased plankton from these reservoirs seem to replenish the forage for lower river fish.</p>	<p>No response required.</p>
<p>At a past RAP Update meeting, some attendees were disappointed in the lack of progress compared to the impressive habitat enhancement projects that NY State had accomplished in the upper Niagara. It's refreshing and reassuring to see interagency cooperation and dedicated efforts being put into [the Niagara River] RAP and the Hamilton Harbour RAP. Enthusiastic about the targeted vegetative aquatic and terrestrial habitat enhancements by Niagara Parks Commission</p>	<p>In the last two years, additional habitat projects have been implemented in the Niagara River Area of Concern by RAP partners, including environmental agencies in the United States. There are additional Niagara River coastal wetland restoration projects planned in 2018 and 2019. Monitoring will be completed to assess these improvements and/or identify next steps.</p> <p>There is a plan for continued interagency cooperation and community engagement in the implementation of the Niagara River (Ontario) Remedial Action Plan.</p>
<p>Concern about the \$3 million Welland River remediation dollars that were granted to the NPCA (accountability and transparency) given that tight natural resources based funding is repeatedly raised.</p>	<p>This comment was forwarded to the Niagara Peninsula Conservation Authority given it does not pertain to the Niagara River Remedial Action Plan. Please contact the Conservation Authority for details.</p>

Summary of Feedback	Response
<i>Submission #3</i>	
<p>Respondent concurs with changing the status as long as conditions are such that we are confident that neither of these two scenarios [Beneficial Use Impairments] are likely to return.</p>	<p>Given that the long-term water quality trends do not indicate issues related to eutrophication or undesirable algae, future impairments are not anticipated.</p> <p>Environment and Climate Change Canada continues to monitor water quality through its Upstream/Downstream Program.</p> <p>No further monitoring of plankton is recommended or required.</p>
<i>Submission #4</i>	
<p>Black Creek [a tributary of the Niagara River] has been used to dump human excrement, thus causing huge blooms of algae. Many other creeks are choked up with algae.</p>	<p>General water chemistry, nutrients, metals and bacterial levels are monitored by the Niagara Peninsula Conservation Authority at two monitoring stations on Black Creek. The data do not indicate any recent (i.e., past 5 years) issues related to human sewage pollution. The Conservation Authority continues to monitor water quality parameters in the region and reports on results annually.</p> <p>The Ontario Ministry of Environment and Climate Change also reviewed their files and found no reports related to water quality problems in Black Creek. Any pollution incidents can be reported to the local ministry district office (905-704-3900) or Ontario's Spills Action Centre (1-866-663-8477).</p>

## Feedback Form

Your comments are important! We want to know what you think about the recommendation to change the status related to these two ecological indicators: *Eutrophication or Undesirable Algae* and *Phytoplankton and Zooplankton Populations*. Please fill out the following feedback form and drop into the comment box or mail to: Niagara River Remedial Action Plan, 3<sup>rd</sup> Floor, 250 Thorold Road West, Welland, Ontario, L3C 1W2.

Comments will be reviewed and addressed by the RAP Team. If you wish to be contacted in follow-up to your submission, please be sure to provide your contact information. Comments will be compiled and shared in the form of a summary report after the deadline; however, personal information (name, email, phone number) will remain confidential. To obtain a copy of the technical and summary reports visit our website: [ourniagarariver.ca](http://ourniagarariver.ca) or contact Natalie Green at [info@ourniagarariver.ca](mailto:info@ourniagarariver.ca) or 905-788-3135 x243. **The comment period closes November 25, 2017.** Thank you for your feedback.

### Name

### Email

If you wish to be contacted by someone to follow-up on your comments, please provide an email address. It will not be shared publicly.

### Phone

If you wish to be contacted by someone to follow-up on your comments, please provide a phone number. It will not be shared publicly.

### 1. How did you hear about the recommendation to change the status of these two BUIs?

- ☐ Attended the Nov. 15 Open House
- ☐ Social Media (Facebook, Twitter)
- ☐ Website
- ☐ E-newsletter
- ☐ Colleague
- ☐

### 2. Have you read the supporting documents?

- ☐ Yes
- ☐ No
- ☐ I don't know

If you answered 'Yes' to the question 2 above, please indicate which documents you read.

- ☐ Eutrophication/Undesirable Algae Summary
- ☐ Plankton Populations Summary
- ☐ Technical Report on Eutrophication/Undesirable Algae
- ☐ Technical Report on Plankton Populations
- ☐ All of the above
- ☐ Not Applicable / Did not read any documents

**3. Eutrophication/Undesirable Algae BUI**

Choose the statement that best describes your opinion for the status of Eutrophication or Undesirable Algae BUI in the Niagara River (Ontario) AOC.

- ☐ I agree with the recommendation to change the status to 'Not Impaired'
- ☐ I do not agree with the recommendation to change the status to 'Not Impaired'
- ☐ I don't know

**4. Plankton Populations BUI**

Choose the statement that best describes your opinion for the status of Phytoplankton & Zooplankton Populations BUI in the Niagara River (Ontario) AOC.

- ☐ I agree with the recommendation to change the status to 'Not Impaired'
- ☐ I do not agree with the recommendation to change the status to 'Not Impaired'
- ☐ I don't know

**5. General Comments**

Please provide any additional comments or concerns related to the recommendation to change the status of the two BUIs.

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**APPENDIX 4:**  
**Supporting Communication and Outreach Materials**

# DEGRADATION OF PHYTOPLANKTON AND ZOOPLANKTON POPULATIONS

Recent scientific evidence supports changing the status of the Degradation of Phytoplankton and Zooplankton Populations BUI from “Requires Further Assessment” to “Not Impaired”.

## WHAT ARE PLANKTON?

**Plankton** are small organisms that live in the water. They are grouped into three general categories: phytoplankton, zooplankton and microbes. Plankton are an important food source for fish in the Niagara River such as Yellow Perch, Emerald Shiner, and Gizzard Shad.

**Phytoplankton** consist of microscopic plants that come in many forms. They make energy from sunlight, similar to land-based plants. An example of a well-known type of phytoplankton are diatoms.

**Zooplankton** range in size from microscopic organisms such as water fleas (*Daphnia sp.*) down to smaller organisms like mussel larvae (called veligers). Zooplankton feed on phytoplankton and smaller zooplankton.

**Microbes** include the smallest single celled organisms including bacteria and protozoans. Certain bacteria can be a problem in aquatic systems (e.g., *E. coli*), resulting in beach closures, but most are a natural part of the ecosystem and an important food source for zooplankton.

## WHY ARE PLANKTON IMPORTANT?

Plankton form the base of the food web in aquatic environments. Phytoplankton are primary producers that make energy from sunlight, providing a food source for zooplankton. In turn, zooplankton become food for fish and other animals, which then may become food for people. There must be enough phytoplankton in the water to form the base of the food web. If there is not enough phytoplankton, the web is broken and the rest of the organisms in the food web may suffer.

On the other hand, too much plankton can be detrimental. When there is too much plankton due to excess nutrients in the water (known as eutrophication), harmful algal blooms can result. These can decrease the sunlight and oxygen in the water, which can disrupt the natural ecosystem.

## WHY ARE PLANKTON A BENEFICIAL USE IMPAIRMENT INDICATOR?

Plankton are very sensitive to changes in water quality. As such, they can give clues about the overall health of an aquatic environment. In the Niagara River, plankton communities can be disturbed by:

- toxins from historical contamination;
- excess nutrients in the water (leading to eutrophication);
- sewer overflow and agricultural runoff;
- increased sunlight in very clear water; and
- physical damage from hydroelectric turbines and from the falls themselves.

## HOW WAS THE PLANKTON BUI ASSESSED?

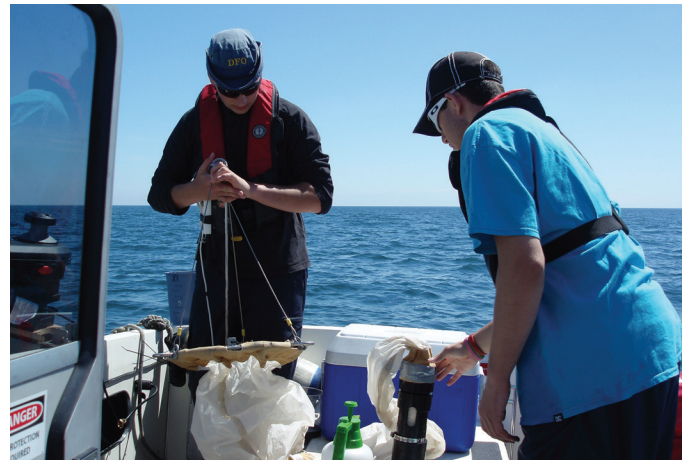
In 2014, six monitoring sites along the Niagara River were sampled monthly (from June to October) for water chemistry, phytoplankton and zooplankton composition. The assessment was conducted by scientists at Fisheries and Oceans Canada. The full report can be found on our website.

## WHAT WERE THE FINDINGS?

**The assessment showed that there are no issues related to populations of phytoplankton and zooplankton in the Niagara River Area of concern.**

Below is a brief summary of results:

- Plankton population levels were low but consistent with expectations for a large river system with low nutrients (oligotrophic) and a high flow rate.
- The most prominent plankton in the Niagara River were rotifers, water fleas, copepods, mussel veligers, and filamentous diatom algae which thrives in high-flow environments.
- The amount of plankton decreased downstream with lowest plankton levels below the Niagara Falls.
- A small increase in plankton populations was found downstream of the hydroelectric reservoirs, where plankton have refuge from the fast-flowing river and time to recover.



- Minor diatom and algae peaks in August and September, respectively, did not negatively impact the environment.
- Phytoplankton levels were very low—similar to oligotrophic Lake Erie (consistent with the findings that the river is not impaired with respect to eutrophication and algae).
- There were no dramatic changes in zooplankton species composition down river.
- A reduction in zooplankton densities in the upper river (closest to Lake Erie) is most likely due to plankton-eating fishes such as Emerald Shiner and Yellow Perch.

### FOR MORE INFORMATION

[www.ourniagarariver.ca](http://www.ourniagarariver.ca)  
[info@ourniagarariver.ca](mailto:info@ourniagarariver.ca)

## ABOUT THE NIAGARA RIVER

The Niagara River is a 58 km connecting channel, linking Lake Erie to Lake Ontario, shared by both Canada and the United States.

The Niagara River is one of 43 degraded locations called an Area of Concern (AOC) through the Canada-U.S. Great Lakes Water Quality Agreement. Each of these areas face significant water quality problems that could cause a negative impact on the way people or wildlife use the water resource. These negative impacts are known as Beneficial Use Impairments (BUIs). The Degradation of Phytoplankton and Zooplankton Populations BUI is one of 14 potential indicators that inform us about the health of the Niagara River.

The goal of the Niagara River (Ontario) Remedial Action Plan is to address the issues related to BUIs, and ultimately, remove the Niagara River from the list of Great Lakes AOCs. The focus of our efforts is on the Canadian side of the river only, while a separate plan is in place on the American side.



# NIAGARA RIVER

Remedial Action Plan

[ourniagarariver.ca](http://ourniagarariver.ca)

## Tipping the Scales Toward Delisting

### Public Information Open House

**Wednesday, November 15<sup>th</sup>, 2017 / 6:30–8:30 PM**

Presentations at 7 PM / Light refreshments provided

Recent scientific research shows that two of the Niagara River's environmental indicators are not impaired. The Niagara River Remedial Action Plan (RAP) Team invites you to learn about these two recent scientific assessments and to have your say about the recommendation to change the status of two ecological indicators related to Eutrophication and Plankton Populations in the Niagara River.

Scientists from the Department of Fisheries and Oceans Canada and the Ontario Ministry of the Environment and Climate Change will provide information on their research and will be available to answer your questions. There will also be an opportunity to learn more about the RAP program and to be a part of this important discussion.

## Have Your Say!



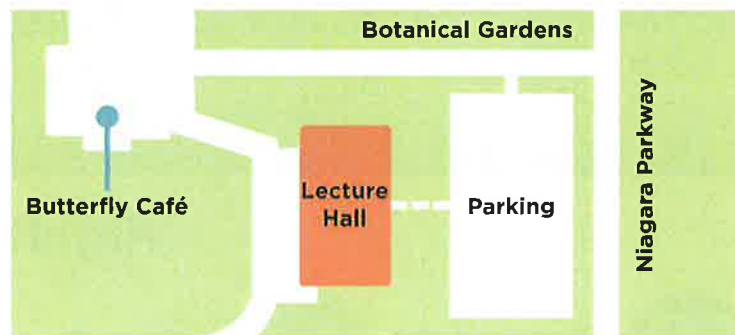
Online



Email



In Person



Niagara Parks School of Horticulture Lecture Hall  
2405 Niagara Parkway, Niagara Falls, Ontario

For more information:

[ourniagarariver.ca/latest-news](http://ourniagarariver.ca/latest-news) • [info@ourniagarariver.ca](mailto:info@ourniagarariver.ca) • (905) 788-3135 x243



# Rolling by the River Bus Tour

Wednesday, October 25<sup>th</sup>, 2017 / 10 AM-3 PM



You're invited to join a special Niagara River Remedial Action Plan (RAP) bus tour to explore and learn about the Niagara River Area of Concern (AOC) and some of the great projects completed or in progress that help us achieve a healthier Niagara River ecosystem

Coffee & Conversation 9:30 am / Bus Boards 10 am / Lunch provided  
Meet at NOTL Community Centre (Mori Room) / 14 Anderson Lane / Niagara-on-the-Lake, ON

## Highlights



Review of the  
RAP Program



Sediment  
Remediation



Habitat  
Restoration



Monitoring &  
Research

**Space is limited! Please RSVP by October 17<sup>th</sup>, 2017 to confirm your spot**  
[ngreen@npca.ca](mailto:ngreen@npca.ca) / (905) 788-3135 x243

## Rolling by the River 2017

### RAP Highlights Bus Tour Schedule\*

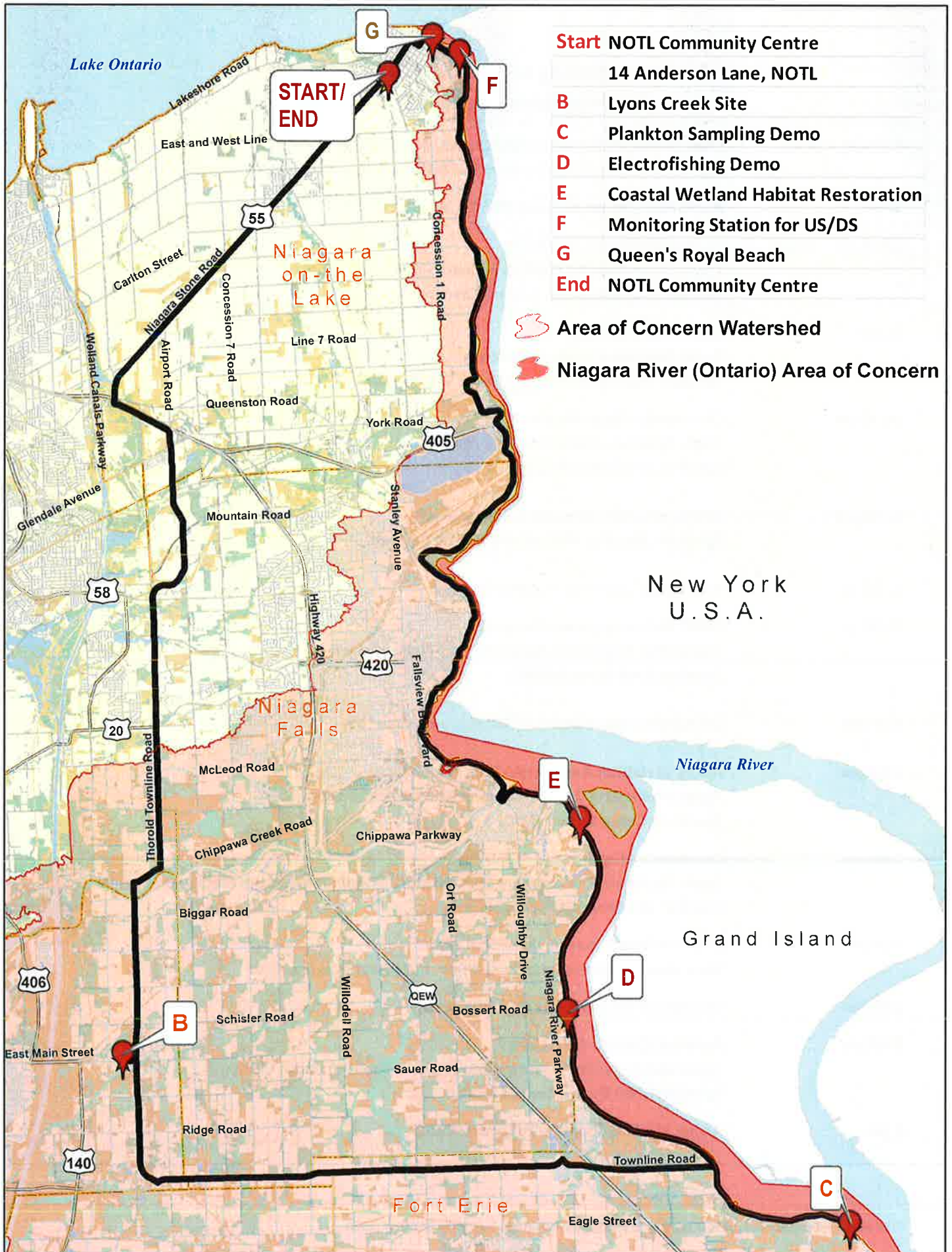
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<b>9:30 am – 10 am</b>	<b>Meet at the NOTL Community Centre, 14 Anderson Lane (A)</b> Sign-in / Meet and Greet in the Mori Room / coffee, tea, cookies provided
<b>10 am</b>	<b>Board Bus (Depart no later than 10:30 am)</b>
<b>10:30 am – 11 am</b>	On Route to Lyon's Creek site Topic: Housekeeping / RAP Overview / GLWQA Revisions Speakers: Natalie Green & Mark Chambers (ECCC)
<b>11 am</b>	<b>Lyon's Creek site (B)</b> <b>Topic: Sediment Studies / Benthos</b> <b>Speaker: Natalie Green &amp; Cheriene Vieira (MOECC)</b>
<b>11:10 am</b>	On route to Upper Niagara River site Topic: Watershed Water Quality Monitoring Speaker: Josh Diamond (NPCA)
<b>11:35 am</b>	<b>DFO Freshwater Ecosystem Research (C)</b> <b>Speakers: Heather Niblock and Robert Bonnell</b>
<b>12:00 pm</b>	Board bus / Lunch on route to next site
<b>12:30 pm</b>	<b>MNRF Fish Assessment Demo (D)</b> <b>Topic: Fish Population Assessments / Electrofishing</b> <b>Speaker: Joad Durst (MNRF)</b>
<b>1:00 pm</b>	On route to stop E (Habitat Restoration) / Free time
<b>1:10 pm</b>	<b>Arrive at Habitat Restoration Sites (E)</b> <b>Topic: Prairie and Coastal Wetland Habitat Restoration</b> <b>Speakers: Corey Burant (NPC)</b>
<b>1:40 pm</b>	On route to stop F Topic: Upstream/Downstream Monitoring & Niagara River Toxics Management Plan Speaker: Cheriene Vieira (MOECC)
<b>2:30 pm</b>	<b>Arrive at Stop F (pause, do not get out)</b> <b>View downstream monitoring station and Lower Niagara River</b>
<b>2:35 pm</b>	On route to Stop G (Queen's Royal Beach)
<b>2:40 pm</b>	<b>Arrive at Queen's Royal Beach</b> <b>Topic: water quality investigations (<i>E. coli</i> related to Beach Closings)</b> <b>Speaker: Brett Ruck (Town of NOTL)</b>
<b>3 pm</b>	<b>Arrive at NOTL Community Centre; End.</b>

*[Turn over for map]*

\*Times are estimated and route is subject to change due to adverse weather or other issues.







**MEDIA RELEASE**

***For immediate release***

**NIAGARA RIVER REMEDIATION TEAM SEEKS PUBLIC INPUT ON  
STATUS OF TWO ENVIRONMENTAL INDICATORS**

*Studies show the base of the food web is healthy*

**WELLAND, Ont. (October 23, 2017)** – The Niagara River (Ontario) Remedial Action Plan Team is seeking public input on the recommendation to change the status of two of the Niagara River's environmental indicators. Two separate scientific studies were completed that show that the base of the food web is healthy and there are no issues related to excess algae and plankton populations in the Niagara River.

Plankton such as algae, microbes and water fleas are small organisms that live in the water. "Plankton form the base of the food web in aquatic environments and are an important food source for Niagara River fishes such as Yellow Perch, Emerald Shiner, and Gizzard Shad, which in turn are eaten by larger sport fishes" explains Dr. Warren Currie, research scientist at Fisheries and Oceans Canada. "Too little or too much plankton can be an indicator of ecosystem disruption."

The two separate scientific studies examined water quality parameters, water chemistry and plankton densities to determine if there were problems with excess algae and plankton populations in the Niagara River. Water chemistry in the Niagara River is consistent with water from eastern Lake Erie. Results of the plankton assessment indicate plankton populations are lower than Lake Erie, but consistent with expectations for a high-velocity, low nutrient (oligotrophic) river system. Dominant plankton species found were those that survive in fast-flowing environments. Water quality parameters compiled from various sources showed there are no issues with excessive or undesirable algae in the Niagara River. Although the Welland River and other tributaries to the Niagara River may have localized impacts related to water quality, overall, they do not appear to directly impact the Niagara River in relation to nutrient levels or algae.

There are many ways for the public to learn about the research and have a say on the recommended status change. The reports are available for review [online](#) and comments can be submitted until November 25 by completing a short electronic survey, via email, by mail and in-person at a **Public Information Open House on November 15, 2017 from 6:30 pm to 8:30 pm at the Niagara Parks School of Horticulture Lecture Hall (2405 Niagara Parkway, Niagara Falls, Ontario)**. The Open House will provide

the opportunity to hear from the scientists, ask questions, and submit comments in person. Light refreshments will be provided.

The Niagara River is one of 36 remaining degraded locations called an Area of Concern in the Canada-U.S. Great Lakes Water Quality Agreement and the federal-provincial Canada-Ontario Agreement. Historically, each of these areas faced significant water quality problems that caused negative impacts on the way people or wildlife use the water resource. These negative impacts are known as Beneficial Use Impairments. *Eutrophication or Undesirable Algae* and *Degradation of Phytoplankton and Zooplankton Populations* are two of 14 potential indicators that inform us about the health of the Niagara River Area of Concern.

The goal of the Niagara River Remedial Action Plan is to address the environmental issues related to the Beneficial Use Impairments, and ultimately, to restore water quality and ecosystem health in the Niagara River and remove it from the list of Great Lakes Areas of Concern. A separate but complementary plan is in place on the American side of the river.

**FOR MORE INFORMATION** visit [ourniagarariver.ca/latest-news](http://ourniagarariver.ca/latest-news). Follow us on [Facebook](#) and [Twitter](#) for more updates.

###

*The Niagara River Remedial Action Plan is a community-based partnership to restore and protect water quality and ecosystem health in the Niagara River Area of Concern. This initiative is made possible with funding from the Government of Canada and the Province of Ontario, in partnership with the Niagara Peninsula Conservation Authority. To get involved, contact [info@ourniagarariver.ca](mailto:info@ourniagarariver.ca).*

Media Contact:

Natalie Green, Niagara River RAP Project Manager  
Niagara Peninsula Conservation Authority  
[ngreen@npca.ca](mailto:ngreen@npca.ca)  
905-788-3135 x243

## **MEDIA ADVISORY**

### **Public invited to learn about recent progress on Niagara River ecosystem**

**WELLAND, Ont. (November 13, 2017)**— The Niagara River (Ontario) Remedial Action Plan Team is seeking public input on the recommendation to change the status of two of the Niagara River's environmental indicators.

Two separate scientific studies were completed, which show that the base of the food web is healthy and there are no issues related to excess algae and plankton populations in the Niagara River. The reports are available for review [online](#) and comments can be submitted until November 25 by completing a short electronic survey, via email, by mail and in-person at the Public Information Open House. Light refreshments will be served.

**WHAT:** Niagara River Public Information Open House

**WHEN:** Wednesday, November 15, 2017  
**6:30 to 8:30 p.m.**

**WHERE:** Niagara Parks School of Horticulture Lecture Hall  
2405 Niagara Parkway  
Niagara Falls, ON

#### **OPPORTUNITY:**

The public and the media will get an opportunity to learn about the research related to two ecosystem indicators and to have a say on the recommended status change in the Niagara River Area of Concern.

Scientists from Fisheries and Oceans Canada, the Ministry of the Environment and Climate Change and representatives from the Niagara River Remedial Action Plan initiative will be available for interviews and photos.

For more information, please contact Natalie Green at [ngreen@npca.ca](mailto:ngreen@npca.ca) or 905-788-3135 x243.

**FOR MORE INFORMATION** visit [ourniagarariver.ca/latest-news](http://ourniagarariver.ca/latest-news). Follow us on [Facebook](#) and [Twitter](#) for more updates.

**###**

*The Niagara River Remedial Action Plan is a community-based partnership to restore and protect water quality and ecosystem health in the Niagara River Area of Concern. This initiative is made possible with funding from the Government of Canada and the Province of Ontario, in partnership with the Niagara Peninsula Conservation Authority. To get involved, contact [info@ourniagarariver.ca](mailto:info@ourniagarariver.ca).*

# Open house to discuss Niagara River health

Postmedia Staff

The health of the Niagara River's ecosystem seems to be improving, according to new scientific research conducted on the waterway.

As a result of those studies, the Niagara River Remedial Action Plan is inviting the community to an open house to discuss the potential of upgrading the status of the river – one of 36 waterways listed as areas of concern in the Canada-U.S. Great Lakes Water Quality Agreement and

the Canada-Ontario Agreement.

In a media release issued Monday, the organization run in partnership with the Niagara Peninsula Conservation Authority, says two separate scientific studies looked into water quality parameters, chemistry and plankton densities and determined that the food web base was healthy, and that there were no issues related to excess algae and plankton populations.

There has been significant water quality problems within

the river in past years, negatively impacting people and wildlife.

Reports on the studies are available online at [ourniagarariver.ca/latest-news](http://ourniagarariver.ca/latest-news), and comments can be submitted online until Nov. 25, or in person at a public information open house, Nov. 15 from 6:30 to 8:30 p.m. at the Niagara Parks School of Horticulture Lecture Hall, 2405 Niagara Parkway, Niagara Falls, where scientists involved in the studies will be available to discuss their findings and answer questions.

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APPENDIX 5:  
Presentation slide deck - Assessment of the  
*Degradation of Phytoplankton and Zooplankton Populations* Beneficial Use  
Impairment in the Niagara River (Ontario) Area of Concern

# Assessment of the Phytoplankton and Zooplankton Populations in the Niagara River Area of Concern

R.M. Rozon, K.L. Bowen, H.A. Niblock,  
M.A.J. Fitzpatrick and W.J.S. Currie



Fisheries and Oceans Canada  
Pêches et Océans Canada

Great Lakes Laboratory for Fisheries and Aquatic Sciences  
**Ecosystem Research**



## Tech Report Available

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick and W.J.S. Currie. 2016. Assessment of the Phytoplankton and Zooplankton Populations in the Niagara River (Canada) Area of Concern in 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3184: iv + 66p.

<http://cat.cisti-icist.nrc-cnrc.gc.ca/record=b4059760>

<http://waves-vagues.dfo-mpo.gc.ca/Library/4059760x.pdf>

Assessment of the phytoplankton and zooplankton populations in the Niagara River (Canada) Area of Concern in 2014

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick and W.J.S. Currie

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## Niagara River

- A 58 km long connecting channel from Lake Erie to Lake Ontario
- Avg. flow rate of 5,800 m/s
- Residence time of ~1 day
- Two major disruptions:
  - Niagara Falls
  - Hydroelectric facilities which divert up to 60% of the upper river into reservoirs on both sides
- Very limited/non-existent plankton studies



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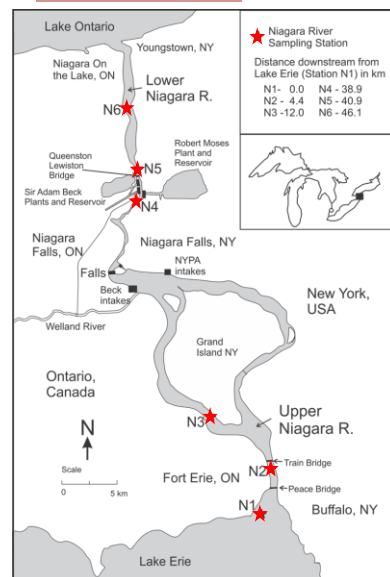
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## Sampling sites

- 3 zones of the Niagara River
  - Upper River, Above & Below turbine outflows
- ~Monthly (Jun-Oct 2014)
- 6 stations + Lake Erie reference
  - N1, N3, N4 & N6
    - Phytoplankton prod. + species
    - Water chemistry
  - All 6 stns = Zooplankton
- N4 & N5 to monitor expected influence from reservoirs
- Transects (N2, N3, N6)



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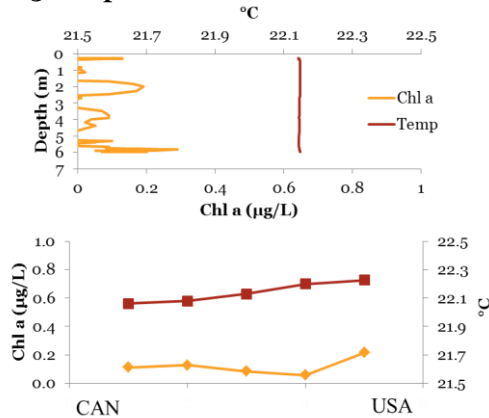


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## Environment & Habitat

### N3 – Sept. 10



- The river was found to be well-mixed

▫ Both vertically though the water column..

▫ And by transects across the river.



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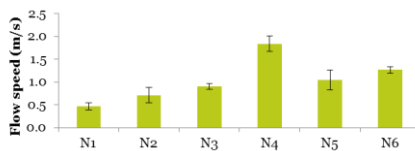
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## Environment & Habitat

- Flow rates increased up to the hydroelectric outflows



- Water chemistry

	TP (mg L <sup>-1</sup> )	TKN (mg L <sup>-1</sup> )	chl a. (ug L <sup>-1</sup> )
N1	0.015	0.25	1.31
N3	0.014	0.27	1.03
N4	0.017	0.25	1.32
N6	0.018	0.27	1.53

▫ varied little over the season



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## Methods

## Physico-chemical

### Current speeds impacted all sampling techniques

- Multiparameter sondes
  - Chl  $a$ , phycocyanin, turb., temp., DO, pH...
- Surface current speed
- Light attenuation ( $K_d$ )
- Integrated water samples (up to 7 meters)
  - Nutrient analyses
  - Extracted chlorophyll  $a$



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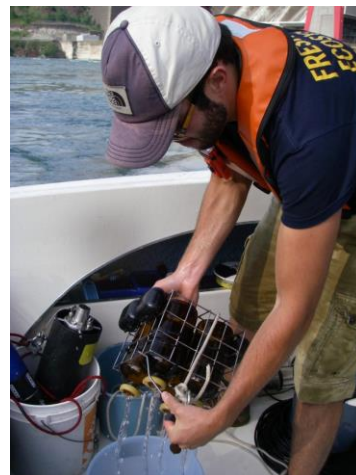
## Methods

## Phytoplankton & Microbial loop

### Integrated samples (0-7 m)

- Primary productivity
- Bacterial growth rate
- Microbial loop
- Preserved samples for phytoplankton community ID

The lab measurements of bacterial and phytoplankton growth give optimal rates  
\*not harsh in-situ conditions



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## Methods

## Zooplankton

- 64  $\mu\text{m}$  “vertical” net + flow meter + MK9 depth sensor
- Zooplankton species ID
  - Genus level
  - N1, N3, N6: species level
- Zooplankton June-Oct total production estimates
  - Egg Ratio for *Bythotrephes*
  - Production/Biomass - others
- Rotifer species
  - Seasonal composite @ 4 stns



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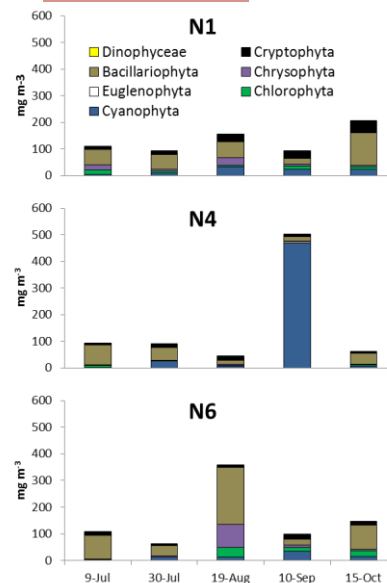


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## Results

## Phytoplankton

- Biomass range: 44-503  $\text{mg}/\text{m}^3$
- Average = 148  $\text{mg}/\text{m}^3$
- August N6 peak
  - Bacillariophyta (Diatoms):
    - *Fragilaria crotonensis* (45.3%)
  - Cryptophyceae:
    - *Ochromonas* sp. (21.2%)
- September N4 peak
  - Cyanophyta:
    - *Lyngbya birgei* (89.4%)
- Generally, diatoms dominated
  - *F. crotonensis*, *Stephanodiscus* sp., *Cocconeis pediculus*
- Cryptophytes (*Rhodomonas minuta nannoplantica*) & filamentous cyanophytes (*L. birgei* and *Heteroleibleinia* sp.) also contributed



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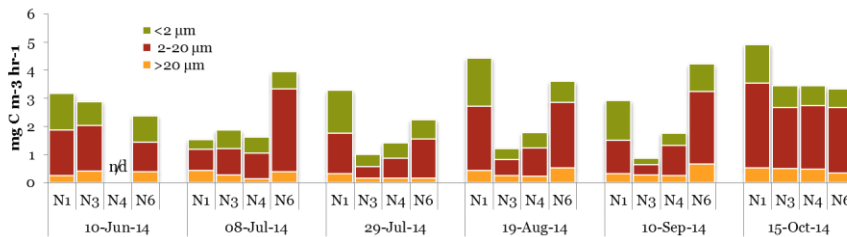
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## Results

## Primary Productivity



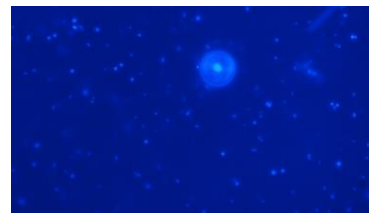
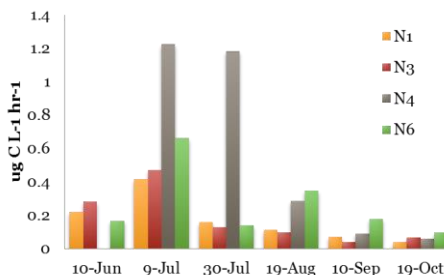
- Range of 0.87 - 4.91 mg C m<sup>-3</sup> h<sup>-1</sup> , with N1 and N6 most productive
- Increased in late fall
- Dominated by the 2-20 µm fraction ranging from 40% to 75% of total production
  - Exceptions in late July at N1 & N3, as well as in Sept. at N1 (<2 um).

## Results

## Bacterial production &amp; Microbial loop

Bacterial production:

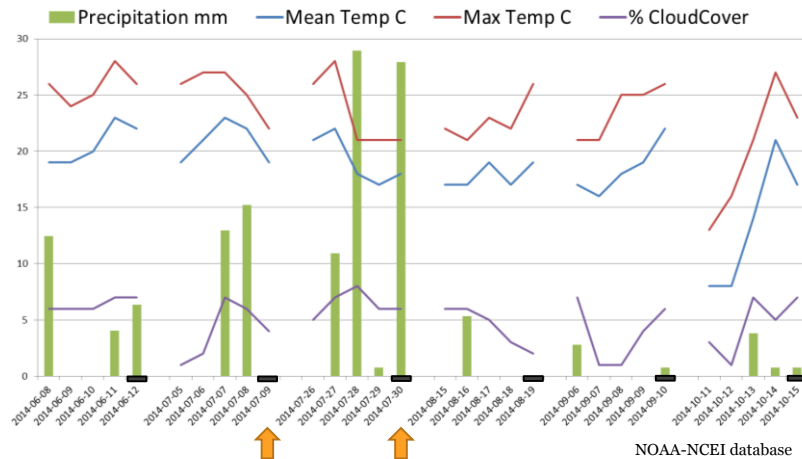
- Highest in July (2 days of rain)
- Tends to increase below turbine outflows

Microbial Loop

- Range: 0.63-3.05 g/m<sup>3</sup>
- Average: 1.3 g/m<sup>3</sup> (N1 in Sept)
- Avg. 91% of total ML is bacteria
  - APP: 7.3%
  - HNF: 2.7%

## Results

## Precipitation at Niagara Airport (IAG)



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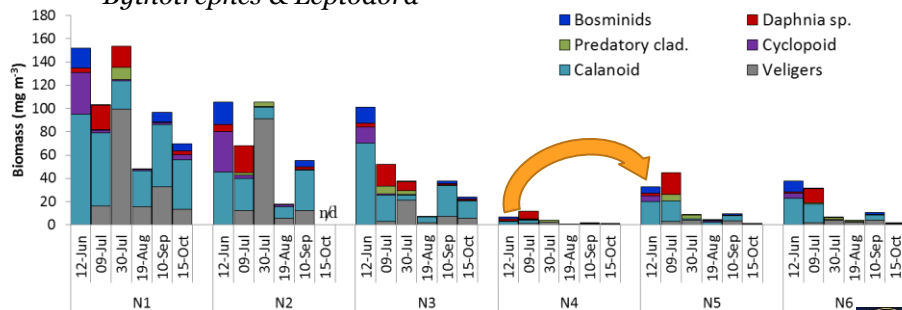


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## Results

## Zooplankton community composition

- June different than the rest of the year
  - Cyclopoid copepods and bosminids, replaced by veligers
- Veligers most abundant, but small in size
- Calanoid copepods dominate biomass
- Predatory cladocerans peak in July
  - *Bythotrephes* & *Leptodora*



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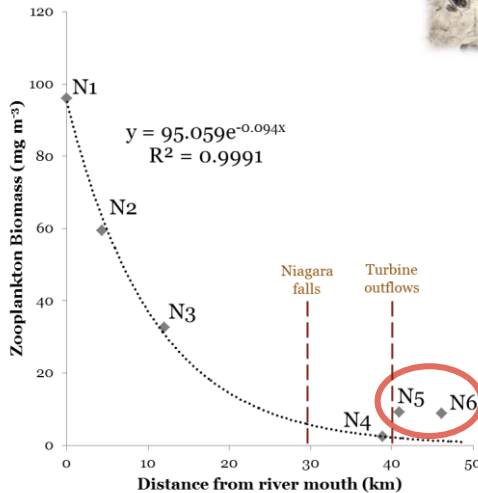
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## Results

## Zooplankton



- Biomass (& density) show a sharp decline with distance down river
- Expected trend deviates from actual data at N5 & N6
  - Input from the reservoirs
  - 8.3x and 12.2x greater, respectively, than would have been expected if the turbine outflows had no effect.
- Statistically significant difference between upper and lower river biomass



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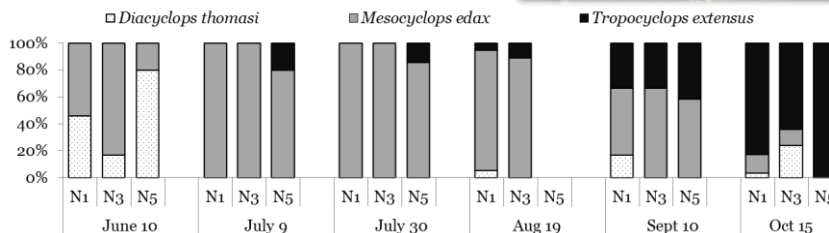


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## Results

## Zooplankton community composition

- No dramatic changes in zooplankton species composition down river
- Abundant cladocerans:
  - *D. galeata mendotae* and *Bosmina*
- Copepod seasonal succession as seen in East. Erie and H.H.



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## Results

## Zooplankton June-Oct total production

Production (mg m <sup>-3</sup> )	Bosminid	Daphnia	Predatory Cladocera	Cyclopoid	Calanoid	Veliger	Total	Rotifer
Lake Erie	97	251	369	119	209	178	1331	
N1	93	114	47	56	335	415	1059	15
N2	71	84	24	53	138	263	632	
N3	51	81	31	29	159	95	445	7
N4	6	19	13	3	6	12	58	1
N5	18	50	45	10	42	27	192	
N6	26	29	22	7	37	33	153	1.5

- Similar decline with increasing distance into the river.
  - Shows some recovery beyond the turbine outflows (N5 & N6)
- Assumes that all individuals in the sample were alive at time of collection
- Viability of zooplankton was not directly addressed in this study
  - Animals were noted to be actively swimming in the samples prior to preservation.



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## Results

## Rotifer community composition

- Rotifer abundance and biomass also declined with distance downriver
  - N1: 19.5 ind/L
  - N4: 2.1 ind/L
  - N6: 3.6 ind/L
- Dominant species were:
  - *Conochilus unicornis*,
  - *Keratella cochlearis*, &
  - *Kellicottia longispina*
- Large soft-body taxa (*Asplanchna* sp.) were most impacted by riverine conditions



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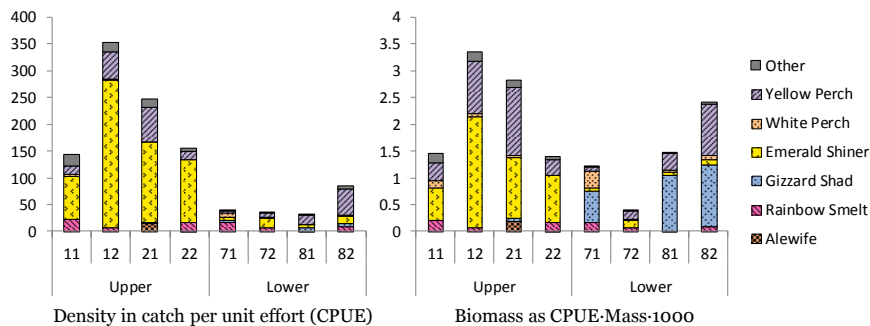


## Results

## Planktivorous Fish



- 2015 surveys by SAR-DFO shows fish community composition was very different between the upper and lower river biomass
  - Upper river dominated Emerald Shiner, lower by larger Gizzard Shad



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## Discussion

- Niagara River is a unique system
  - Difficult to study and has few freshwater analogues
- Trend of declining zooplankton biomass with distance downstream is common in rivers, but why?
  - Residence time  $\propto$  plankton abundances
  - Turbulence, advective transport of food/individuals, trauma, predation, turbidity, etc.
- Partial recovery beyond the turbine outflows
  - Reservoirs appear to be acting as lentic refuge for plankton augmenting populations down-river



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## Summary

- Niagara River acts more like a connecting channel and less like a typical river
  - Very short retention time, low flow variability
  - More akin to an oceanic strait
- Niagara River water is Eastern Lake Erie water
  - Low-productivity (bacteria?), clear-phase system
- Reductions in plankton biomass are consistent with expectations for a large river system
- Plankton communities are composed of species better suited to survive turbulent conditions
  - Strong skeletal structure of Diatoms
  - Small size = fewer negative advection effects
    - Bacteria, phytoplankton, small zooplankters



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## Future Research

- Entrainment in the hydroelectric reservoirs may promote increase in plankton population
  - Future sampling would include directly sampling within the reservoirs
  - Role of treatment plants and Welland River to productivity in the reservoirs and forebays
  - Does diet of planktivorous fish change below turbines



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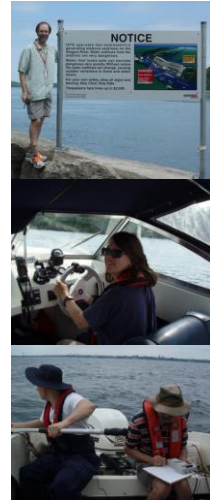
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## Acknowledgements

- DFO Field and Lab crews
- Fish data generously provided by
  - DFO SAR: Robin Gáspárdy & Lynn Bouvier
  - The Niagara River Emerald Shiner Project: Alicia Pérez-Fuentetaja.
- Additional Lake Erie samples collected by Erin Hillis, U. Windsor
- Thanks to all the taxonomists!



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APPENDIX 6:

Assessment of the *Degradation of Phytoplankton and Zooplankton Populations*  
Beneficial Use Impairment in the Niagara River (Ontario) Area of Concern

# **Assessment of the phytoplankton and zooplankton populations in the Niagara River (Canada) Area of Concern in 2014**

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick and W.J.S. Currie

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Central and Arctic Region, Fisheries and Oceans Canada  
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Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

## **Rapport technique canadien des sciences halieutiques et aquatiques**

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

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Assessment of the phytoplankton and zooplankton populations in the Niagara River  
(Canada) Area of Concern in 2014

by

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick and W.J.S. Currie

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3184: iv + 66p.

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## ABSTRACT

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick and W.J.S. Currie. 2016. Assessment of the Phytoplankton and Zooplankton Populations in the Niagara River (Canada) Area of Concern in 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3184: iv + 66p.

This report collects all available plankton community data for the Niagara River Area of Concern (AOC) designated *requires further assessment* for the Beneficial Use Impairment (BUI 13): "degradation of phytoplankton and zooplankton populations". The Niagara River connecting channel, though it joins well-studied Lake Erie and Lake Ontario is data-poor, with no active plankton sampling programs. A single season of sampling in 2014 took place monthly from June-Oct for water quality, zooplankton and phytoplankton composition and density. Oligotrophic conditions persisted throughout the season and plankton densities were extremely low, though this was expected in a high-flow system such as the Niagara River. The residence time for plankton in the Niagara River is only 11-28 hours, but could be much longer if plankton are entrained in the hydroelectric reservoirs. Given the results of this survey, no impairment of plankton populations is indicated.

## RÉSUMÉ

R.M. Rozon, K.L. Bowen, H.A. Niblock, M.A.J. Fitzpatrick and W.J.S. Currie. 2016. Évaluation du phytoplancton et du zooplancton Populations secteur préoccupant de la rivière Niagara (Canada) en 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3184: iv + 66p.

Ce rapport rassemble toutes les communautés planctoniques de données disponibles pour le secteur préoccupant Niagara River (SP) désignée comme exigeant une évaluation plus approfondie d'utilisations bénéfiques altérées (UBA 13): "la dégradation des populations de phytoplancton et de zooplancton". La rivière Niagara canal de liaison, mais il rejoint le lac Érié bien étudié et le lac Ontario est pauvre en données, sans programmes d'échantillonnage de plancton actifs. Une seule saison d'échantillonnage en 2014 A eu lieu chaque mois de Juin-Oct pour la qualité de l'eau, le zooplancton et la composition du phytoplancton et la densité. Les conditions oligotrophes persistent tout au long de la saison et les densités de plancton sont extrêmement faibles, bien que cela soit attendu dans un système à débit élevé comme la rivière Niagara. Le temps de séjour du plancton dans la rivière Niagara est de seulement 11-28 heures, mais pourrait être beaucoup plus long si le plancton est entraîné dans les réservoirs hydroélectriques. Étant donné les résultats de cette enquête, aucune dégradation des populations de plancton n'est indiquée.

## EXECUTIVE SUMMARY

This report documents the data collected in 2014 by Fisheries and Oceans Canada (DFO) to assess the effect of the Niagara River environment on zooplankton and phytoplankton community composition, in order to recommend a status of the plankton populations BUI for the Niagara River Area of Concern (AOC). To accomplish this, six monitoring sites were sampled monthly for water chemistry, phytoplankton and zooplankton composition along the river including one site at the outflow of Lake Erie. The Welland River watershed was not included in this study.

In 2014 the Niagara River exhibited the conditions of a low-productivity, oligotrophic, clear-phase system. The water chemistry values are similar to the water that enters the river from Lake Erie, including values of chlorophyll *a* below  $2.5 \mu\text{g}\cdot\text{L}^{-1}$ . While plankton densities in the Niagara River are very low compared to the adjacent lakes, reduced densities of phytoplankton and zooplankton are expected in high flow riverine environments, given a well-documented relationship between increased current speed and decreased plankton biomass. The low plankton biomass within the river should thus not be of concern. There is some evidence that entrainment time in the hydroelectric reservoirs might be promoting an increase in phytoplankton and zooplankton growth, though it was outside the scope of this monitoring survey to include them in the sampling program. In general, the phytoplankton and zooplankton communities found in the Niagara River are similar to those in other lentic environments and predictably, dominated by species better suited to highly turbulent conditions. The phytoplankton community within the river is dominated by diatoms, particularly by filamentous or colonial forms that are suited to high-energy flow systems such as *Fragilaria crotonensis* and *Skeletonema potamos*. There is no evidence to suggest that the small diatom peak (August), or blue-green algae peak (September), were persistent or were likely detrimental to the system. Overall, levels of peak algal biomass did not exceed  $503 \text{ mg m}^{-3}$ , significantly less than the definition of a eutrophic algal bloom.

The Niagara River zooplankton community is dominated by dreissenid veligers throughout the summer, though this matched the pattern found from Lake Erie, and the Niagara River itself is known to have high densities of adult dreissenid mussels. The rest of the zooplankton community biomass comprised mostly adult and juvenile forms of calanoid copepods, which are known to be resilient in high flow environments. While the decrease in zooplankton biomass from  $103.9$  to  $4.19 \text{ mg m}^{-3}$  is precipitous down the river, the loss of zooplankton occurs across all groups and some natural mortality is expected in rivers, especially one with a large waterfall mid-river. Furthermore, planktivorous fish populations are high in the upper river, dominated by Emerald Shiner, which likely contribute to the reductions in zooplankton. Copepods were found at higher densities at stations below the hydroelectric plants suggesting the reservoir system may be a suitable location for zooplankton reproduction, but no sampling occurred within these reservoirs for this study.

Any reductions in biomass and changes in species compositions are consistent with expectations for a large river system, indicating no impairment of phytoplankton or zooplankton populations in the Niagara River. Any future sampling should include the hydroelectric reservoirs on both sides of the river, in particular on the Canadian side, since the Sir Adam Beck reservoir receives input from both the Welland River and the Niagara Falls Wastewater Treatment Plant, which fall within the watershed of the Welland River.

## INTRODUCTION

The Niagara River is a 58 km long connecting channel from Lake Erie to Lake Ontario, flowing north over the Niagara Escarpment at Niagara Falls. It also serves as the international boundary between Canada and the United States. More than half of the flow is diverted for electrical power generation on both sides of the river and is held in the Lewiston Reservoir on the American side and the Sir Adam Beck Power Reservoir on the Canadian side. Thus, 60% of the river water has a lentic (lake-like) existence for a portion of time before entering the lower river. Areas of Concern (AOCs) which are connecting channels (e.g. Niagara River, St. Clair River, Detroit River, St. Lawrence River) are particularly challenging to manage compared to other AOCs because they require strong binational cooperation and a basin-wide ecosystem perspective for their restoration and protection (Great Lakes Connecting Channels 2009). The Canadian section of the Niagara River was originally listed as an AOC under the 1987 Binational Great Lakes Water Quality Agreement (GLWQA; International Joint Commission 1989) because available data at the time indicated degraded water quality and environmental conditions from contaminated sediments and nutrient rich runoff from agricultural areas. The Niagara River AOC has both a Canadian and American Remedial Action Plan (RAP) process, with the Canadian section of the Niagara River representing the entire length of the western side of the river, including the Canadian side of Niagara Falls. The Canadian focus is on loss and degradation of wetlands and fish habitat due to non-point sources of rural pollution. In contrast, most environmental concerns in the United States are associated with toxic contamination and the discharge of municipal wastes.

In the Stage 2 report of the Niagara River RAP (April, 1995) and in the follow up Status of Beneficial Use Impairments Niagara River (September, 2010), the status of the Beneficial Use Impairment (BUI) 'Degradation of phytoplankton and zooplankton populations' has been identified as *requires further assessment*. Previous work around this topic has been a study of chlorophyll *a* levels in the Welland River as an indicator of eutrophication, more suited to the Eutrophication or undesirable algae BUI. Until now, there have been no extensive assessments of the status of phytoplankton or zooplankton communities in the Niagara River. This report focuses on the plankton of the Niagara River as defined by the Niagara River RAP, therefore the Welland River was only examined in a cursory fashion and is only briefly discussed.

Phytoplankton and zooplankton play an important role in the transfer of energy through aquatic trophic food webs. The role of phytoplankton in converting nutrients and light into biomass through photosynthesis is understood by most people, as is the fact that zooplankton consume this primary production. However, the interconnections within the planktonic food web are complex, driven by a number of factors and are ever changing (Sommer et al. 2012). Furthermore, the role of the other heterotrophs in this food web: ciliates, nanoflagellates and other protists grouped into the term "microbial loop" are even less understood. What is known is that proper food web function relies on the contribution of each of these groups, and that an excess of one or more of them can lead to an unstable community (Legendre and Rassoulzadegan 1999).

There are a variety of potential factors which can disrupt phytoplankton and zooplankton communities and change community composition, including toxic influence from historical contamination (notably heavy metals and chlorinated hydrocarbons; Walsh 1978; Durham and Oliver 1983; Munawar et al. 1983), influences of eutrophication, sewer overflow and agricultural runoff, influences from residence time in the hydroelectric reservoirs (Akopian et al. 1999; Williams et al. 2003), increased surface irradiance in very clear water (Reynolds et al. 1994), as well as physical damage due to turbulence from the turbines and the falls themselves (Horvath and Lamberti 1999).

Connecting channels between closely adjacent large lakes are very uncommon outside of the Laurentian Great Lakes (Edwards et al. 1989). Connecting channels are different from other large rivers in that, while they have high discharge rates, they are short in length. One parallel can be found in the straits between ocean basins, but beyond their characteristic high salinities, these are usually much larger in size and very deep (e.g., Øresund strait connecting the Baltic Sea and the North Sea), and rarely considered “rivers”. The transition from one lentic system to another via a strong flowing connection with a short retention time makes connecting channels very difficult to assess (Walks and Cyr 2004).

There is a general consensus in the scientific community that the transition from a lentic (lake-like) to a lotic (river-like) ecosystem has a powerful effect on the community composition of phytoplankton and zooplankton; lotic ecosystems contain less phytoplankton and zooplankton as compared to lentic environments (Pace et al. 1992) and certain species (termed potamoplankton) show better success in riverine conditions than others (Pace et al. 1992; Rojo et al. 1994; Walks and Cyr 2004). Shallow systems, including rivers can generally be grouped into two phases: turbid, phytoplankton dominated, or clear, macrophyte dominated systems (Vis et al. 2007). Low nutrient rivers tend to have the primary producer community dominated by aquatic plants (Reynolds et al. 1994; Hilt et al. 2011). Zooplankton biomass is lowest in nontidal rivers, followed by tidal rivers, estuaries and then lakes (Pace et al. 1992). In riverine environments, the rapidly changing water provides little or no time for plankton to adapt to the changing conditions (Köhler 1994). River conditions are not ideal for the survival of plankton; increased turbidity, high concentrations of organic and inorganic particles, and limited high-quality food are all regulating phytoplankton and zooplankton growth (Pace et al. 1992). In fact, all aspects of plankton growth, feeding and reproduction are negatively affected by water currents (Wahl et al. 2008). As water currents increase downstream of the river mouth, noting that this distance is related to river size (Walks and Cyr 2004), it is common for zooplankton populations to drop off. This is likely caused by avoidance of high velocity areas, increased predation and interference with feeding activity due to the advective processes of the river (Pace et al. 1992).

Increased flow is more detrimental to zooplankton populations compared to phytoplankton, since zooplankton have longer generation times and cannot compensate for losses as quickly as phytoplankton. In slow moving rivers, as residence time increases, so does plankton biomass (Pace et al. 1992). Walks (2003) suggested that water residence times correlate well with zooplankton biomass but less well with phytoplankton, therefore flushing rates are acting as a controlling factor in phytoplankton biomass. In fast moving rivers, such as the Niagara River, residence times are very low, therefore benthos, eddies, back waters, reservoirs and low-flow areas become important refugia for phytoplankton (Reynolds et al. 1994; Speirs and Gurney 2001; Walks 2003; Genin et al. 2005; Walks 2007). Pace et al. (1992) hypothesized that smaller zooplankton species would be favored in riverine ecosystems due in part to their shortened generation times, their ability to feed and grow more successfully in the presence of filamentous or toxic algae, and their survival advantage in turbid waters (notably rotifers). Reynolds et al. (1994) suggested that successful phytoplankton species will be those that can survive high-frequency irradiance fluctuations, have fast growth rates and show resilience in high flow systems, notably diatoms and chlorococcal green algae.

The purpose of this report is to assess the effect of the Niagara River environment on zooplankton and phytoplankton community composition and to recommend status of the plankton populations BUI. This was accomplished by surveying sites in the upper and lower river to determine plankton biomass, taxonomic composition and productivity over the 2014 growing season (June – Oct.) and comparing these estimates to other riverine systems.

## METHODS

### Study sites

The Niagara River consists of three distinct zones: the upper river, from Lake Erie to Niagara Falls which contains relatively shallow, fast moving laminar flow, vertically mixed water with flow in mid-channel approximately twice that found at the margins; above the turbines, from Niagara Falls to the turbine outflows which consists of a deep narrow gorge transporting water through rapids with flow at mid-channel ~3x that found at the margins and a large eddy at the whirlpool; and from the turbines outflows to Lake Ontario (below the turbines), where the river widens and with a deep channel, the current slows, and eddies are common [A. Thompson and S. Rodrigues, National Hydrologic Service of Environment and Climate Change Canada (ECCC), personal communication] (Figure 1). Contributing factors outside the AOC important to plankton ecological dynamics are the hydroelectric reservoirs, although not sampled, will be discussed. Water is removed from the river flow just above the falls and pumped into large holding reservoirs which are recharged primarily during the night and released from the reservoirs gradually throughout the day for peak power generation (Figure 2). The amount and timing of water diverted into the reservoirs is highly regulated by the Niagara River Water Diversion Treaty (1950) and creates strong day-night flow dynamics in the river. The zones in the upper river and above the turbines offer very few opportunities for plankton refugia, unlike the downstream system eddies, deep channels and the lentic environments in the reservoirs.

The average daily Niagara River flow rate is  $5,800 \text{ m}^3\text{s}^{-1}$ , and varies little ( $\pm 20\%$ ) throughout the year. The required minimum scenic flow over Niagara Falls is  $2,832 \text{ m}^3\text{s}^{-1}$  during the daytime (08:00 to 22:00) of tourist season, April through October, but during the night and non-tourist season, November to March, the required minimum flow is reduced to  $1,416 \text{ m}^3\text{s}^{-1}$ . Excess water is permitted to be taken from the Niagara River for power generation, which accounts for up to 60% of the overall flow, drawn from the river 4 km above Niagara Falls on the US side and 2 km above the Falls and from the Welland River (via the Chippawa-Queenston Canal) on the Canadian side (Figure 2). At night, a substantial fraction ( $2,300 \text{ m}^3 \text{ s}^{-1}$ ) of the river flow is diverted into the Robert Moses Niagara Power Station (NY Power Authority) forebay on the US side, with excess pumped into the upper Lewiston Reservoir (770 ha,  $8.3 \times 10^7 \text{ m}^3$ ). The same pattern exists on the Canadian side for the Ontario Power Generation (OPG) Sir Adam Beck Hydroelectric Generating Stations with water being pumped into the smaller (300 ha,  $1.9 \times 10^7 \text{ m}^3$ ) reservoir (Williams et al. 2003).

Complete filling of either reservoir can take up to 8 hours, but the water is taken in a cyclical method, being pumped up in the night when excess flow is made available and reservoir is drawn down during the day when power generation is at its maximum. The water level of the reservoir peaks during the weekend and gradually reduces until late Friday evening (Miller and Kappel 1987). This makes determination of residence time very difficult for the individual reservoirs. Knowledge of the pumped volume and water levels/volume must be known to calculate residence time, but it will fall into the range of days-weeks. The volume of the reservoir can drop considerably each day (down ~7-8 m) but the water is always taken from one end of the basin, meaning that plankters may have a refugium if they occur on the opposite side away from the main outflow.

From June to October 2014 DFO staff from the Great Lakes Laboratory for Fisheries and Aquatic Sciences in Burlington, Ontario, surveyed the river approximately once a month in Lake Erie and each of the three river zones; the upper river above the falls (Lake Erie to river km 30), the lower river below the falls above the turbines (km 30 to km 39), and the lower river below the turbines (km 39 to Lake Ontario; see Figure 1 and Table 1). The initial June survey was exploratory and included a number of land-based stations as well as mid-river stations. Based



on the sites surveyed in June, six stations were selected [NIA10 (mouth of Lake Erie), NIA11 (upstream of the Fort Erie train bridge), NIA12 (Grand Island), NIA13 (upstream of the turbines), NIA14 (Queenston Bridge), and NIA4 (lower river stretch downstream of turbines)] to collect zooplankton samples for the rest of the season. Water samples for phytoplankton production and taxonomy and water chemistry were collected from NIA10, NIA12, NIA13 and NIA4. Sites above (NIA13) and below the turbine outflows (NIA14) were chosen because there was an expected influence from the reservoirs and matching river discharge measurements from ECCC were available.

### **Physico-chemical**

Over nine sampling excursions from June to October 2014 (see Appendix 1), sonde profiles were collected at multiple stations along and across (transects) the river in order to determine how the physical and biological properties of the river change based on location, relative to the two hydroelectric generating stations in particular (note the location of the hydroelectric plants and reservoirs on Figure 1). Multiparameter sondes [an EXO2 (YSI), a FluoroProbe (bbe-Moldaenke) and Hydrolab HL4] were used to collect data on chlorophyll *a*, phycocyanin, turbidity, temperature, conductivity, dissolved oxygen, pH, and phytoplankton-group pigments. These sondes were used concurrently due to difficulties with instrument reliability working in rugged conditions in the Niagara River. In particular, the EXO2 was susceptible to instrument reset when bumped due to a power issue, which resulted in a company recall the following winter. Due to the speed of the current at all stations, the vessel was allowed to drift in order to take the most vertical profile possible. In a flowing river, the standard method of determining water clarity with a Secchi disc is problematic. Instead, the vertical light attenuation coefficient ( $k_d$ ) was estimated using Licor quantum irradiance sensor.

Water column averages were calculated for each station. Horizontal cross-river transects were also done at selected stations (NIA12, NIA18 (Queenston boat launch), NIA4) to verify the relevance of values at the station locations. In late July an additional upper river transect (NIA11) was also completed. Transects could not be performed near the turbines (NIA13 and NIA14) due to the strong current and exclusion zones. Occasionally, sonde malfunctions occurred, resulting in no salvageable data being available from any of the probes.

Due to the speed of the current at all stations, the vessel was allowed to drift in order to take the most vertical profile possible. In spite of this, the samples were still more oblique than would have been expected at a station with less current. This made targeting specific depths with bottle samplers very difficult. Water samples were instead collected with a “glug-glug” bottle integrator and a best attempt was made to integrate the sample over the estimated euphotic depth. However due to the strong water current, the maximum possible sample depth was ~7 m (Table 2). This is expected to be representative because the water column at all of the stations was well mixed to near bottom based on sonde profiles and Acoustic Doppler Current Profiler (ADCP) data. Samples were stored in the dark and kept cool until analysis. Water samples for chlorophyll *a*, DIC, DOC, POC, PON,  $\text{NH}_3$ ,  $\text{NO}_3^- + \text{NO}_2^-$ , TN, SRP, TP,  $\text{SiO}_2$ ,  $\text{Na}^+$ ,  $\text{Mg}^{+2}$ ,  $\text{K}^+$  and  $\text{Ca}^{+2}$  were collected at NIA10, NIA12, NIA13 and NIA4 and processed the next day back at the laboratory in Burlington. Analysis of nutrients and major ions was conducted according to the standard protocols of the Environment Canada’s National Laboratory for Environmental Testing (NLET 1997). Results underwent QA/QC for questionable values, and any outliers (e.g., DOC of  $11.6 \text{ mg L}^{-1}$  and SRP  $772 \text{ } \mu\text{g L}^{-1}$  and resulting TP in early July at NIA10) were confirmed with corresponding data from ECCC Niagara phosphorus monitoring program at Fort Erie (D. Burniston, ECCC, March 2016 personal communication), and excluded from analysis. Chlorophyll *a* concentrations were determined by cold acetone pigment extraction and spectrophotometric analysis (Strickland and Parsons 1968) at the DFO laboratory.

Current speed at the surface at all stations and transects was collected using a General Oceanics mechanical flow meter mounted on a pole directed into the current. The boat was kept as stationary as possible during flow measurements. Eddies or backwater flows were noted and quantified when possible. Acoustic Doppler Current Profiler (ADCP) flow cross-sections typical of conditions at NIA12 (upper river), NIA13 (cableway above power stations) and NIA14 (below power stations) were obtained from ECCC (A. Thompson and S. Rodrigues, National Hydrologic Service of ECCC, personal communication). The Niagara River flow is very consistent over the year due to its status as a connecting channel, and is controlled almost entirely by the water level of Eastern Lake Erie. This is quite different from other large rivers, which can vary in discharge by more than 30x (Broderick 2009).

### **Phytoplankton and microbial loop**

Water was collected as described for water chemistry above. Primary productivity and bacterial growth experiments were undertaken the next day back at the DFO laboratory.

Whole water was fixed with Lugol's iodine upon collection for analysis of phytoplankton communities at stations NIA10, NIA13 and NIA4. Enumeration and measurement followed the HPMA (2-hydroxypropyl methacrylate) technique described by Crumpton (1987) which is broadly compatible with the Utermöhl (1958) inverted microscope technique. A minimum of 200 units were counted to achieve an acceptable counting efficiency (Lund et al. 1958). Within each sample, cell dimensions were measured directly and the average cell volume for each species was determined by applying the average cell dimensions to a standard geometric shape that most closely resembled the species. In the case of colonial forms, the average number of cells per colony was determined. Cell volume was converted to biomass assuming a specific gravity of 1.0 (Strickland 1960).

Microbial loop samples, including bacteria, autotrophic picoplankton and heterotrophic nanoflagellates, were fixed with 1.6% formaldehyde and enumerated using DAPI staining (Porter and Feig, 1980) under epi-fluorescence microscopy (Munawar and Weisse 1989). Size fractionated primary productivity was estimated for three size categories of phytoplankton (<2 µm, 2-20 µm and >20 µm) by the <sup>14</sup>Carbon technique as per the standard protocol of Munawar and Munawar (1996). Whole water samples were spiked with Na<sup>14</sup>CO<sub>3</sub>, incubated for 4 h at surface temperature and exposed to a constant light level of 240 µE s<sup>-1</sup> m<sup>-2</sup>. Because light and temperature levels are constant in these experiments, the results should be interpreted as potential productivity rather than actual. After incubation, size classes were determined by filtration of the sample through polycarbonate filters, all filters were rinsed with hydrochloric acid (0.5N) in order to remove excess <sup>14</sup>C-CO<sub>2</sub>. Radioactivity was determined by liquid scintillation.

Bacterial growth rates were estimated by <sup>3</sup>H-Leucine incorporation into bacterial proteins following the protocol of Jørgensen (1992) and radioactivity was determined by liquid scintillation. Detailed procedures are available in Heath and Munawar (2004). The growth measurements for both bacteria and phytoplankton estimated by these techniques represent optimal growth rather than in-situ growth, because they occur in motionless bottles rather than the energetic conditions found within the river.

### **Zooplankton and rotifers**

Zooplankton samples were collected monthly from NIA10, NIA11, NIA12, NIA13, NIA14 and NIA4. Animals were collected using a metered 30 cm diameter, 64 µm mesh Wisconsin style net, approximately 1.2 m long. In an attempt to have the net sink as deep in the water column as possible, up to two 1 kg dive weights were affixed to the net hoop in addition to the weighted cod end, however due to the speed of the current near the hydroelectric plants, the entire water column could not be sampled (Table 2). Water was flowing strongly and well mixed vertically so this is unlikely to be problematic. Net casts were achieved by letting out line, allowing the net to

sink through the water column (or pulled in the current), and retrieving it as an oblique tow. Flow rates through the net were determined by a General Oceanics flow meter and maximum depth recorded by a Wildlife Computers MK9 tag affixed to the hoop. Beginning in August, two replicate nets were collected and pooled in the field due to inadequate sample volume concerns. All samples were preserved in 4% sugar buffered formalin solution, counted and identified to standard taxonomic groupings: Cladocerans including bosminids (*Bosmina* sp. and *Eubosmina* sp.), *Daphnia* sp., predatory species (*Bythotrephes longimanus*, *Cercopagis pengoi* and *Leptodora kindti*), calanoid copepods, cyclopoid copepods, copepod nauplii and dreissenid veligers. Loose and attached copepod and cladoceran eggs were also counted in each sample. At NIA10, NIA12 and NIA4, zooplankton were also enumerated and identified to the lowest possible taxonomic level (usually species) by a trained taxonomist. Zooplankton lengths were measured at NIA10 and weights determined using the length-weight relationships in Bowen (2017). On each date, the mean weight of each taxonomic group at NIA10 was applied to densities of that taxon at the rest of the stations to calculate biomass. For taxa that only occurred a few times, the seasonal mean weight was used. Total seasonal zooplankton production values (June to October) were determined using the production/biomass ( $P/B$ ) equations from Shuter and Ing (1997) for copepods and Stockwell and Johannsson (1997) for cladocerans. Details on enumeration methods and production calculations are given in Bowen (2017).

At each of NIA10, NIA12, NIA13 and NIA4, rotifers were collected by filtering 10 L of integrated water (described above) through a 20  $\mu\text{m}$  sieve. Samples were narcotized with carbonated water and preserved as above. For each station, a June to October seasonal composite was created by combining half of each rotifer sample taken on each date. Rotifers in these seasonal composites were identified to species whenever possible, counted and measured for biomass estimation (Bowen, 2017). Presence of larger rotifer species were also noted in the zooplankton samples collected on each date at NIA10, but these were not quantified.

## RESULTS

### Physico-chemical

The monthly weather data from the Niagara Airport (IAG, Buffalo) for 2014 are seen in Figure 3 (National Oceanic and Atmospheric Administration's National Centers for Environmental Information (NOAA-NCEI), <https://www.ncdc.noaa.gov/>, accessed Jan. 2016). While April was a wet month, July had an exceptionally high precipitation value and a slightly depressed maximum temperature value. Daily weather values for date of sampling and the four previous days, illustrating when precipitation occurred just prior to the sampling date. High levels of precipitation occurred on the two days preceding the early July sampling while there was very high precipitation on two days prior to the late July sampling date, but also on the day of sampling. The mean air temperature on sampling days was not very different June-September (19-22 °C) and only slightly cooler in October at 17 °C.

Flow rates within the river increased downriver, but were reduced in the lower river past the power plants approaching NIA4. Despite difficulties getting measurements in high current areas, current speeds at any given station in the Niagara River remained fairly consistent over the sampling period, never varying more than 0.2  $\text{m s}^{-1}$ . On average, the slowest currents were recorded at NIA10 (0.47  $\text{m s}^{-1}$ ) while the fastest currents were found in the lower river at NIA13 (1.84  $\text{m s}^{-1}$ ). Average current speeds from all six stations are presented in Figure 4. In general, current speed increased with distance down river. The current data remained fairly comparable at a number of cross-river transects at stations in the upper and lower river, therefore we only present data from three transects (NIA4, NIA18, NIA12) on each of two sampling days (June

10<sup>th</sup> and October 14<sup>th</sup>) (Figure 4). Our surface flow measurements are comparable to whole water column ADCP measurements conducted by ECCC (Tables 2 and 3). Current speed is highest at the center of the river, with tendencies for current speed to be marginally greater on the American side (Table 3). This was confirmed by ADCP transect data for NIA12, 13 and 14 from Oct-Nov 2013, which also verified that the entire water column was well mixed to near bottom (A. Thompson and S. Rodrigues, National Hydrologic Service of ECCC, personal communication). It should be noted that the river flow at NIA18 illustrates an example of a very pronounced counter current eddy nearest to the Canadian side.

The water-column flow measurement from each of the ADCP transects were used to calculate residence time within the river, which ranged from 11-28 hrs for the entire length of the river (Table 4). Two scenarios were considered: that any organism would be well-mixed across the river, or if they spent the majority of their time in the central, fast-flowing channel of the river.

### **Transects and station sampling**

During each of the sampling cruises, transects were done to examine any cross-river trends of the Niagara River, showing little or no trends in any of the measures (Appendix 1). Transects from NIA12, NIA4 and NIA18 are summarised in Table 5 and Figure 5. Transects in early and late July both showed consistency across the river. In August, transects were completed, but data capture failed at both lower river stations. In September or October, there were again no significant changes in turbidity, temperature or conductivity along the transect (Figure 5). Occasionally, increases in measures such as chlorophyll *a* were encountered during transects which were likely related to transient macrophyte fragments. Chlorophyll *a* values for all points along each of the transects were usually comparable to the corresponding single-point profiles and were generally low ( $< 1 \mu\text{g L}^{-1}$ ) (Table 6). No changes in temperature and only minimal changes in turbidity or conductivity were observed, usually associated with samples adjacent to the river banks.

The results from the station profiles are summarized in Table 6 and Appendix 2. The data presented are from the EXO2 sonde unless otherwise stated. In June, profiles were collected over three days (5<sup>th</sup>, 10<sup>th</sup> and 12<sup>th</sup>) as part of the initial survey of potential sampling locations, so they include stations not sampled again during the project. All profiles found the water column to be well mixed. For general trends, temperature did not vary significantly along the river, while turbidity tended to increase after going over the falls (with one exception) and conductivity tended to increase marginally (between  $1.04$  and  $7.42 \mu\text{S cm}^{-1}$ ) after going over the falls. High current speeds made light attenuation difficult to measure. The vertical light attenuation coefficient ( $k_d$ ) and calculation of euphotic depth were estimated from Licor PAR quantum sensor measurements. The  $k_d$  values illustrate the very clear water conditions of the river typical of oligotrophic systems. Average values were only slightly higher in the lower river than the upper river during July (Table 7) which had elevated precipitation (Figure 3), reflecting the slightly reduced clarity of the lower river.

Chlorophyll *a* was generally very low across the sampling season (Table 6, Appendix 2), averaging  $0.5 \mu\text{g L}^{-1}$  for the upper river (NIA10, 11 and 12),  $0.2 \mu\text{g L}^{-1}$  above the turbines (NIA13), and  $0.7 \mu\text{g L}^{-1}$  below the turbines (NIA18 and 19; Figure 6). The Welland River site during the preliminary survey showed similar chlorophyll levels to the Niagara River but higher temperatures and turbidity. High turbidity and chlorophyll *a* values were measured during July 10 at NIA18 (Appendix 2), which is likely a shoreline influence associated with the backflow on the Canadian side at this station (Figure 4).

### **Water chemistry**

Results from water chemistry are presented in Appendix 3. Water chemistry values were not significantly different from those collected weekly June-Oct from ECCC's Niagara River

Monitoring Program, with the exception of SRP (DFO's slightly higher and more variable,  $t=3.35$ ,  $p=0.001$ ) and marginally lower dissolved calcium ( $t=2.62$ ,  $p=0.01$ ) and higher magnesium ( $t=2.22$ ,  $p=0.03$ ). Total phosphorus (TP) was low and varied little across the season, with an average of  $0.015 \text{ mg L}^{-1}$ . Soluble reactive phosphorus (SRP) was variable ( $0.0062 \text{ mg L}^{-1} \pm 0.16 \text{ SD}$ ) with sampling date and station. Though the Welland River enters into the Niagara River via the Chippawa Canal and power stations, there is no significant increase in TP below the hydroelectric outputs. There was some suggestion, though insignificant, of increased nitrogen ions ( $\text{NO}_x$ ,  $\text{NH}_3$ ) below the power stations.

Average extracted chlorophyll *a* in the Niagara River was  $1.3 \mu\text{g L}^{-1}$ , with chlorophyll highest at  $2.5 \mu\text{g L}^{-1}$  at NIA13 on July 9<sup>th</sup>, which is similar to eastern Lake Erie at  $< 2 \mu\text{g L}^{-1}$ , May through October 2001-2002 (Depew et al. 2006). Lake Erie Surveillance at Station 931 (nearest Niagara River, in  $\sim 10 \text{ m}$  water,  $42.85^\circ$ ,  $-78.94^\circ$ ) also confirms these values; Chlorophyll *a* (uncorrected) was  $1.41 \pm 1.00$  (SD) from 2000-2013 (ECCC, STAR database, 2016). Dissolved inorganic carbon (DIC) showed a consistent declining trend from NIA10 to NIA13, then increase again at NIA4, with an overall average of  $21.9 \text{ mg L}^{-1}$ . Dissolved organic carbon (DOC) was usually highest at NIA10 and then fairly consistent throughout the rest of the river. The average DOC for the river was  $2.57 \text{ mg L}^{-1}$ , excluding the DOC outlier in early July at NIA10 of  $11.6 \text{ mg L}^{-1}$ . Particulate organic carbon (POC), Particulate organic nitrogen (PON), Ammonia ( $\text{NH}_3$ ), Nitrate-Nitrite ( $\text{NO}_3^-/\text{NO}_2^-$ ), Total Nitrogen (TN), silica ( $\text{SiO}_2$ ), sodium ( $\text{Na}^+$ ) and total calcium ( $\text{Ca}^{+2}$ ) all varied little over the sampling season, with NIA4 often having only slightly elevated concentrations.

### Phytoplankton and microbial loop

The total phytoplankton biomass measurements in the Niagara River ranged from 44 to  $503 \text{ mg m}^{-3}$  over the sampling season, with an overall average of  $148 \text{ mg m}^{-3}$  (Figure 7). There was little seasonal fluctuation at NIA10, and NIA4 biomass peaked in August driven by Diatomeae (Bacillariophyta): *Fragilaria crotonensis* (45.3%) and by Cryptophyceae: *Ochromonas* sp. (21.2%; Table 8). In September, NIA13 biomass jumped (Figure 8), driven by an increase of the filamentous blue green (Cyanophyta): *Lyngbya birgei* (89.4%). Generally, diatoms were the dominant group in the river community (*F. crotonensis*, *Stephanodiscus* sp., *Cocconeis pediculus*). Cryptophytes (mainly *Rhodomonas minuta nannoplanctica*) and filamentous cyanophytes (namely *L. birgei* and *Heteroleibleinia* sp. (formerly *Lyngbya* sp.)) also contributed significantly to the total biomass, particularly in the fall (Table 8 and Appendix 4). Filamentous forms were generally more common at the downstream sites.

The primary production measurements showed that total phytoplankton productivity was very low in the Niagara River ranging from  $0.87$  (NIA12, September 10<sup>th</sup>) to  $4.91 \text{ mg C m}^{-3} \text{ h}^{-1}$  (NIA10, October 15<sup>th</sup>), with NIA10 and NIA4 being the most productive overall ( $3.37$  and  $3.27 \text{ mg C m}^{-3} \text{ h}^{-1}$ , respectively). In general, primary productivity of the upper river (NIA12) was highest in the spring and late fall. NIA13 and NIA12 were also most productive in the fall, with the lower river (NIA4) being the most productive during the September cruise. Productivity at NIA4 was significantly higher than NIA13 (paired  $t(4) = 2.77$ ,  $p=0.04$ ). Primary productivity was dominated by the nanoplankton-sized fraction ( $2\text{--}20 \mu\text{m}$ ) ranging from 40% to 75% of total production. The only exceptions occurred in late July at NIA12 and NIA10, as well as in September at NIA10. In each of these cases, picoplankton ( $< 2 \mu\text{m}$ ) were the major contributor to productivity, representing between 43 and 48% of the total, followed by nanoplankton and then netplankton (Figure 9). These values are indicative of an oligotrophic system. Phytoplankton productivity at the mouth of the river shows a strong correlation ( $r^2 = 0.9016$ ) to productivity in the lower river when lagged to the next sampling event, approximately one month later. To be clear, periods of low (or high) productivity at NIA10 are followed by periods of low (or high) productivity at NIA4 during the following cruise, an average of 25 days later (Figure 9).

This trend is not seen in the phytoplankton biomass data for the same stations. Average production to biomass ratios (P/B) expressed as carbon turnover rates ( $\text{d}^{-1}$ ) were nearly identical at all three stations (NIA10:  $0.267 \pm 0.04$ ; NIA13:  $0.269 \pm 0.10$ ; NIA4:  $0.294 \pm 0.06$ ). P/B was consistently highest in picoplankton (the smallest fraction  $< 2 \mu\text{m}$ ), ranging from 1.01 to  $13.32 \text{ d}^{-1}$  at all three stations. High picoplankton turnover rates are typical of oligotrophic systems and suggest that these organisms may be heavily grazed by zooplankton and other heterotrophs. However, productivity estimates reflect ideal laboratory conditions and may not reflect the more harsh conditions observed in situ within the river.

Bacterial productivity was highest at all stations in early July (Figure 10), which was the month with the highest total precipitation (Figure 3). The highest values were at NIA13, above the hydroelectric reservoirs output, at  $1.2 \mu\text{g C l}^{-1} \text{ hr}^{-1}$  which stayed high through July 30<sup>th</sup> then fell to levels more comparable with the rest of the river. In the later part of the year, downstream stations showed slightly higher bacterial productivity than upstream stations.

Total microbial loop biomass ranged from  $0.63$  to  $3.05 \text{ g m}^{-3}$  with an average of  $1.3 \text{ g m}^{-3}$  (Figure 11). The highest microbial loop biomass value occurred at NIA10 in September and consisted of bacteria and a sudden increase in autotrophic picoplankton (APP). On average, microbial loop biomass remained consistent between the upper and lower river with a tendency to have higher biomass at the mouth (NIA10) and lower river (NIA4). The majority of the total microbial loop biomass is made up of bacteria, with autotrophic picoplankton (APP) and heterotrophic nanoflagellates (HNF) contributing a maximum of 30.1% and 24.2% to the total, respectively.

### Zooplankton and rotifers

Zooplankton and rotifer species found in the Niagara River were typical of eastern Lake Erie and epilimnetic waters of the Great Lakes (Tables 9A-C). Total zooplankton density ranged from  $0.69$  to  $133 \text{ individuals L}^{-1}$  with biomass ranging from  $0.5 \text{ mg m}^{-3}$  to a peak of  $153.5 \text{ mg m}^{-3}$  occurring on July 30<sup>th</sup> at NIA10 (Figure 12). Both density and biomass trends showed a sharp decline from NIA10 into the upper river. Zooplankton biomass and density were always lowest at NIA13, and then increased beyond the turbines at NIA14 and NIA4 (Figure 12). This decline in zooplankton biomass can be described by the following equation ( $r^2 = 0.937$ ) based on distance from the mouth of the river:

$$y = 95.39e^{-0.081x} \quad (1)$$

where June to October mean biomass declined by ~54% as compared to the mouth of the river after entering 10 km into the river, and by ~79% after 20 km (Figure 13). The decline of zooplankton density into the river can be described as:

$$y = 76820e^{-0.086x} \quad (2)$$

where June to October mean density declined by ~61% as compared to the mouth of the river after 10 km, and by 83% after 20 km (Figure 13). The expected trend deviates from actual data at NIA14 and NIA4 (eqn. 1 and 2) likely due to input from the hydroelectric reservoirs (shown by arrows in Figure 13). Zooplankton biomass at NIA14 and NIA4 were  $3.7\times$  ( $12.76 \text{ mg m}^{-3}$ ) and  $5.5\times$  ( $12.48 \text{ mg m}^{-3}$ ) greater respectively, than would have been expected if the turbine outflows had no effect. Zooplankton densities at NIA14 and NIA4 also increased by  $2.7\times$  ( $6.23 \text{ individuals L}^{-1}$ ) and  $5.3\times$  ( $7.73 \text{ individuals L}^{-1}$ ), respectively.

A one-way ANOVA indicated significant density differences between the Lake Erie station (NIA10), the upper river (NIA11, NIA12) and the lower river stations (NIA13, NIA14, NIA4;  $F=44.48$ ,  $DF=34$ ,  $p<0.0001$ ; Tukey-Kramer  $p<0.05$ ) and also for biomass ( $F=11.20$ ,  $DF=34$ ,  $p<0.0001$ ; Tukey-Kramer  $p<0.05$ ). There was also a significant difference in densities between NIA13 (above power stations) and NIA14 (below turbines) for calanoid copepods ( $t=2.85$ ,

DF=10,  $p=0.017$ ), and the standard error of the mean was very small for NIA13 ( $0.21 \pm 0.08$  ind·L<sup>-1</sup>) throughout the year compared to NIA14 ( $1.56 \pm 0.47$  mg·m<sup>-3</sup>). The extra copepod numbers were likely sourced from the hydroelectric reservoir system.

Zooplankton community composition was quite different in June compared to the other dates (Figure 12), with both cyclopoid copepods (particularly juveniles) and the small cladoceran *Bosmina* most numerous early in the season when dreissenid veliger larvae were virtually absent. Veligers were the most abundant group on the remaining dates, however due to their small size, they only dominated biomass on July 30 (>70% of the total). Calanoid copepods dominated the zooplankton biomass on the remaining dates [ $49\% \pm 17$  (SD)]. Cladocerans were generally a minor component of the zooplankton biomass at  $15\% \pm 12$  (SD). Bosminids (nearly entirely *Bosmina* sp.) appeared in the zooplankton community only in the spring and fall, *Daphnia* sp. biomass peaked in early July, and the biomass of predatory cladoceran species such as *Leptodora kindti* and the invasive spiny water flea *Bythotrephes longimanus* peaked throughout July (Figure 12).

In addition to the genus/group counts presented above, enumeration of the zooplankton community was taken to the species level at NIA10, NIA12 and NIA14 (Table 9A). Although densities and biomass of zooplankton taxa dropped precipitously with increasing distance downstream, there were generally only minor differences in community composition among these three stations (Figure 14). *Daphnia galeata mendotae* was the dominant *Daphnia* species in the river, with only occasional occurrences of the smaller *D. retrocurva*. The biomass was dominated by juvenile copepods, especially cyclopoid copepodites in the early part of the year and calanoid copepodites and adults throughout the sampling season. Composition of adult cyclopoids exhibited seasonal succession, with *Diacyclops thomasi* and *Mesocyclops edax* dominating in June, *M. edax* throughout the summer and *Tropocyclops extensus* increasing from late summer into the fall. Calanoid density varied little between stations or between sampling events, and was dominated by *Skistodiaptomus oregonensis*, followed by *Epischura lacustris* with minor contributions from *D. minutus* (Figure 14; Table 9A). Starting midsummer, the proportion of adult to juvenile (copepodid) copepods often increased in the river compared to the Lake Erie site, although the densities and biomass of each group declined with increasing distance downstream.

Rotifer densities and biomass also showed declines with increasing distance downstream, with the lowest values observed below the falls, and a small subsequent increase below the reservoir discharge (Table 9B). When averaged across the season, rotifer density was 19.5 individuals L<sup>-1</sup> (17% of macrozooplankton + rotifer density) at the entrance to the river, but only 2.1 individuals L<sup>-1</sup> below the falls (42%). In general, rotifers did not decline as rapidly as zooplankton, although large, soft-bodied taxa such as *Asplanchna* sp. were most impacted by riverine conditions. Rotifers represented only a small fraction of macrozooplankton + rotifer biomass in the river due to their small size, totalling 0.51 mg m<sup>-3</sup> (0.5%) at N1 to 0.04 mg m<sup>-3</sup> (0.8%) at N4. The dominant rotifer species at NIA10 in Lake Erie were *Conochilus unicornis* (34% by density), *Keratella cochlearis* (29%), *Kellicottia longispina* (12%), *Polyarthra vulgaris* (10%) and *Synchaeta kitina* (4.1%). *Asplanchna* sp. represented 47% of total rotifer biomass. Based on qualitative evaluation of the zooplankton samples taken at this site, *Asplanchna* sp., *K. longispina* and *K. cochlearis* were observed throughout the sampling season, *Keratella quadrata* and *C. unicornis* were noted in June and early July, and *Polyarthra* sp. and several species of *Ploesoma* dominated in the latter part of the season (Table 9C).

At stations NIA13 and 14, copepods had more eggs per individual than cladocerans in June and early July (Figure 15). Cladoceran egg densities were significantly higher at NIA14 (pooled over time, assuming equal variances) as compared to NIA13 (One-way ANOVA;  $F=7.20$ , DF=10,  $p=0.02$ ). Copepod egg numbers per individual were not different between these two stations



(F=0.074, DF=10, p=0.79). There also was no evidence of increased copepod juveniles (nauplii or copepodids of either group) downstream of the reservoirs relative to upstream (Figure 14).

When averaged across the sampling season we observed a declining trend in density and biomass from the mouth of the river towards the falls, minimal zooplankton presence above the turbines, with a small measure of recovery further downstream (Table 10). Veligers comprised the largest portion of zooplankton density and calanoids dominated the biomass at all stations. The total potential seasonal production (which assumes that all individuals in the sample were alive at time of collection) for the zooplankton community also reflects these trends (Table 10). Viability of zooplankton was not directly addressed in this report, though animals were noted to be actively swimming in the sample prior to preservation.

### Hydroelectric reservoir contribution to lower river plankton

Calculation of the combined reservoirs plankton biomass can be done through a mass-balance relationship, based on combining solutions with different volumes and concentrations. This uses the assumption that 60% of the total daily flow of the Niagara River is diverted for hydroelectric purposes (Miller and Kappel 1987; URS Corporation et al. 2005) and enters the river between NIA13 and NIA14 (see Figure 1):

$$\text{Final Conc} = \frac{\text{Conc1} \times \text{Vol1}}{\text{Vol1} + \text{Vol2}} + \frac{\text{Conc2} \times \text{Vol2}}{\text{Vol1} + \text{Vol2}}$$

where,

$$\text{Volume of river at NIA13} = V_{13} \text{ [m}^3\text{]}$$

$$\text{Vol. Reservoir Discharge} = V_{13} \times \frac{60}{40} \text{ (e.g. 60\% of total volume)} = V_{13} \times 1.5 \text{ [m}^3\text{]}$$

$$\text{Total volume at NIA14} = V_{13} + (V_{13} \times 1.5)$$

and,

$$\text{Contribution of NIA13} = \text{NIA13 [mg m}^{-3}\text{]} \times \frac{V_{13}}{V_{13} + V_{13} \times 1.5}$$

$$\text{Contribution of Reservoirs} = \text{Res [mg m}^{-3}\text{]} \times \frac{V_{13} \times 1.5}{V_{13} + V_{13} \times 1.5}$$

therefore,

$$\text{NIA14 [mg m}^{-3}\text{]} = \text{NIA13 [mg m}^{-3}\text{]} \times \frac{V_{13}}{V_{13} + V_{13} \times 1.5} + \text{Res [mg m}^{-3}\text{]} \times \frac{V_{13} \times 1.5}{V_{13} + V_{13} \times 1.5}$$

$$= \text{NIA13 [mg m}^{-3}\text{]} \times \frac{V_{13}}{2.5 \times V_{13}} + \text{Res [mg m}^{-3}\text{]} \times \frac{V_{13} \times 1.5}{2.5 \times V_{13}}$$

reorganised as a function of the reservoirs,

$$\begin{aligned} \text{Reservoir Conc. [mg m}^{-3}\text{]} &= ((\text{NIA14 [mg m}^{-3}\text{]} \times 2.5) - \text{NIA13 [mg m}^{-3}\text{]}) / 1.5 \\ &= (\text{NIA14} \times 1.67) - (\text{NIA13} \times 0.67) \end{aligned} \quad (3)$$

Any difference between the reservoirs (US and Canadian) cannot be discriminated, because both of the hydroelectric plants empty into the same location on the river. Using this relationship, the reservoir system is likely to have ~1.5x (±0.5 SD) the biomass of algae at NIA13 based on chlorophyll *a* concentration. The total phytoplankton biomass is likely ~3.5x (±5.4 SD) the value at NIA13, with chrysophytes having the greatest contribution (~22.1x ±22.8 SD). The total zooplankton biomass is likely ~6.7x (±4.1 SD) the value at NIA13, with copepods having the greatest contribution (Calanoids ~11.3x ±6.3 SD and Cyclopoids ~8.9x ±10.9 SD).

### Planktivorous fishes

Results from electrofishing surveys completed in 2015 in the upper and lower Niagara River by DFO are used to characterize the typical fish communities of the river (Biodiversity Database, DFO). A full report of the fish community is forthcoming (R. Gáspárdy, pers. comm.). Data from the four closest transect stations to NIA11 and NIA12 were used in the upper river (DFO Species at Risk (SAR) Stations 11, 12, 21, 22) and NIA14 and NIA4 in the lower river (DFO SAR Stations 71, 72, 81, 82) for comparison. Overall, the Niagara River fish densities were 0.09 fish s<sup>-1</sup>, intermediate compared to the Detroit (0.169 fish s<sup>-1</sup>) and St. Clair River (0.063 fish s<sup>-1</sup>) surveys from DFO. The fish community composition was very different between the upper and lower river, with much lower catches (density) but similar overall biomass in the lower river due to the dominance of larger sized fishes (Figure 16). Piscivorous fishes were common in the lower river dominated by salmonids, Lake Trout (*Salvelinus namaycush*), Smallmouth Bass (*Micropterus dolomieu*), and Bowfin (*Amia calva*). The primary piscivores in the upper river were Largemouth Bass (*M. salmoides*), Smallmouth Bass and Pumpkinseed (*Lepomis gibbosus*). Planktivorous fish biomass in the lower river was dominated by large-bodied Gizzard Shad (*Dorosoma cepedianum*) and Yellow Perch (*Perca flavescens*), but the smaller, but much more numerous Emerald Shiner (*Notropis atherinoides*) and Yellow Perch (*P. flavescens*) were common in the upper river. Densities of planktivorous fishes were significantly higher in the upper river  $75 \pm 88$  (SD) CPUE(x1000) s<sup>-1</sup> compared to the lower river  $15.5 \pm 13$  (SD) CPUE(x1000) s<sup>-1</sup> ( $F=5.30$ ,  $DF=23$ ,  $p<0.03$ ) due to the very high densities of Emerald Shiner. However, when accounting for the larger-bodied Gizzard Shad in the lower river, there is no significant difference between upper  $2.2 \pm 2.6$  (SD) [CPUE-Mass s<sup>-1</sup>] and lower river  $1.3 \pm 1.4$  (SD) planktivorous fishes biomass ( $F=0.96$ ,  $DF=23$ ,  $p=0.34$ ).

## DISCUSSION

The Canadian section of the Niagara River AOC currently includes the entire length of the western side of the river, including the Canadian side of Niagara Falls (and the Welland River watershed). The Niagara River does not act as a traditional river; instead it serves as a connecting channel between two large lakes where the flow is high, but consistent throughout the year, varying only by changes in Lake Erie levels. The high discharge, but short retention time within connecting channels makes them a challenging system to assess for plankton ecology studies. Since connecting channels between large lakes exist almost uniquely within Laurentian Great Lakes, comparing their impact on the ecology of plankton to other sites is very challenging. The only system outside of the Great Lakes that has been studied for plankton ecology are the connecting channels associated with the Sea of Marmara, which is connected to the Black Sea via the Bosphorus and with the Aegean Sea of the Mediterranean via the Dardanelles. Both of these are considered straits because the seas have different salinities, very complex flow dynamics which are dependent on the resulting density differences (surface water outflow and deep salty water inflow). These physical characteristics fundamentally drive the ecology of this system (Kovalev et al. 1999; Isinibilir et al. 2011), which do not occur in a freshwater system such as the Niagara River. Other Great Lakes connecting channel assessments of plankton are ongoing (e.g., Detroit River).

Although it has a high discharge, the Niagara River is relatively constant compared to large rivers, and does not undergo large fluctuations in flow or depth throughout the year. This consistency has allowed extensive infrastructure for shipping associated with the Erie Canal to be built on the US side of the Niagara River. These efforts to improve navigation have led to significant changes to the morphology of the river. The Niagara River receives generally high quality source water from Lake Erie, with contaminants usually locally sourced from the industry

along the river (Edwards et al. 1989). The American shores of the upper Niagara River had extensive industrial, chemical and manufacturing infrastructure compared to the Canadian side of the river (Rossi 1996). Concerns on the U.S. side include legacy of these hazardous waste sites, made notorious by the events of Love Canal. The east branch of the Niagara River flowing around Grand Island also has very high recreational boating usage. Most impacts of concern for the Canadian RAP have focused on nutrient abatement, releases of untreated wastewater discharges and some contaminated sediment pollution from industry, almost entirely within the Welland River. The Welland River empties into the Niagara River via the Chippawa Canal and hydroelectric power system, which was not sampled for this study. Instead, this report infers the impact of the reservoirs on the lower Niagara River by comparing samples collected above the turbines (NIA13) to samples collected below the turbines (NIA14); these sites were chosen deliberately because there was an expected effect of water impoundment.

The Niagara River is thermally well mixed across and vertically through the water channel with temperatures varying only  $\pm 0.2$  °C at most, along the river at any one sampling event. This was expected given the high flows known within the river (URS Corporation et al. 2005). The cross-river transects showed very little difference in chlorophyll, turbidity and conductivity across the river, with the exception of occasional minor differences associated with the very nearshore of riverbanks. The flow near the banks is approximately half of the center channel, with habitat in the form of local eddies and back flows, which may provide increased residence time to plankton in the river, but overall these results suggest that the river is well mixed from top to bottom and bank to bank.

Both the EXO2 and the FluoroProbe use chlorophyll fluorescence sensors and have similar detection limits ( $\sim 0.1$ - $0.2 \mu\text{g L}^{-1}$ ). The chlorophyll *a* levels reported by these sondes in the Niagara River are extremely low, ranging from 0.0 to  $2.1 \mu\text{g L}^{-1}$ ; with 26% and 59% of the EXO and fluorometer readings below reliable measurement limits, respectively. The chlorophyll values reported by the sondes are supported by standard extraction techniques (average of  $1.3 \mu\text{g L}^{-1}$ ). Small fluctuations between stations are likely a result of the probes measuring extremely low levels of chlorophyll at the detection limits of the instruments. This is not unexpected because the outflow waters of Lake Erie generally have low chlorophyll *a* levels, and given the high flows in the Niagara River, the system is likely to be dominated by attached macrophytes (Vis et al. 2007). Gunderson (2015) found that macrophytes in the Niagara River around Grand Island were common in the nearshore, being encountered up to 80% of the time depending on sediment coarseness.

There is a clear delineation between Lake Erie stations and those within the Niagara River, but the zones within the Niagara River are less well defined. Lake Erie water feeding into the River has similar chlorophyll *a* levels throughout the sampling season (less than  $2 \mu\text{g L}^{-1}$ , May through October 2001-2002) (Depew et al. 2006). Generally speaking, chlorophyll *a* was lowest above the turbines, turbidity increased as water traveled over the falls towards Lake Ontario and conductivity increased by a trivial amount ( $\sim 2 \mu\text{S cm}^{-1}$ ) after going over the falls. Potential causes of chlorophyll *a* decline within the river could be consumption by filter-feeders such as dresseinid mussels or herbivorous zooplankton (Twiss et al. 2010). The lower river increase in chlorophyll may be from input from the hydroelectric reservoirs where algae had a refuge. The reservoirs could also be acting as a nutrient and contaminant source which could have impacts on the plankton, though no contaminants were measured for this study. Onuska et al. (1983) showed that sediment at the Niagara River mouth contained a multitude of organic contaminants. Kauss and Post (1987) and Williams et al. (2003) showed that the Sir Adam Beck Power Reservoir also contains heavy metal and organic contaminants. Through the processes of bioaccumulation and transport in zooplankton tissues and feces, pollutants may be carried

into Lake Ontario and sink into the sediment once the river current slows (Durham and Oliver 1983; Strickland 1983).

The Sir Adam Beck hydroelectric reservoirs are not explicitly included in this study, though impoundments have been shown to potentially alter the natural community composition of the plankton in large Chinese rivers (Li et al. 2013). With about 60% of the Niagara flow being diverted the Sir Adam Beck forebay and reservoir (storage for about  $1.9 \times 10^7 \text{ m}^3$  of water) and Lewiston forebay and reservoir ( $8.5 \times 10^7 \text{ m}^3$  of water) on the US side, these structures may provide plankton with a refuge from the fast-flowing river and the opportunity to recover (Williams et al. 2003). Given the correct conditions and sufficient residence time, eutrophication of the reservoirs could conceivably occur (see Li et al. 2013). This could be intensified by release of untreated wastewater into the Chippawa Canal. Eutrophication mechanics and phytoplankton assemblage dynamics have been influenced by cascading dams such as the Paranapanema River in Brazil (Nogueira et al. 2010) and a tributary of Yangtze River in China (Zhang et al. 2010).

Sedimentation is known to occur within the reservoirs (Williams et al. 2003) and Munawar et al. (1983) found that phytoplankton assemblages exposed to Niagara River sediment elutriate in increasing concentrations were increasingly inhibited in their productivity rates. When the elutriate was treated to remove metals, the phytoplankton assemblages showed increased growth over the controls since the removal of the dissolved metals removed the possibility of the synergistic interaction between dissolved metals and organic compounds released in the standard elutriate (Munawar et al. 1983). Increased time of exposure in the hydroelectric reservoirs is likely to exacerbate this effect, but this was not tested in this study (see Williams et al. 2003).

From a nutrient and hydrological perspective, the Niagara River shows many similarities to other oligotrophic systems (Stockner et al. 2005), including low nutrients, domination by small plankters, small diatoms and low primary production rates. Nutrients tended to decrease from the mouth of the river towards the falls, and occasionally rebound in the lower river (NIA4), but levels were low overall. High concentrations of organic and inorganic particles can have negative effects on the survival of certain zooplankton (Pace et al. 1992) however river levels of particulates were less or equal to that of eastern Lake Erie (Dove and Chapra 2015). Some rivers have shown seasonal fluctuations of nutrients which were inversely linked to discharge levels (Thorp et al. 1994), but as stated previously, discharge variability is low for the Niagara River. The St. Lawrence River has shown increased silica concentrations correlated to the thermal stresses in the river and increased TP with transit downstream (Twiss et al. 2010). In contrast, both parameters remained fairly consistent for the entire length of the Niagara River. The Niagara River and the St. Lawrence (Cornwall) AOC both showed similar levels of nitrite+nitrate and TP (Munawar and Fitzpatrick, 2006). Light limitation in riverine environments has been proposed as the factor controlling the development of eutrophic conditions in short-retention-time rivers (Reynolds et al. 1994; Hilton et al. 2006). The light attenuation coefficient at Niagara reflected clear water ( $0.2\text{--}0.7 \text{ m}^{-1}$ ) and was similar to the St. Lawrence River ( $0.1\text{--}0.5 \text{ m}^{-1}$ ; Twiss et al. 2010), where the euphotic depth was estimated to reach the river bottom in most places.

### ***Phytoplankton***

There are no other studies of the plankton of the Niagara River we have found, which differs from the other connecting channels, with Niagara River biota being conspicuously absent from the major review of the connecting rivers within the Great Lakes in Edwards et al. (1986). As such, there is little data to compare this study with over time, so any comparisons are to values found in other connecting channels or large rivers.

Aquatic systems with short residence times and higher flows, particularly rivers, tend to have lower abundances of phytoplankton (Chandler 1937; Pace et al. 1992; Basu and Pick 1996; Walks and Cyr 2004). Søballe and Kimmel (1987) analysed large data sets which included algal cell counts from 136 rivers (average cell abundance of  $8,487 \pm 973$  cells mL<sup>-1</sup>), and found that residence time was an important property distinguishing differences in the abundance of phytoplankton among rivers, reservoirs and lakes. This trend is supported by the phytoplankton biomass observed in the Niagara River which ranged from 44 to 503 mg m<sup>-3</sup> over the sampling season. By comparison, phytoplankton biomass in the St. Lawrence AOC (which includes an 80 km long stretch of the St. Lawrence River) ranged from 46 to 323 mg m<sup>-3</sup> at mid-channel sites during surveys conducted in June, July and September of 2004 (Munawar and Fitzpatrick 2006) which were very similar to the Niagara River, although some higher values were reported at nearshore sites. The slightly wider range observed mid-channel in the Niagara River may be due to a variety of factors, including the water feeding the river or the presence of the hydroelectric reservoirs which diverts the fast moving river into a refuge of sorts and gives phytoplankton biomass an opportunity to recover. Unlike the Niagara River AOC, the St. Lawrence AOC which begins directly downstream of hydroelectric plants, instead relies on the outflow of the river. Boundary effects in the river above the turbines (NIA13) might also provide relatively slower currents which may encourage the accumulation of algal cells. In contrast, the St. Lawrence AOC also had single-species algal blooms at two nearshore sites peaking at 2,365 and 3,760 mg m<sup>-3</sup>, an extent which was not observed in the Niagara River. Flow rates in the St. Lawrence are much less than those found in the Niagara River so this may be contributing factor.

In general, diatoms were the most prevalent group in the Niagara River community. In recent years (2001-2011), diatoms (particularly *Aulacoseira islandica* and *Stephanodiscus parvus*) have been a significant aspect of the phytoplankton ecology of the eastern basin of Lake Erie, particularly in the spring (Alliger and Reavie 2013). Both *Aulacoseira* sp. and *Stephanodiscus* sp. were both found in high numbers in the river. Diatom species are favoured in high flow systems (Reif 1939; Perry et al. 1990; Reynolds et al. 1994; Rojo et al. 1994), because their strong skeletal structure allows them to be more resilient to the turbulent conditions of the river than any other phytoplankton group. *Fragilaria crotonensis*, a species which was a significant contributor to summertime biomass in eastern Lake Erie in 2008 and again in 2011 (Alliger and Reavie 2013), appears to survive the entire length of the Niagara River, as shown by its presence at NIA4 in August 2014. Cryptophytes were also a significant contributor to total phytoplankton biomass, particularly upstream, being sourced from Lake Erie. However, recent Lake Erie data shows a decreasing trend of cryptophyte biomass in the eastern basin (Alliger and Reavie 2013). The Environmental Protection Agency Great Lakes National Program Office (EPA-GLNPO) data presented by Alliger and Reavie (2013) does show an increasing trend of blue-green (Cyanobacteria) biomass in the summer. The elevated biomass observed in September at NIA13 was dominated by the mat forming cyanobacteria *Lyngbya birgei*, which was not observed at any other site in the river in September. This suggests that the conditions necessary for algal success (e.g., back eddies) are present between the upriver sampling site (NIA10) and NIA13, which provide an area of low flow, relatively high levels of substrate to attach to, and increased residence time (Li et al. 2013). It is common for high concentrations of filamentous, colonial, gelatinous and/or toxic algae to be present in rivers with short water residence times (Reif 1939; Pace et al. 1992; Hilton et al. 2006). Common species in the Niagara River were chain-forming diatoms *Fragilaria crotonensis* and *Skeletonema potamos* (a tolerant species adapted to riverine systems), in addition to the filamentous cyanobacteria *Lyngbya*. However, the observed biomass of these (and indeed all) species was actually quite low. Alternatively, in the St. Lawrence AOC, filamentous species (benthic chlorophyte *Zygnema* sp. and the cyanophyte *Microcystis botrys*) were the drivers of peak algal events (Munawar and

Fitzpatrick 2006), which is likely due to the different source water from either Lake Ontario or the localized effects of the Raisin River. Finally, chlorococcal species of phytoplankton were found in the Niagara River (albeit at low concentrations), particularly *Scenedesmus* spp., which are indicators of clear water since they have higher threshold light requirements (Reynolds et al. 1994).

Primary productivity in the Niagara River was highest within Lake Erie at the mouth of the river and decreased sharply when entering the river. From a cell-size perspective, nanoplankton productivity was the highest followed by picoplankton productivity, and similar to observations from the St. Lawrence AOC and in Lake Ontario (Munawar and Fitzpatrick 2006). Primary productivity of Lake Erie also reflects a similar characteristic of nanoplankton and picoplankton dominating the production (Munawar et al. 2008). Total primary productivity declined beyond the mouth of the river but returned to near-original values in the lower river (NIA4). This trend was most apparent during the summer months, when phytoplankton biomass was greatest. A correlation was found between upper and lower river productivity, but only if there was a significant residence time (time lag) in the river. With the average residence time of the river ranging from hours to a day, and the production peaks occurring an average of 25 days apart, it suggests that the primary productivity increase seen in the lower river is due to water being retained within the hydroelectric reservoirs.

While phytoplankton community composition and biomass remain fairly consistent down the length of the Niagara River, the productivity of the Niagara community is influenced by natural or man-made riverine conditions. Excluding the occasional peaks in individual algae species, there is only a small dip in phytoplankton biomass following the falls. This suggests that low phytoplankton biomass is not predominantly caused by physical damage from the turbulence of the falls and/or the turbines (Marcy Jr. et al. 1978), increased predation (Walks and Cyr 2004), increased downstream turbidity (Basu and Pick 1996), or instream macrophyte beds causing decreases in plankton densities (Welker and Walz, 1998; Basu et al. 2000b; Walks and Cyr 2004). Rather, high flow speeds and low water residence time are driving low biomass values along the entire length of the river (see also Pace et al. 1992; Basu and Pick 1996; Walks and Cyr 2004). The result in the Niagara River is a potamoplankton phytoplankton community composed of species best able to survive lotic conditions present from the river mouth to the outlet into Lake Ontario. The productivity of this community suggests that the fast moving upper river is not conducive to phytoplankton growth. However below the falls the river is equally as swift but significantly deeper and suggests a more productive community downstream (NIA4). Furthermore, natural refugia in the lower river: benthic zone, eddies etc. (Reynolds et al. 1994), combined with the input from the hydroelectric reservoirs is creating a more productive phytoplankton community.

Bacterial production fluctuated throughout the season, with early July being of particular note. The peak in bacterial productivity coincided with a slight increase in chlorophyll *a* but not in phytoplankton biomass. High phosphorus was not recorded at the site of highest bacterial production (NIA13). The likely explanation for the increased bacterial production values in the lower river could be increased July precipitation which likely increased runoff and loadings into the power plant canal system. In particular, the Niagara Falls, ON Wastewater Treatment Plant and the Welland River empty into the Niagara River via the Chippawa Canal, both of which could lead to increased bacterial growth in the downstream stations. However, it is unknown if high precipitation in July led to any capacity exceedances or release of untreated sewage.

The increase in microbial loop biomass, which was dominated by bacteria, at NIA4 in July could also be sourced from the hydroelectric reservoirs since it was more than 2.5x the biomass above the turbines (NIA13). The increase at NIA10 in September was a localized effect from Lake Erie, and did not appear to have impacted the microbial biomass downriver. Historically,

eastern Lake Erie has shown high proportions of bacteria, but lower total microbial biomass (Munawar et al. 2008). Bacterial counts from the Eastern end of Lake Erie were found to be an order of magnitude less than those found in the Niagara River at  $1.21 \times 10^6 \text{ ml}^{-1}$  (DeBruyn et al. 2004). In comparison to the St. Lawrence AOC, where HNF were the dominant microbial loop components throughout the year and bacterial biomass ranged from only 0.04 to  $0.18 \text{ g m}^{-3}$  (Munawar and Fitzpatrick 2006), the Niagara River was dominated by bacteria in comparatively high amounts. The microbial loop biomass at Niagara is comparable to the Bay of Quinte, which is noted for its high biomass of microbial heterotrophs (M. Munawar, unpublished data). Of particular note, the presence of HNF is limited to the mouth and foot of the river (NIA10 and NIA4) where conditions in the river are calmer. Increases in bacterial productivity did not coincide with changes in bacterial biomass. Given the small size of bacteria, the effects of turbulence and advection are likely to be minimal, and as observed, the microbial loop biomass is relatively unaffected by transit through the river.

### **Zooplankton**

There is little to no information on historic zooplankton composition in the Niagara River, with only the Patalas (1969) study, which included a Lake Ontario station near the outflow of the river, indicating a differential, warmer habitat for plankton compared to the rest of the lake. There is also very little recent information on zooplankton from the far eastern basin of Lake Erie, and relatively dated past information, with regular sampling programs in Erie ending in the mid-1990s (see Johannsson et al. 1999).

Although zooplankton community composition among the Niagara River stations in 2014 remained relatively unchanged, abundance and biomass declined significantly from Lake Erie downstream into the river. This is consistent with the findings of Walks and Cyr (2004) who found loss of most zooplankton within 50 m into rivers at four sites in Algonquin Park. In contrast to the Niagara River with an outflow of  $6,500 \text{ m}^3 \text{ s}^{-1}$ , Walks and Cyr (2004) studied considerably smaller rivers (outflow discharge of  $0.2\text{-}0.3 \text{ m}^3 \text{ s}^{-1}$ ) with small feeder lakes. They found that lake morphology affects river input and the persistence of plankton in the river. In larger rivers, such as the Niagara, plankton communities persist much further downstream than in smaller rivers (Brook and Rzoska 1954; Rzoska et al. 1955; Cushing 1963; Talling and Rzoska 1967; Shiel et al. 1982; Saunders and Lewis 1988; Kobayashi 1997; Welker and Walz 1998; Basu et al. 2000a), suggesting that persistence is also related to river size (zooplankton density decreases faster in shallow outlet streams than in deeper ones; Walks and Cyr 2004). It is possible that their findings might scale up to larger rivers such as the Niagara, where zooplankton persisted at least 10 km into the river. There is a general consensus in the literature that rivers show a significant decline in zooplankton as compared to lentic environments such as lakes, however there lacks agreement on the cause of this decline which include increased turbidity, high concentrations of organic and inorganic particles, and limited high-quality food (Pace et al. 1992). It has been suggested that lentic zooplankton are simply not able to survive in river environments due to the advective transport of food and individuals by water currents (Wahl et al. 2008). Advection (Pace et al. 1992) and/or residence time of rivers correlates with zooplankton biomass (Basu and Pick 1996; Walz and Welker 1998; Walks 2003), but not with phytoplankton, all of which supports why zooplankton biomass drops off so quickly in the Niagara River while phytoplankton biomass is less affected.

The opportunities for zooplankton persistence in fast flowing rivers consist of refugia from the current in the form of eddies, embayments, low flow areas, slackwater areas and deadzones (Pace et al. 1992; Reynolds et al. 1994; Thorp and Casper 2003; Genin et al. 2005; Walks 2007). As with phytoplankton, there appears to be resilient zooplankton species which survive better in and dominate riverine environments (Reif 1939). Research has shown that some large zooplankters such as the calanoid copepod *Eurytemora affinis* may be strong enough swimmers



to seek refuge lower in the water column of large rivers (Jack et al. 2006), since the water current speeds approach zero near the bottom (Vogel 1981). Another copepod, *Temora longicornis* is able maintain foraging speeds of  $6 \text{ mm s}^{-1}$ , with escape bursts of up to  $80 \text{ mm s}^{-1}$  (Van Duren and Videler 2003). *Bosmina*, a common cladoceran in the Niagara River, can only briefly reach speeds of  $10 \text{ mm s}^{-1}$  so is not likely to navigate the water current (Zaret and Kerfoot 1980), which sometimes approached  $2 \text{ m s}^{-1}$  ( $2,000 \text{ mm s}^{-1}$ ).

Turbulence, like that in coastal shorelines and in the wake of motorized boats, has been found to cause up to 34% mortality in copepods (Bickel et al. 2011). Horvath and Lamberti (1999) found that veligers were highly susceptible to damage by physical forces in high current streams ( $>1.0 \text{ m} \cdot \text{s}^{-1}$ ), which could limit veliger survival during downstream transport. Increased current velocities have been documented to increase mortality up to 20% among cladocerans, 40% in rotifers and 50% in copepods (Telesh 1986) and it has been estimated that current speeds greater than  $0.25 \text{ m s}^{-1}$  will lead to the death of lentic zooplankton (Tang et al. 2014). Niagara River velocities are greater than  $1 \text{ m s}^{-1}$  until approximately midway through the lower river. It is likely that the plankton are not actively feeding or effectively swimming during passage through the river (transit time of hours) and are most likely just drifting along with the current, not given much opportunity to seek out food or shelter (Hart et al. 1996). The relatively short-term turbulence of the river may lead to both positive and negative effects on predator-prey contact and feeding ability of copepods (Pace et al. 1992), with larger calanoid copepods better able to cope than smaller-sized groups (Sluss et al. 2008). In general, powerful swimmers such as predatory copepods, tend to be more successful in maintaining their position and continue to feed in highly turbulent systems compared to much slower and more awkward swimmers such as cladocerans (Visser et al. 2009; Tóth et al. 2011). This corresponds with our results showing a persistence of calanoid copepods (and the juvenile stages of copepodids and nauplii) and dreissenid veligers in the river. That said, we did not observe a decline in the relative contribution of cladocerans with increasing distance downstream, so they did not appear to be impacted by the river forces any more than other zooplankton groups.

Predation is often cited as a leading potential cause of zooplankton biomass decline in rivers (Thorp and Casper 2003; Walks and Cyr, 2004) either from abundant benthic filter-feeding species, notably dreissenid mussels (Welker and Walz 1998; Twiss et al. 2010), feeding on phytoplankton and microzooplankton (rotifers) or by fishes preying on macrozooplankton. Fish planktivory is likely a major factor contributing to the rapid loss of zooplankton biomass as it enters the upper river from Lake Erie. In other rivers, Akopian et al. (1999) and Thorp and Casper (2003) noted that larger zooplankton (particularly *Daphnia* sp. and adult copepods) were being consumed by young Yellow Perch. Emerald Shiner also generally prefer the largest cladocerans, particularly, *Leptodora* or *Bythotrephes* (Pothoven et al. 2009). Emerald Shiner, which along with Yellow Perch dominate the upper Niagara River, show a consumption rate (grams of plankton per gram fish) of  $0.21 \text{ g/g/d}$  (Pothoven et al. 2009). The feeding rates of Gizzard Shad (the dominant lower river planktivore by biomass) are lower, likely ranging from  $0.1\text{-}0.15 \text{ g/g/d}$  at  $20^\circ \text{C}$  (Sebring 2002). These differences in fish species composition and consumption rates suggest that planktivory in the upper river is likely much greater than below the falls, although total planktivore biomass in the two areas were not significantly different. It is expected that planktivory from Emerald Shiner in the upper river may have a considerable contribution to the decline of zooplankton densities within the river. However, Emerald Shiner are known to have a critical swimming velocity  $\sim 0.59 \text{ m s}^{-1}$  (Jones et al. 1974), which is much less than measured within the mid-channel of the Niagara, likely restricting these fish to within close proximity of either shoreline (Allen 2015). More light on this subject may be forthcoming through study of the role of these fishes as part of a collaborative “Emerald Shiner Project” in the upper river being led by Buffalo State University (<http://emeraldshiner.buffalostate.edu>).

There was less evidence of planktivorous fishes altering community composition of zooplankton by selectively consuming larger individuals (Akopian et al. 1999; Thorp and Casper 2003), based on the relatively constant zooplankton community composition observed in the Niagara River. The numerical domination of the river by small taxa (veligers, nauplii, *Bosmina*) is more likely driven by the domination of these organisms in Lake Erie. In general, zooplankton are more strongly affected by residence time in rivers than phytoplankton because of their relatively longer generation times. Smaller species may have an advantage in riverine systems because they have shorter generation times which helps compensate for population losses (Pace et al. 1992), but this is likely not as relevant in the Niagara River given the short retention time.

To determine any river impacts on the zooplankton community, it is also necessary to take into account the seasonal succession patterns in zooplankton. In eastern Lake Erie in the 1990s, cyclopoid copepod species including *Diacyclops thomasi* and cyclopoid nauplii larvae peaked in late spring followed by a summer successional shift from *D. thomasi* to *Mesocyclops edax* and then *Tropocyclops extensus* in the late summer (K. Bowen, unpublished data). The eastern Lake Erie calanoid community remained fairly consistent throughout the year, except for an increased dominance of *Epischura* in the summer. This aligns extremely well with the variability of cyclopoids and calanoids seen in the Niagara River. The overall community composition of the cyclopoids tends to be driven more by seasonal changes than by the environmental conditions of the river, though there is a clear difference in copepod densities in the downstream stations following the input from the hydroelectric plants. In terms of cladocerans, *Daphnia galeata mendotae* and *Bosmina* tended to dominate in the Niagara across the sampling season. The domination of *Bosmina* and the virtual absence of *Eubosmina*, a similar but slightly larger genus, were also consistent with observations in eastern Lake Erie in the 1990s (K. Bowen, unpublished data) and in August 1998 by Barbiero et al. (2001). These sources also indicate both *D. galeata mendotae* and *D. retrocurva* were dominant summer species in the 1990s in eastern Lake Erie, along with *D. longiremis*, a *Daphnia* species not identified in the Niagara River in 2014.

Though reservoir systems have a history of being ignored scientifically, their dynamics and complexity have become an important field of study within limnology given their differences to both lakes and rivers (Thornton et al. 1990). Akopian et al. (1999) showed that the Marne Reservoir (residence time 4-6 month) acts as a zooplankton source for the river. This is relevant for the Niagara River given the presence of hydroelectric reservoirs on both sides of the border. In order for the reservoirs to act as a zooplankton (and phytoplankton) source for the lower river, a portion of the plankton must persist in the reservoir for a period of time, and be viable after having traveled through the hydroelectric turbines. The sources of mortality due to hydroelectric turbines include blade strikes, shear stress, cavitations, turbulence, and barotraumas (Schlezinger et al. 2013). The literature reports zooplankton mortality ranging from 5 to 23% (Dubovskaia et al. 2004; Schlezinger et al. 2013) resulting from passage through hydroelectric power stations, and that mortality may be directly related to animal size (Cada 1990). Our report did not specifically address viability through verification of the proportion of live zooplankton in the river; however qualitative microscopic examination of an unpreserved sample collected in July at NIA14 indicated most animals were alive. Other preserved samples did not appear to show physical damage of zooplankton carapaces, however pressure-induced mortality remains possible. In a similar manner, the primary productivity experiments detailed above clearly demonstrate that phytoplankton were alive and able to photosynthesize after traveling over the falls and/or through the hydroelectric turbines. Our estimates based on combining waters of different plankton concentrations indicates that certain zooplankton groups, in particular copepod densities may be as much as 10x higher in the hydroelectric canal/reservoir system as found within the river, and eggs per individual are higher in cladocerans below the power plants. This suggests an overall positive influence on zooplankton populations in the lower river due to

the impoundment of water in the hydroelectric reservoirs. Future research on Niagara River zooplankton should include sampling within the reservoirs and channels themselves to directly measure this effect.

## SUMMARY AND RECOMMENDATIONS

This survey examined the composition of the phytoplankton and zooplankton communities of the Niagara River during the 2014 sampling season. In this time period, the Niagara River exhibited the conditions of a low-productivity, clear-phase system with considerable primary production by macrophytes enhancing the phytoplankton. This report, which sought to examine the degradation of phytoplankton and zooplankton population for the Niagara River AOC, found that while the plankton levels in the Niagara River are very low as compared to the adjacent lakes, reduced densities of phytoplankton and zooplankton are expected in riverine environments. There is a well-documented correlation between decreased residence time (i.e., increased current speed) and decreased plankton biomass, therefore the low plankton biomass within the river should not immediately be a cause for concern. There is little evidence to suggest that the diatom peak (August), and blue-green algae peak (September), were persistent or were likely detrimental to the system. Overall, the levels of the peak algal biomass did not exceed  $503 \text{ mg m}^{-3}$ , significantly less than the definition of a eutrophic algal bloom. The phytoplankton community within the river is dominated by diatoms, particularly by filamentous or colonial forms that are suited to high-energy flow systems such as *Fragilaria crotonensis* and *Skeletonema potamos*. In general, the phytoplankton and zooplankton communities are similar to those in other lentic environments, dominated by certain species better suited to the highly turbulent conditions found in rivers. While high veliger densities were found throughout the summer, these matched the pattern found in the water entering from Lake Erie, and the Niagara River is known to have high densities of adult dreissenid mussels. Moreover, the planktivorous fish population in the upper river, dominated by Emerald Shiner, is quite high and likely contributes to the reductions in zooplankton densities. Any reductions in biomass and changes in species compositions are consistent with expectations for a large river system, indicating no impairment of phytoplankton or zooplankton populations in the Niagara River. There is some evidence that entrainment time in the hydroelectric reservoirs might be promoting an increase in phytoplankton and zooplankton growth, though it was outside the scope of this monitoring survey. If assessing the role of the hydroelectric reservoirs is deemed important, then the project should include sampling within the reservoirs over the growth period of plankton (i.e., May-October), and any exceedances from the Niagara Falls Wastewater Treatment Plant should be recorded.

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**Table 1.** Niagara River plankton project sample site coordinates (see Figure 1 for map).

Main Stations	Descriptor	Latitude	Longitude
NIA10	Lake Erie inlet	42.88201	-78.92405
NIA11	Fort Erie train bridge	42.91907	-78.90854
NIA12	Grand Island	42.96111	-78.96899
NIA13	Above turbines	43.14113	-79.04274
NIA14	Queenston Bridge	43.15923	-79.04508
NIA4	Lower river	43.20444	-79.05333
Support Sites	Descriptor	Latitude	Longitude
NR15	Crystal beach, Lake Erie	42.8586	-79.05775
NIA15	Shore at train bridge	42.9294	-78.913
NIA16	Netherby boat launch	42.9826	-79.0244
NIA17	Welland River	43.0462	-79.1231
NIA18	Queenston Boat launch	43.1657	-79.0523
NIA19	Shore site at NOTL boat launch	43.2571	-79.06371
NOTL Mid-Channel	Mid-River at NOTL boat launch	43.25825	-79.05775

**Table 2.** Niagara River station summary; depth, clarity (Secchi), flow rate, temperature, maximum depths for integrated water collection and zooplankton nets, and total zooplankton net volume. Beginning in August, two zooplankton nets were pooled from each station. Sonde profiles were also collected at all main stations (summary in Table 6, full details in Appendix 2).

Date	Station	Station Depth (m)	Secchi (m)	Current speed (m s <sup>-1</sup> )	Surface temp (°C)	integrated water depth (m)	net depth (m)	net volume (L)
12-Jun	NIA10	9.1	5.2	nd	16.5	7	7.50	479
12-Jun	NIA11	6.0	5.2	nd	15.1	n/a	3.00	636
12-Jun	NIA12	5.2	bottom	0.98	16.2	5	3.50	715
10-Jun	NIA13	17.0	nd	1.52	16.1	0-3	1.00	776
10-Jun	NIA14	22-30	nd	1.14	16.1	n/a	1.00	667
10-Jun	NIA4	14.6	3.3	nd	16.2	0-6	14.00	747
09-Jul	NIA10	9.2	nd	0.72	22.6	7	7.00	1230
09-Jul	NIA11	8.4	1.8	1.07	22.4	n/a	7.00	327
09-Jul	NIA12	5.7	4.5	0.78	22.7	4	4.50	297
09-Jul	NIA13	15.9	nd	2.21	22.5	1.5	5.50	426
09-Jul	NIA14	40.0	1.8	1.36	22.7	n/a	6.00	664
09-Jul	NIA4	13.1	1	1.42	22.7	3	13.50	763
30-Jul	NIA10	8.9	3	0.54	21.3	6	8.50	559
30-Jul	NIA11	7.8	4.6	0.81	21.7	n/a	4.50	350
30-Jul	NIA12	5.9	4.9	1.12	21.7	4	5.50	327
30-Jul	NIA13	16.6	1.9	1.48	21.4	4	8.00	551
30-Jul	NIA14	22.0	1.6	1.32	21.4	n/a	10.50	791
30-Jul	NIA4	13.2	2.1	1.44	21.4	4	12.00	763
19-Aug	NIA10	9.0	5	0.29	22.2	7	7.00	728
19-Aug	NIA11	3.6	bottom	0.40	21	n/a	3.75	648
19-Aug	NIA12	5.0	bottom	0.77	21.7	5	4.00	494
19-Aug	NIA13	17.8	2.5	2.36	22	nd	9.00	1164
19-Aug	NIA14	39.0	2.3	1.24	21.9	n/a	8.25	1814
19-Aug	NIA4	13.8	3.3	1.22	21.9	5	10.00	1253
10-Sep	NIA10	8.2	4.5	0.40	23.1	5	7.25	1951
10-Sep	NIA11	5.6-8.7	6.9	0.23	22.6	n/a	6.25	850
10-Sep	NIA12	4.8	bottom	0.75	22.8	4.5	4.00	626
10-Sep	NIA13	14.9 - 17.6	3.25	2.04	23.5	5	3.00	848
10-Sep	NIA14	25	3.25	0.19	22.9	n/a	7.00	1436
10-Sep	NIA4	13 - 14.8	4	1.11	22.9	5	10.25	1208
15-Oct	NIA10	8.7	3	0.39	17.2	6	8.75	1812
15-Oct	NIA11	7.6	4.2	1.04	17	n/a	n/a	n/a
15-Oct	NIA12	5.3	4.2	1.01	16.9	6	4.25	594
15-Oct	NIA13	17.4	nd	1.43	16.9	5	9.75	1216
15-Oct	NIA14	18	nd	nd	16.6	n/a	7.50	1569
15-Oct	NIA4	14	2.75	1.12	16.7	6	13.75	1526

nd = no data

n/a = not applicable (nothing was collected)

**Table 3.** Average measured flows and discharge at NIA11, NIA13 and NIA14 using whole water column estimates summarized from Acoustic Doppler Current Profiler surveys completed in October 2014 (pers. comm. A. Thompson and S. Rodrigues, National Hydrologic Service of ECCC, Feb. 2016).

Site	CAN shore $\text{m}\cdot\text{s}^{-1}$	Mid-channel $\text{m}\cdot\text{s}^{-1}$	US shore $\text{m}\cdot\text{s}^{-1}$	Discharge $\text{m}^3\text{s}^{-1}$
Fort Erie	1.3	1.7	1.0	5600
Above Power Stations	0.9	3.0	1.4	3300
Below Power Stations	0.8	1.3	0.3	6200

**Table 4.** Estimate of Niagara River residence time based on flow rates from Table 3, where average flow rates for entire river assumes equal likelihood of being in each section of the river (Canadian shore, mid-channel or US shore).

	Avg flow entire river km h <sup>-1</sup>	Avg. mid- channel flow km h <sup>-1</sup>	River section km	Hours for avg. river flow	Hours for mid-channel flow
Upper Niagara River	1.7	4.8	28	16.5	5.8
Falls to Power Stations	3	6.4	9	3	1.4
Power Stations to L.Ontario	1.3	2.9	11	8.5	3.8
			Total:	28	11

**Table 5.** Cross-river transect profile summary (average of sonde transect) for Niagara River stations.

Date	Transect at Station	EXO				FluoroProbe
		Chl. <i>a</i> ( $\mu\text{g L}^{-1}$ )	Turbidity (FNU)	Temperature ( $^{\circ}\text{C}$ )	Conductivity ( $\mu\text{S cm}^{-1}$ )	Chl. <i>a</i> ( $\mu\text{g L}^{-1}$ )
12 Jun	NIA 12	0.63 $\pm$ 0.07	0.00 $\pm$ 0.30	15.8 $\pm$ 0.22	238 $\pm$ 0.8	0.29 $\pm$ 0.25
	NIA 18	--	--	--	--	0.23 $\pm$ 0.21
	NIA 4	--	--	--	--	1.35 $\pm$ 0.90
9 July	NIA 18	0.73 $\pm$ 0.04	5.86 $\pm$ 0.06	22.2 $\pm$ 0.00	278 $\pm$ 0.2	--
	NIA 4	0.93 $\pm$ 0.17	5.10 $\pm$ 0.08	22.2 $\pm$ 0.02	279 $\pm$ 0.1	--
	NIA 11 <sup>1</sup>	0.31	0.00	22.1	271	--
30 July	NIA 11 <sup>1</sup>	0.50 $\pm$ 0.11	1.30 $\pm$ 1.05	21.5 $\pm$ 0.19	278 $\pm$ 0.5	0.66 $\pm$ 0.08
	NIA 12 <sup>1</sup>	0.30 $\pm$ 0.03	0.00 $\pm$ 0.11	21.4 $\pm$ 0.15	280 $\pm$ 0.2	0.39 $\pm$ 0.01
	NIA 18 <sup>1</sup>	0.68 $\pm$ 0.04	1.95 $\pm$ 0.16	21.5 $\pm$ 0.01	280 $\pm$ 0.0	0.92 $\pm$ 0.12
	NIA 4 <sup>1</sup>	0.66 $\pm$ 0.03	2.33 $\pm$ 0.48	21.6 $\pm$ 0.01	281 $\pm$ 0.3	0.77 $\pm$ 0.03
19 Aug	NIA 12 <sup>1</sup>	0.29	0.00	21.3	273	0.00
	NIA 18	--	--	--	--	--
	NIA 4	--	--	--	--	--
10 Sep	NIA 12	0.09 $\pm$ 0.02	0.00 $\pm$ 0.13	22.1 $\pm$ 0.03	268 $\pm$ 0.4	--
	NIA 18	0.22 $\pm$ 0.06	0.00 $\pm$ 0.28	22.4 $\pm$ 0.00	271 $\pm$ 0.0	0.00 $\pm$ 0.00
	NIA 4	0.20 $\pm$ 0.02	0.00 $\pm$ 0.03	22.4 $\pm$ 0.00	271 $\pm$ 0.1	0.00 $\pm$ 0.00
15 Oct	NIA 12	0.10 $\pm$ 0.05	2.05 $\pm$ 0.13	16.2 $\pm$ 0.02	224 $\pm$ 0.5	--
	NIA 18	0.35 $\pm$ 0.14	2.24 $\pm$ 0.07	16.3 $\pm$ 0.00	226 $\pm$ 0.2	--
	NIA 4	0.10 $\pm$ 0.06	2.39 $\pm$ 0.10	16.3 $\pm$ 0.00	226 $\pm$ 0.1	--
<b>Mean <math>\pm</math>SE</b>	NIA 12	0.32 $\pm$ 0.06	0.03 $\pm$ 0.31	18.8 $\pm$ 0.7	251 $\pm$ 4.8	0.28 $\pm$ 0.11
	NIA 18	0.43 $\pm$ 0.05	2.36 $\pm$ 0.50	20.5 $\pm$ 0.5	262 $\pm$ 4.5	0.31 $\pm$ 0.09
	NIA 4	0.52 $\pm$ 0.08	2.74 $\pm$ 0.42	20.5 $\pm$ 0.5	263 $\pm$ 4.2	0.64 $\pm$ 0.20

<sup>1</sup> From transect across river

**Table 6.** Single-point Niagara River station summary (average  $\pm$  SE of sonde profile). Upper River grouping includes NIA11 and 12 while Below Turbines grouping includes NIA 14 and 4. Double-dashes indicate no measurements were taken.

		<b>EXO</b>				<b>FluoroProbe</b>
Date	Designation	Chl. <i>a</i> ( $\mu\text{g L}^{-1}$ )	Turbidity (FNU)	Temperature ( $^{\circ}\text{C}$ )	Conductivity ( $\mu\text{S cm}^{-1}$ )	Chl. <i>a</i> ( $\mu\text{g L}^{-1}$ )
12 Jun	Lake Erie	23.95	2.53	13.85	230.62	--
	Welland River	1.06	12.27	17.12	276.14	--
	Upper River	1.00 $\pm$ 0.10	0.31 $\pm$ 0.68	15.40 $\pm$ 0.29	237.12 $\pm$ 2.28	0.04 $\pm$ 0.02
	Above Turbines	0.37	1.74	16.10	240.00	--
	Below Turbines	1.19 $\pm$ 0.30	3.60 $\pm$ 0.99	16.01 $\pm$ 0.09	241.20 $\pm$ 2.72	0.07 $\pm$ 0.04
9 July	Welland River	--	--	--	--	2.14
	Upper River	0.58 $\pm$ 0.25	1.58 $\pm$ 0.48	22.02 $\pm$ 0.04	270.22 $\pm$ 0.81	0.00 $\pm$ 0.00
	Above Turbines	--	--	--	--	--
	Below Turbines	0.72	--	22.35	277.64	--
30 July	Upper River	0.47 $\pm$ 0.06	0.07 $\pm$ 0.08	21.31 $\pm$ 0.09	278.61 $\pm$ 0.49	0.59 $\pm$ 0.08
	Above Turbines	0.41	1.89	21.50	278.62	0.55
	Below Turbines	0.59	2.00 $\pm$ 0.04	21.54 $\pm$ 0.01	280.02 $\pm$ 0.34	0.76 $\pm$ 0.04
19 Aug	Upper River	0.61 $\pm$ 0.12	2.14 $\pm$ 1.48	21.18 $\pm$ 0.09	276.02 $\pm$ 1.01	0.47 $\pm$ 0.37
	Above Turbines	--	--	--	--	0.00
	Below Turbines	--	--	--	--	0.01 $\pm$ 0.01
10 Sep	Upper River	0.15 $\pm$ 0.05	0.00 $\pm$ 4.61	22.08 $\pm$ 0.02	268.37 $\pm$ 0.24	0.00 $\pm$ 0.00
	Above Turbines	0.07	0.05	22.32	270.00	0.00
	Below Turbines	0.21	0.00	22.37	270.92	0.00
15 Oct	Upper River	0.32 $\pm$ 0.10	2.13 $\pm$ 0.35	16.27 $\pm$ 0.02	223.96 $\pm$ 0.37	0.92 $\pm$ 0.04
	Above Turbines	0.00	2.53	16.38	225.00	1.04
	Below Turbines	0.20 $\pm$ 0.04	2.28 $\pm$ 0.20	16.32 $\pm$ 0.01	226.00 $\pm$ 0.00	0.68 $\pm$ 0.63
<b>Mean <math>\pm</math>SE</b>	Upper River	0.54 $\pm$ 0.06	0.92 $\pm$ 0.33	19.7 $\pm$ 0.54	258 $\pm$ 3.7	0.34 $\pm$ 0.08
	Above Turbines	0.20 $\pm$ 0.09	1.55 $\pm$ 0.43	19.1 $\pm$ 1.34	253 $\pm$ 10	0.40 $\pm$ 0.20
	Below Turbines	0.68 $\pm$ 0.14	2.74 $\pm$ 0.48	18.7 $\pm$ 0.72	254 $\pm$ 5.5	0.29 $\pm$ 0.11

**Table 7.** Vertical light attenuation coefficient  $k_d$  ( $m^{-1}$ ) estimates for Niagara River. Double-dashes indicate no measurement.

	June	Early July	Late July	August	September	October	Station Average
NIA10	0.275	--	0.275	0.229	0.211	0.304	0.259
NIA11	--	--	0.236	0.733	0.154	0.352	0.369
NIA12	0.233	--	--	0.266	0.216	0.241	0.239
NIA13	--	--	0.12	0.443	0.294	0.445	0.326
NIA14	0.327	--	0.646	--	0.393	0.382	0.437
NIA4	0.369	0.903	0.585	0.367	0.266	0.448	0.490
Cruise Average	0.301	0.903	0.372	0.408	0.256	0.362	



**Table 8.** Selected common phytoplankton species in the Niagara River by percent contribution to total biomass.

Group	Species	09-Jul			30-Jul			19-Aug			10-Sep			15-Oct		
		NIA10	NIA13	NIA4	NIA10	NIA13	NIA4	NIA10	NIA13	NIA4	NIA10	NIA13	NIA4	NIA10	NIA13	NIA4
Cyanophyta	<i>Heteroleibleinia</i> sp.												13.9			
	<i>Lyngbya</i> sp.					18.0										
	<i>Lyngbya birgei</i>											89.4				
Chlorophyta	<i>Sphaerocystis Schroeteri</i>	12.0														
	<i>Tetracystis pulchra</i>															11.3
Chrysophyta	<i>Ochromonas</i> sp.							16.0	6.6	21.2	0.4	0.1	4.0			
Diatoma	<i>Aulacoseira muzzanensis</i>	12.0														
	<i>Cocconeis pediculus</i>		38.1	44.8	19.7	3.3	22.8		6.2							13.0
	<i>Diatoma vulgare vulgare</i>														15.5	
	<i>Fragilaria construens</i>					15.7										
	<i>Fragilaria crotonensis</i>		11.9					25.8		45.3	7.1			26.3	28.1	
	<i>Gomphonema olivaceum</i>		11.1													
	<i>Navicula tripunctata</i>					9.5										
	<i>Nitzschia heufleriana</i>			19.7												
	<i>Nitzschia intermedia</i>	8.6														
	<i>Skeletonema potamos</i>			11.3			35.0			0.2			8.7			
	<i>Stephanodiscus alpinus</i>				19.7									15.9		40.7
	<i>Stephanodiscus binderanus</i>									10.7						
	<i>Stephanodiscus medius</i>				13.4			8.3								5.1
	<i>Stephanodiscus parvus</i>	11.0	4.2													
Cryptophyta	<i>Rhodomonas minuta nannoplanctica</i>	10.0	5.5	6.3	13.7	10.3	10.3	18.6	29.0	1.3	26.0	1.8	11.8	9.9	6.5	4.8

**Table 9A.** Zooplankton species by major groupings for the Niagara River stations. An X indicates species was present.

			10-Jun-14			9-Jul-14*			30-Jul-14			19-Aug-14			10-Sep-14			15-Oct-14		
			NIA10	NIA12	NIA14	NIA10	NIA12	NIA14	NIA10	NIA12	NIA14	NIA10	NIA12	NIA14	NIA10	NIA12	NIA14	NIA10	NIA12	NIA14
Zooplankton	Cladocera	<i>Alona</i> sp.																		X
		<i>Bosmina longirostris</i>	X	X	X	X	X		X	X		X	X		X	X	X	X	X	X
		<i>Bythotrephes longimanus</i>				X	X	X	X	X	X	X		X						
		<i>Chydorus sphaericus</i>					X													
		<i>Daphnia galeata mendotae</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		<i>Daphnia retrocurva</i>	X	X	X						X									X
		<i>Leptodiptomus minutus</i>	X					X			X									
		<i>Eubosmina coregoni</i>	X						X							X				
		<i>Eurycercus lamellatus</i>		X																
		<i>Holopedium gibberum</i>	X																	
		<i>Leptodora kindtii</i>	X					X	X	X	X	X	X	X	X					
	Cyclopoids	<i>Diacyclops thomasi</i>	X	X	X							X			X			X	X	
		<i>Cyclops vernalis</i>									X									
		Cyclopoida copepodites	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		Cyclopoida nauplii	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
		<i>Eucyclops agilis</i>															X			
		<i>Mesocyclops edax</i>	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	
		<i>Tropocyclops extensus</i>						X			X	X	X		X	X	X	X	X	X
		Calanoida copepodites	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Calanoids	Calanoida nauplii	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		<i>Leptodiptomus ashlandi</i>	X																	
		<i>Leptodiptomus minutus</i>				X	X	X	X	X	X	X	X		X	X	X	X		
		<i>Skistodiptomus oregonensis</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		<i>Epischura</i> copepodid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		<i>Epischura lacustris</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		<i>Eurytemora affinis</i>						X					X			X	X		X	X
		<i>Limnocalanus</i> copepodites	X																	
		<i>Limnocalanus macrurus</i>	X																	
		Harpacticoida						X	X	X	X		X	X		X	X	X	X	X

\**Cercopagis pengoi* was noted at NIA11 on July 9<sup>th</sup>.

**Table 9B.** Rotifer densities and dry biomass values in June - October seasonal composite samples collected in the Niagara River in 2014. Dominant taxa at the river entrance are given in bold.

Taxa Name	density (no.m <sup>-3</sup> )				dry biomass (mg m <sup>-3</sup> )			
	NIA10	NIA12	NIA13	NIA4	NIA10	NIA12	NIA13	NIA4
<i>Asplanchna</i> sp.	400	133	0	0	0.237	0.101	0.000	0.000
<i>Colurella</i> sp.	0	133	0	0	0.000	0.001	0.000	0.000
<b><i>Conochilus unicornis</i></b>	6533	4933	267	600	0.120	0.071	0.006	0.008
<i>Gastropus stylifer</i>	133	133	0	100	0.001	0.003	0.000	0.001
<b><i>Kellicottia longispina</i></b>	2400	933	267	600	0.012	0.005	0.002	0.003
<i>Keratella quadrata</i>	400	0	0	300	0.024	0.000	0.000	0.019
<b><i>Keratella cochlearis</i></b>	5600	2933	667	1000	0.045	0.017	0.004	0.009
<i>Keratella cochlearis tecta</i>	0	133	133	0	0.000	0.000	0.000	0.000
<i>Monostyla</i> sp.	0	0	133	0	0.000	0.000	0.000	0.000
<i>Pleosoma hudsoni</i>	0	0	0	100	0.000	0.000	0.000	0.003
<i>Pleosoma lenticulare</i>	133	133	133	100	0.001	0.005	0.012	0.003
<i>Polyarthra major</i>	400	400	133	0	0.009	0.004	0.005	0.000
<b><i>Polyarthra vulgaris</i></b>	2000	1600	400	200	0.027	0.018	0.006	0.003
<i>Pompholyx sulcata</i>	133	0	0	0	0.001	0.000	0.000	0.000
<b><i>Synchaeta kitina</i></b>	800	0	0	500	0.008	0.000	0.000	0.006
<i>Synchaeta pectinata</i>	133	0	0	0	0.005	0.000	0.000	0.000
<i>Synchaeta stylata</i>	400	0	0	100	0.018	0.000	0.000	0.006
<b>Total</b>	<b>19467</b>	<b>11467</b>	<b>2133</b>	<b>3600</b>	<b>0.507</b>	<b>0.224</b>	<b>0.035</b>	<b>0.062</b>

**Table 9C.** Rotifer species list for station NIA10 on each sampling date developed from qualitative observations of the 64 µm zooplankton net samples.

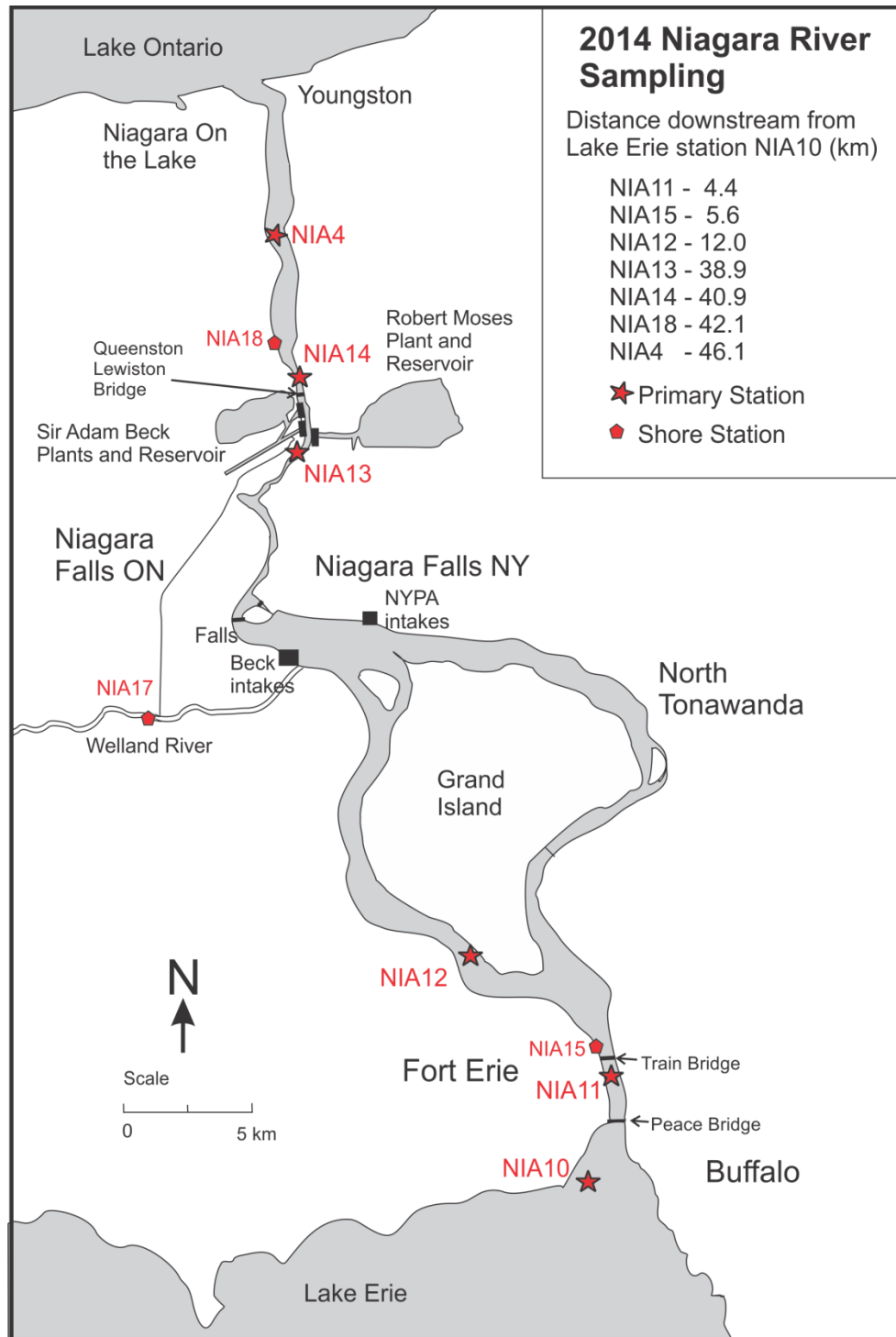
	<b>Species Name</b>	12-Jun	9-Jul	30-Jul	19-Aug	10-Sep	15-Oct
<b>Rotifers</b>	<i>Asplanchna sp.</i>	X		X	X		X
	<i>Conochilus unicornis</i>	X	X				
	<i>Kellicottia longispina</i>	X	X		X		X
	<i>Keratella cochlearis</i>	X	X	X	X	XX	X
	<i>Keratella quadrata</i>	X					
	<i>Ploesoma hudsoni</i>				X	X	
	<i>Ploesoma lenticulare</i>				X		X
	<i>Ploesoma truncatum</i>				X		
	<i>Polarthra sp.</i>			X	XX		X
	<i>Trichocerca cylindrica</i>		X		X		

X = Present, XX = Abundant

**Table 10.** June to October mean density, mean biomass and total seasonal production for major zooplankton groups at Niagara River stations.

<b>Density (no L<sup>-1</sup>)</b>	<b>Bosminid</b>	<b>Daphnia</b>	<b>Predatory Cladoceran</b>	<b>Cyclopoid</b>	<b>Calanoid</b>	<b>Nauplii</b>	<b>Veliger</b>	<b>Total</b>
NIA10	4.81	1.09	0.05	7.17	15.51	13.58	51.32	93.53
NIA11	3.47	0.77	0.01	6.23	5.92	5.30	28.41	50.10
NIA12	2.32	0.74	0.02	2.72	5.97	1.88	10.24	23.90
NIA13	0.28	0.19	0.01	0.16	0.21	0.18	1.88	2.92
NIA14	0.97	0.53	0.01	1.03	1.56	0.40	4.17	8.66
NIA4	1.53	0.33	0.01	0.75	1.35	0.52	4.84	9.33
<b>Biomass (mg m<sup>-3</sup>)</b>	<b>Bosminid</b>	<b>Daphnia</b>	<b>Predatory Cladoceran</b>	<b>Cyclopoid</b>	<b>Calanoid</b>	<b>Nauplii</b>	<b>Veliger</b>	<b>Total</b>
NIA10	5.40	7.76	1.97	7.44	50.28	1.42	29.66	103.94
NIA11	4.17	5.23	0.84	6.49	21.06	0.51	20.18	58.48
NIA12	1.65	5.67	3.72	1.53	13.04	2.19	7.51	35.30
NIA13	0.37	1.33	0.37	0.19	1.09	0.02	0.83	4.19
NIA14	1.20	3.68	1.52	1.09	7.59	0.04	1.83	16.96
NIA4	1.93	2.33	0.61	0.77	7.33	0.05	2.27	15.28
<b>Production (mg m<sup>-3</sup>)*</b>	<b>Bosminid</b>	<b>Daphnia</b>	<b>Predatory Cladoceran</b>	<b>Cyclopoid</b>	<b>Calanoid</b>	<b>Nauplii</b>	<b>Veliger</b>	<b>Total</b>
NIA10	69.9	88.1	46.5	101.8	326.9	12.8	415.3	1061.3
NIA11	48.2	58.4	23.2	92.7	135.1	5.2	262.5	625.4
NIA12	33.1	57.1	24.6	45.3	157.8	2.1	94.7	414.7
NIA13	3.8	14.4	12.0	3.3	6.2	0.2	11.6	51.4
NIA14	13.5	41.9	42.5	15.2	42.3	0.4	26.6	182.3
NIA4	22.3	25.7	21.2	10.2	36.6	0.4	32.9	149.4

\*Production calculated based on volumetric biomass standardized production (P:B)

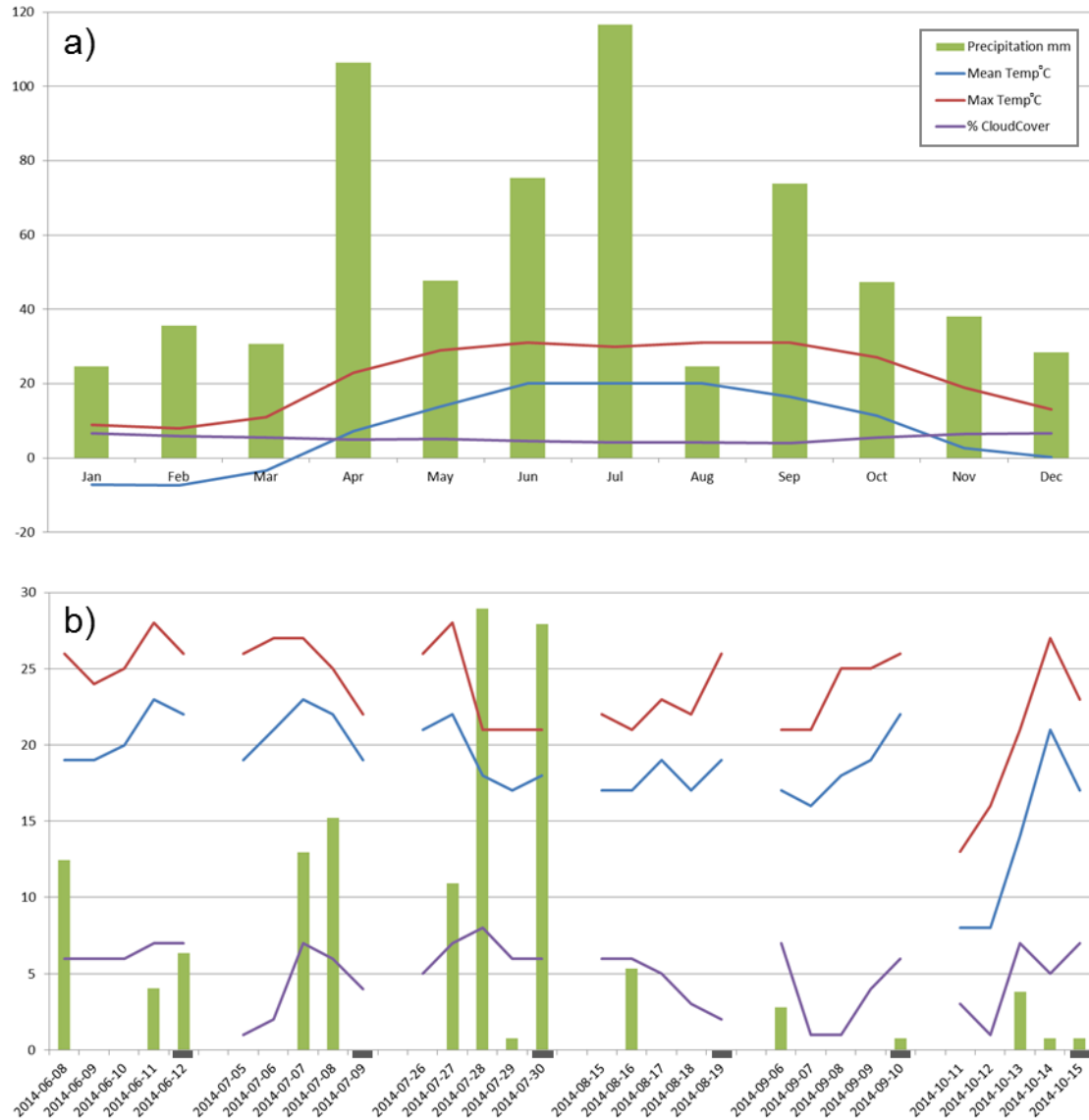


**Figure 1.** Map of Niagara River study site showing the location of the sampling stations relative to the hydroelectric installations on the American and Canadian side. The insert shows distance downriver of sampling sites relative to NIA10.

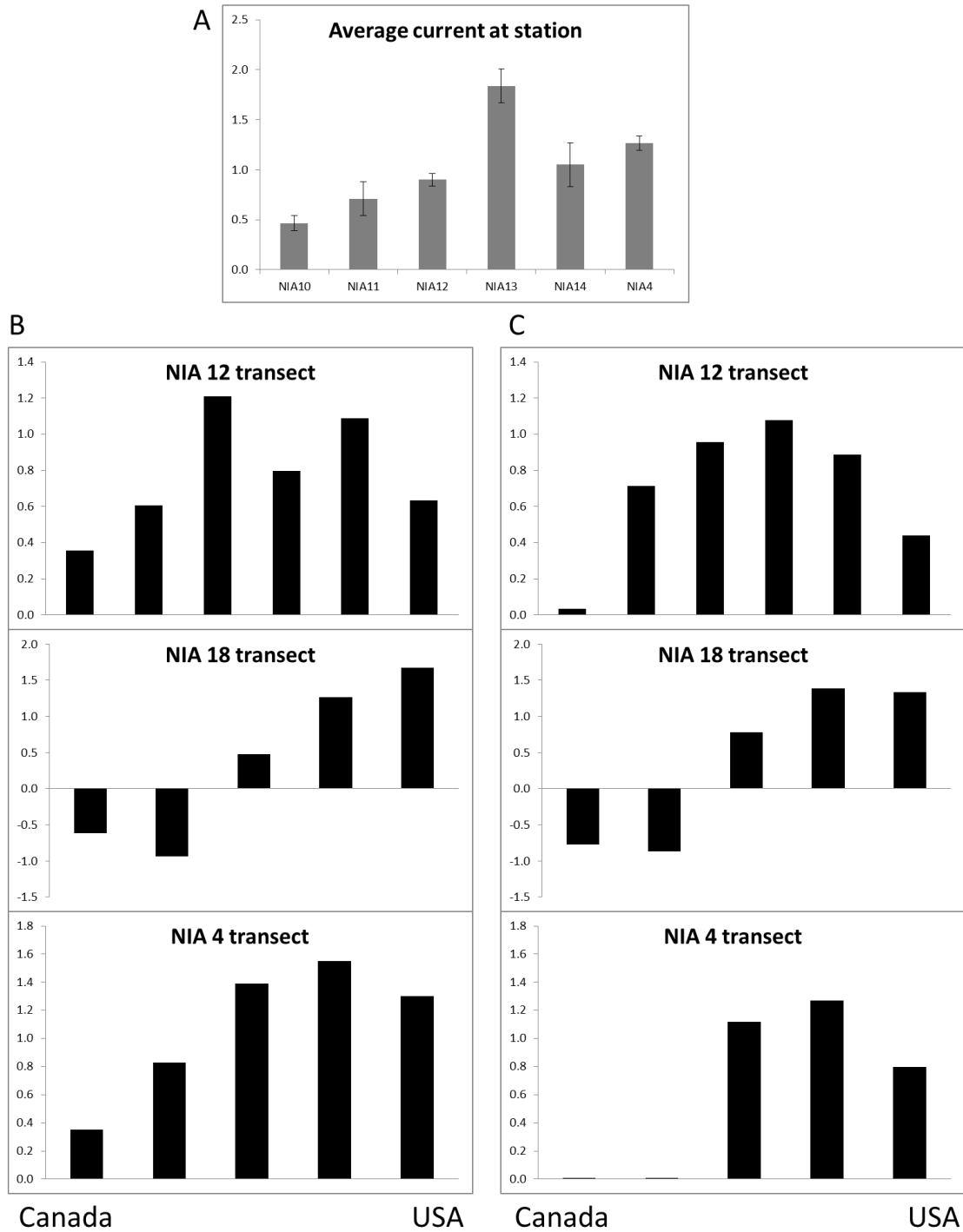


**Figure 2.** Map showing locations of hydroelectric power stations, water supply tunnels and wastewater treatment plants (a); and photographs of Sir Adam Beck Power Stations, canals and reservoir (b), detail of the pumped reservoir system (c), the new Niagara Tunnel completed 2013 (d) and the original Chippawa-Lewiston canal originating from the Welland River (e). Images are modified from Ontario Power Generation Niagara Tunnel Project portal (<http://www.opg.com/generating-power/hydro/projects/niagara-tunnel-project/>).

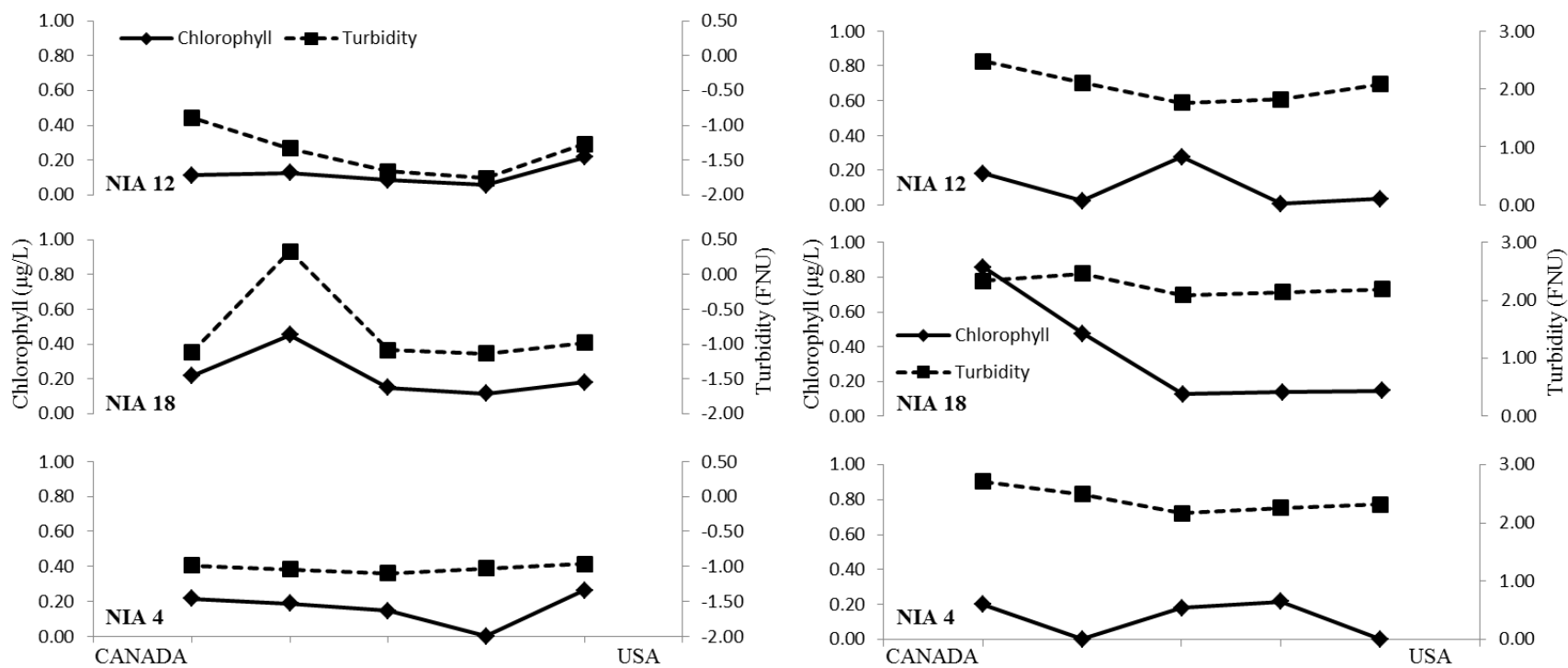




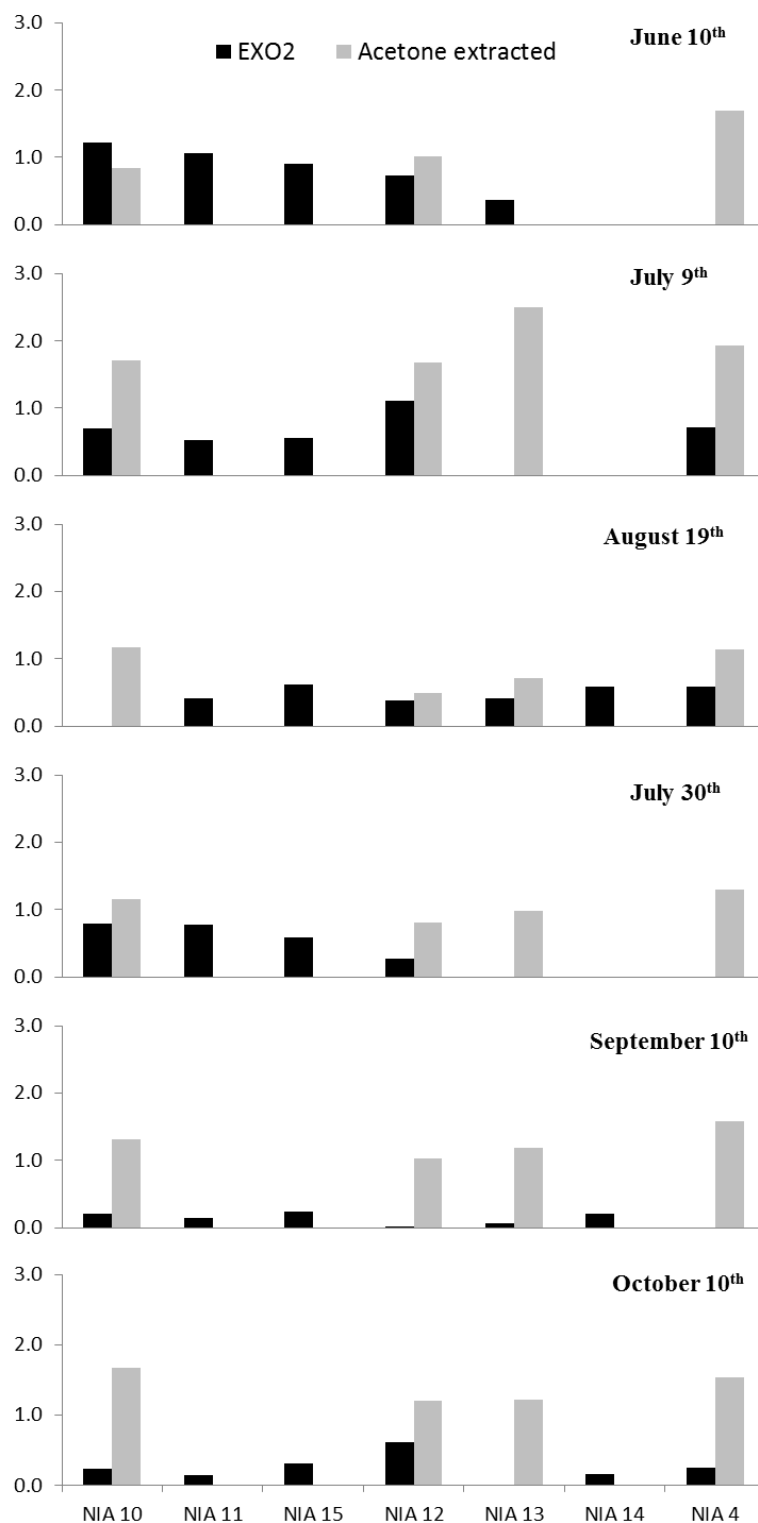
**Figure 3.** Monthly 2014 mean temperatures (daily mean and maxima °C), % cloud cover and total precipitation (green bar, mm) (a) taken from Niagara airport (IAG), and daily values (b) for the four days preceding the date of sampling indicated by the dark bar. Data taken from NOAA-NCEI database.



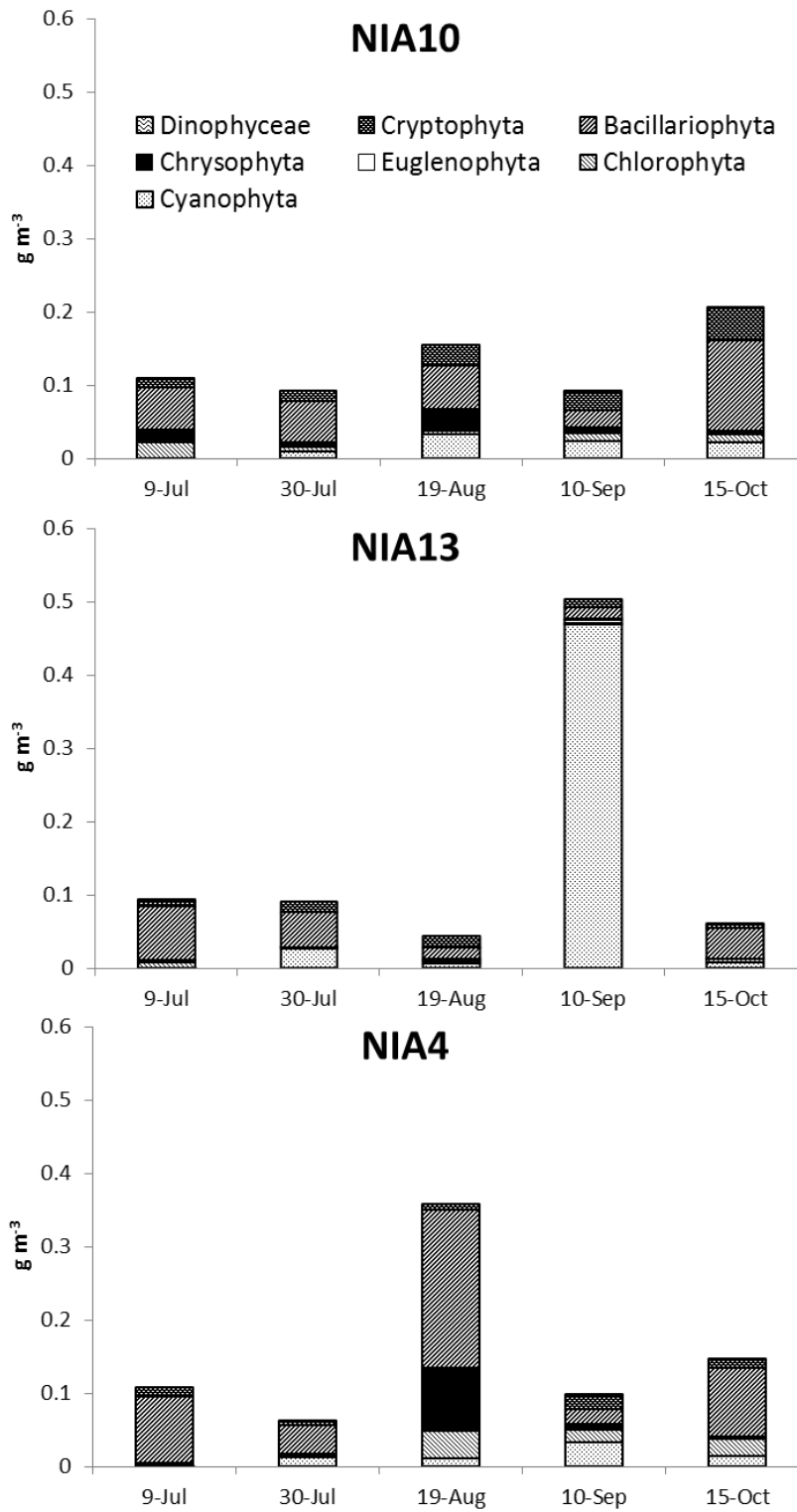
**Figure 4.** A) Average downstream current speeds (m s<sup>-1</sup>) from the primary sampling stations, B) current speeds from above the falls (NIA12) and below the turbines (NIA18 and NIA4) on June 10<sup>th</sup>, and C) current speeds on October 15<sup>th</sup>. Note the back-eddy closest to the Canadian shore at NIA18.



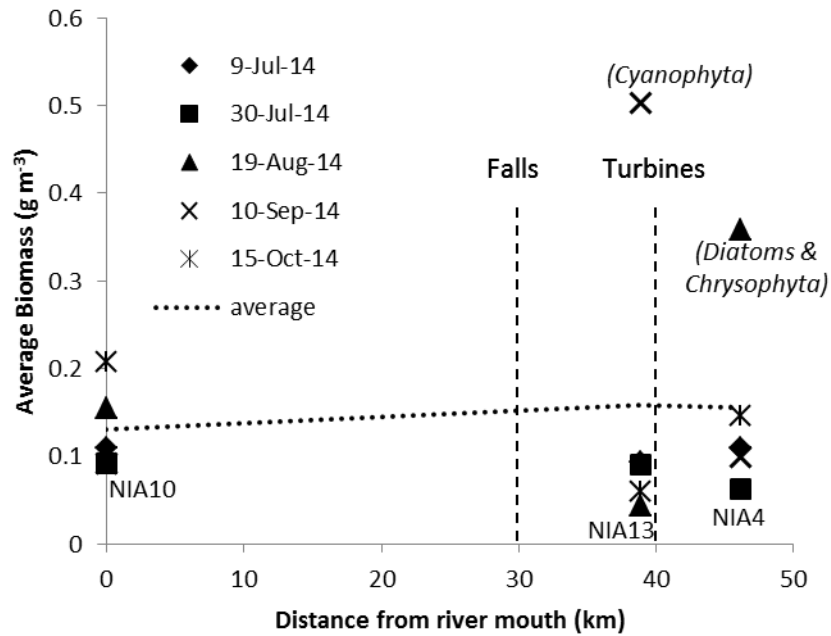
**Figure 5.** Cross-river transects from above Niagara Falls (NIA12) and below the turbines (NIA18 and NIA4) on September 10<sup>th</sup>, 2014 (left) and October 15<sup>th</sup>, 2014 (right).



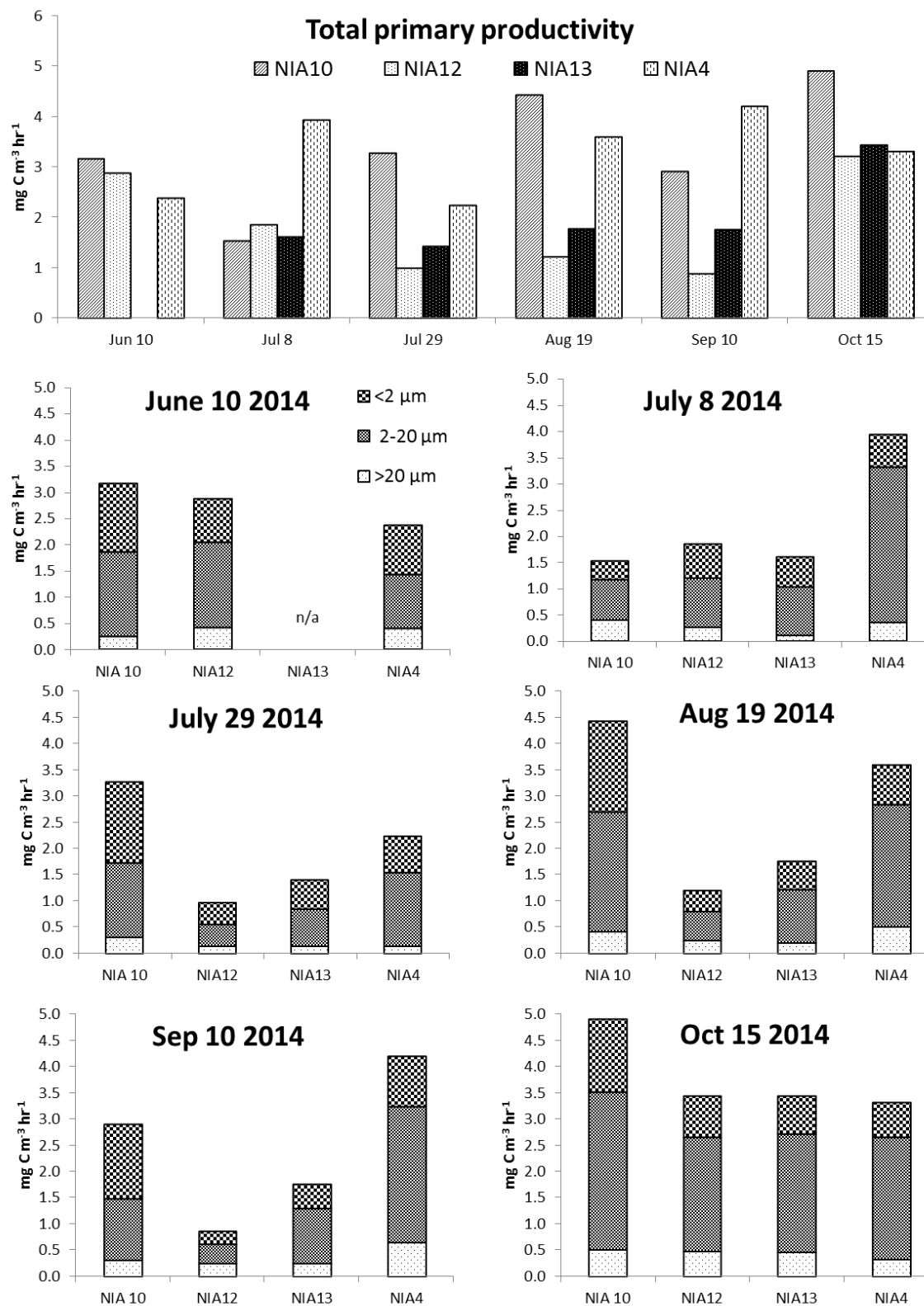
**Figure 6** Comparison of chlorophyll *a* ( $\mu\text{g L}^{-1}$ ) by cruise for seven stations from the upper to lower river as determined by the EXO2 sonde and by acetone extraction (total uncorrected). Values are consistently very low ( $< 2 \mu\text{g L}^{-1}$ ).



**Figure 7.** Niagara phytoplankton biomass ( $\text{g m}^{-3}$ ) for major groups by station for each date.

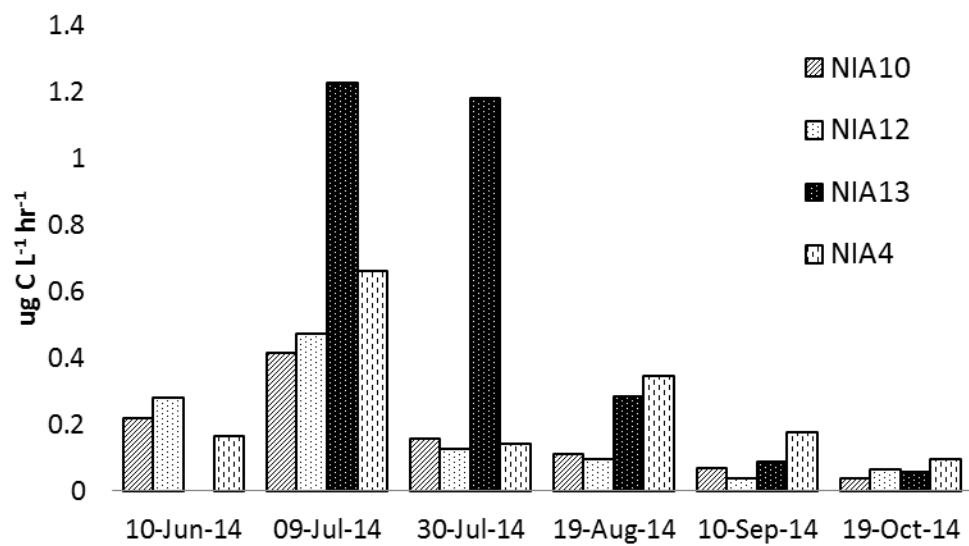


**Figure 8.** Phytoplankton biomass ( $\text{g m}^{-3}$ ) by distance from the Niagara River mouth. Extreme values at NIA13 and NIA4 were caused by peaks in algal biomass (groups noted in parentheses and discussed in text). Locations of Niagara Falls and hydroelectric plant turbines are noted by vertical dashed lines.

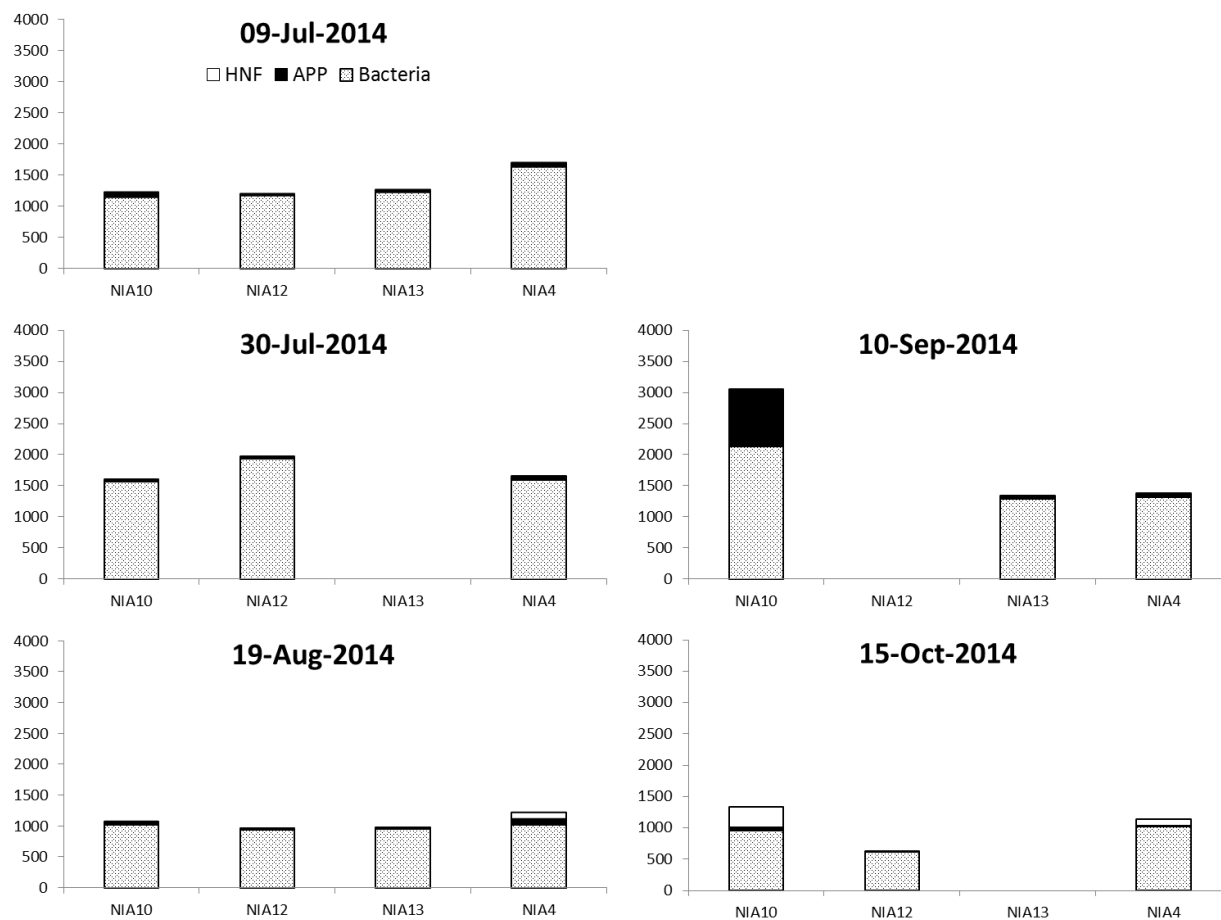


**Figure 9.** Total and size-fractionated primary productivity by Niagara River station and date.



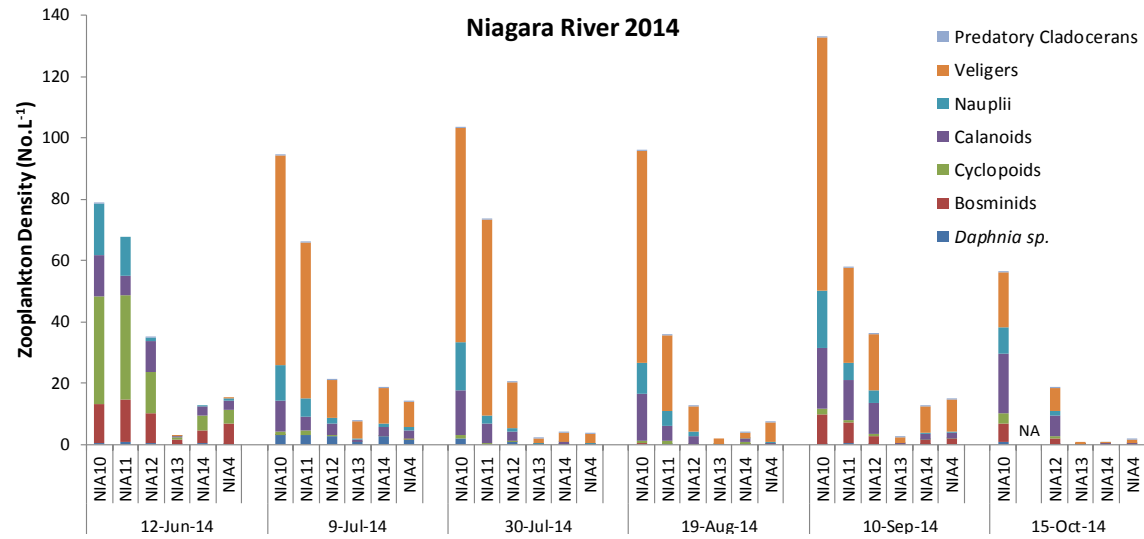


**Figure 10.** Bacterial potential growth rate for selected Niagara River stations by date.

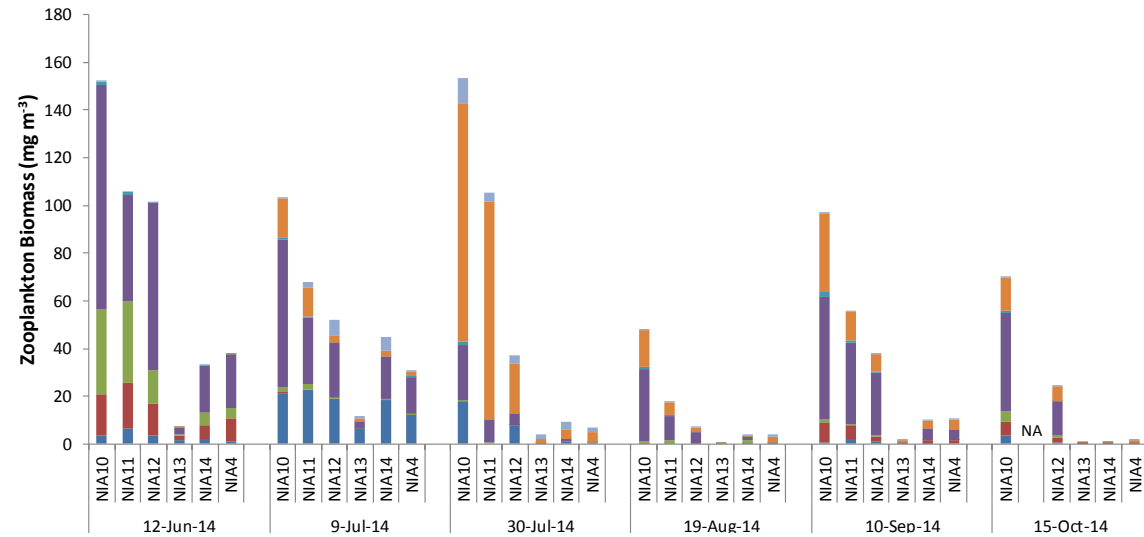


**Figure 11.** Microbial loop biomass ( $\text{mg m}^{-3}$ ) by major group: heterotrophic nanoflagellates (HNF), autotrophic picoplankton (APP) and bacteria for stations in the Niagara River by date.

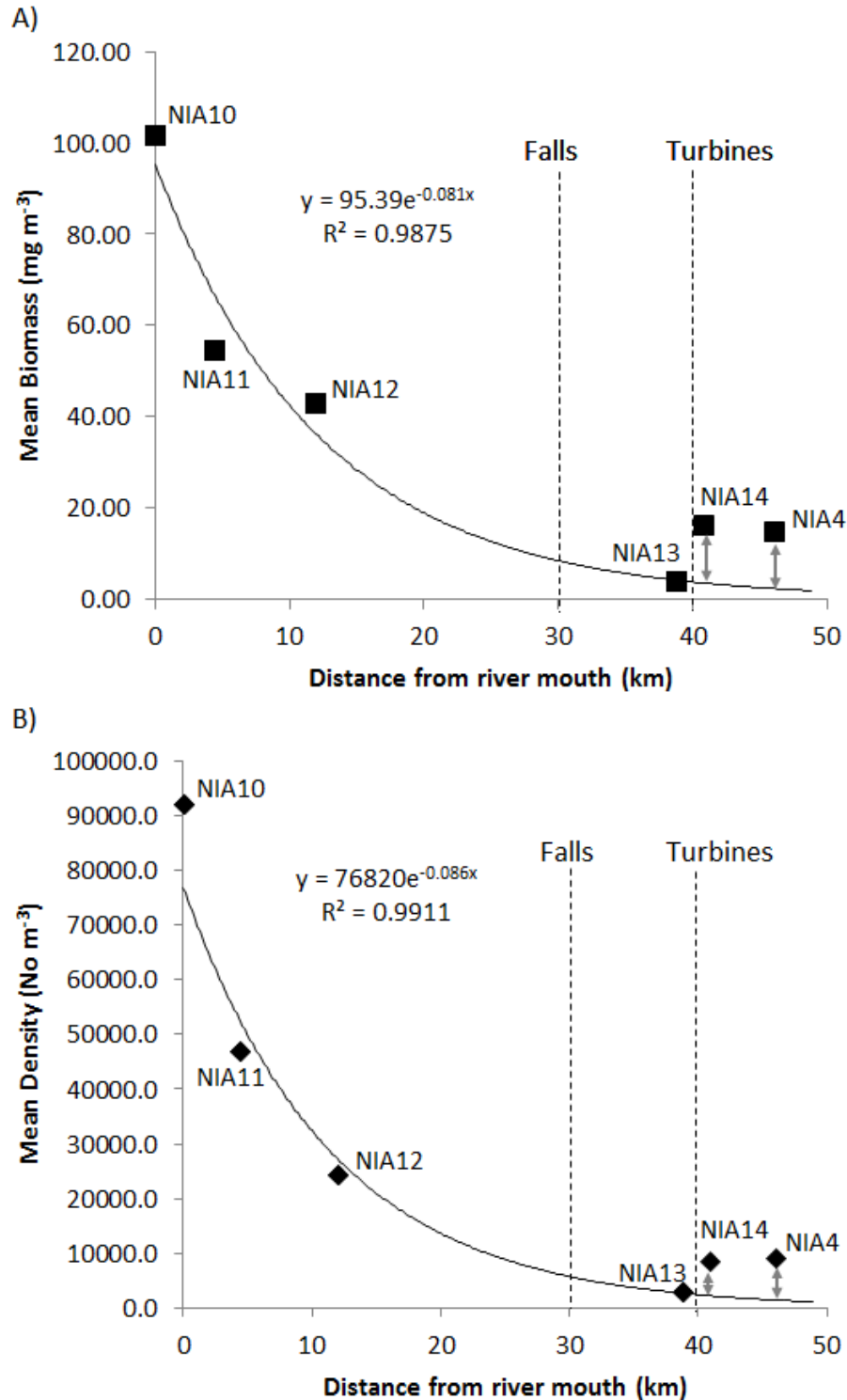
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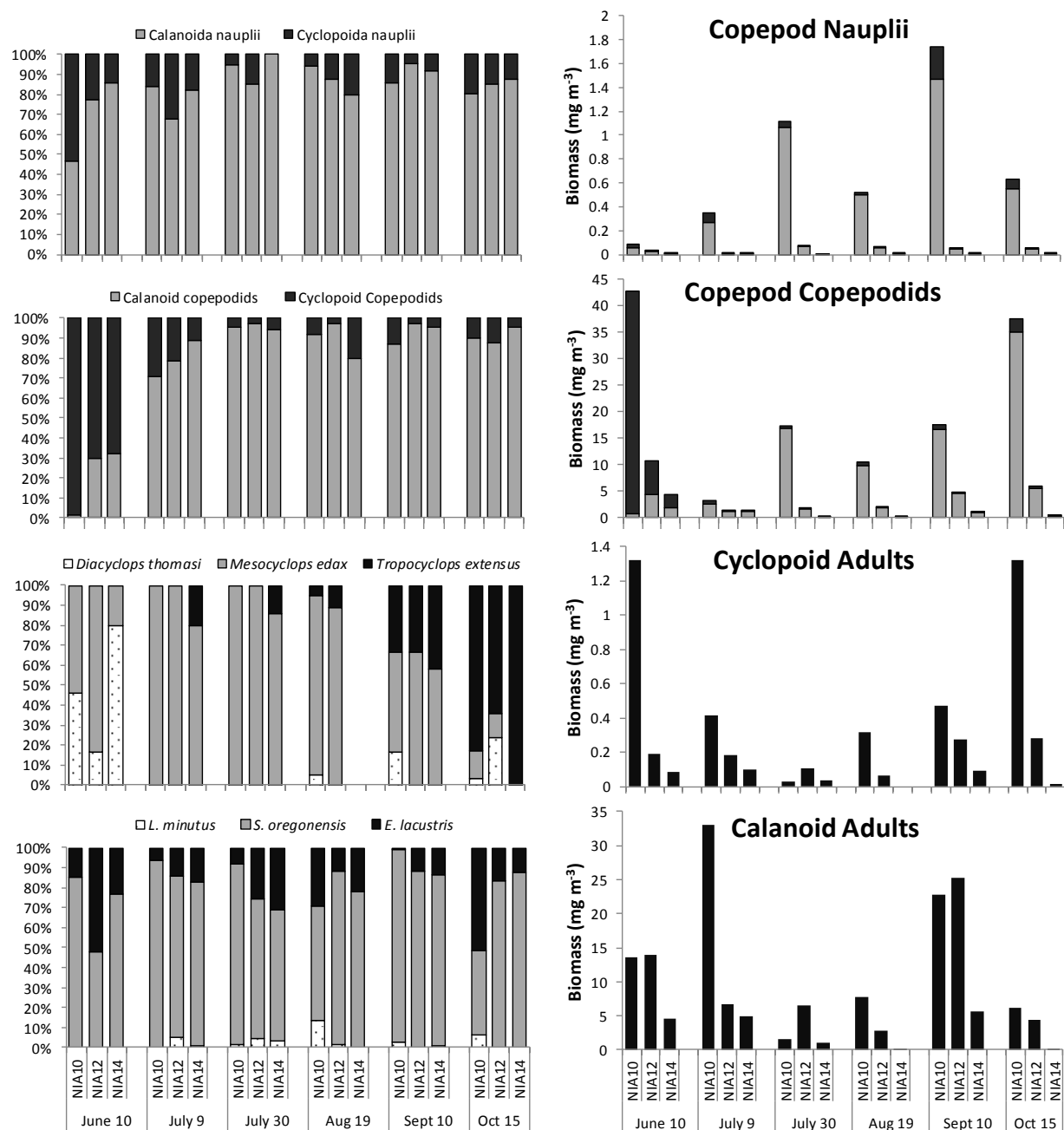
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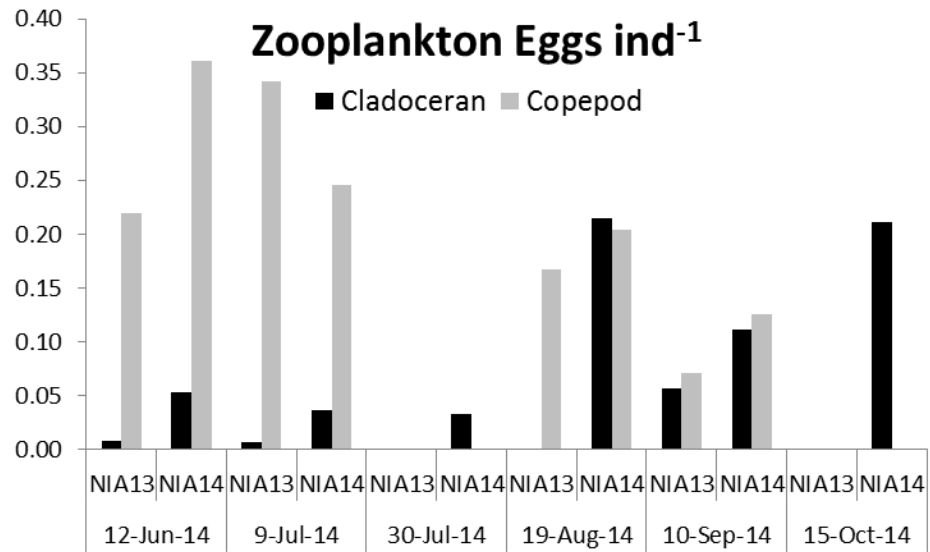
**Figure 12.** A) Zooplankton density ( $\text{No m}^{-3}$ ) and B) Zooplankton biomass ( $\text{mg m}^{-3}$ ) for major groups (see text).



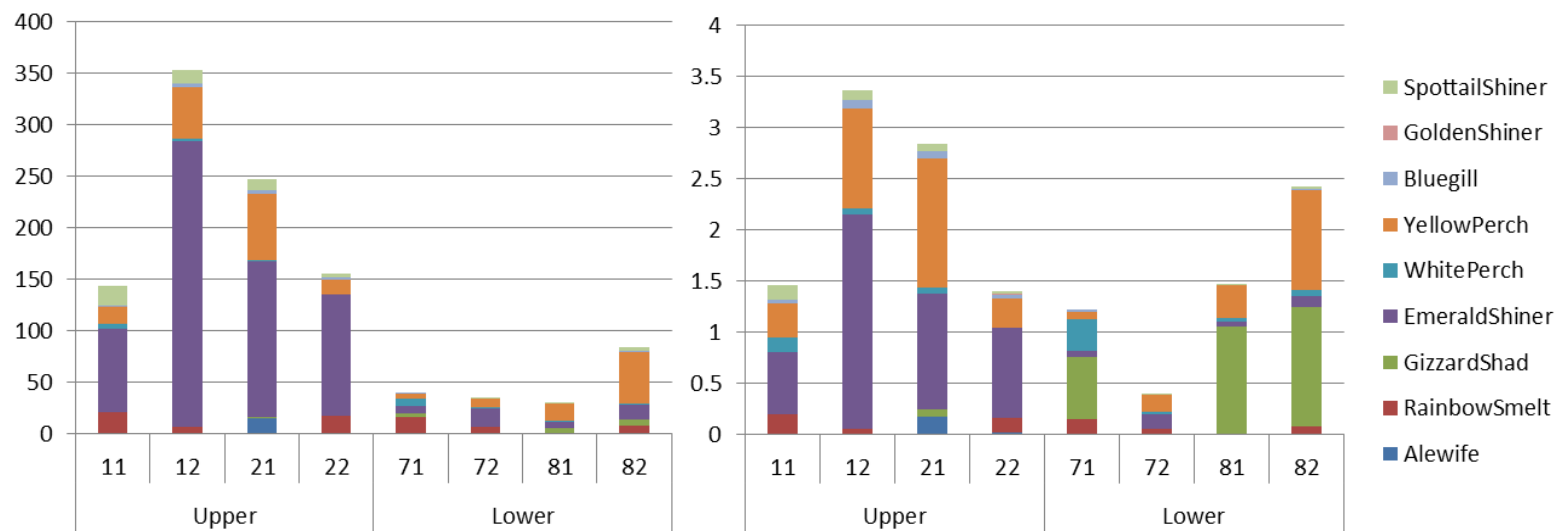
**Figure 13.** June to October seasonally weighted mean A) zooplankton biomass and B) density, by distance from Niagara River mouth. Grey arrows indicate deviation from the anticipated trend at NIA14 and NIA4 below the hydroelectric plant output (see text).



**Figure 14.** Proportions by density (left) and biomass (right) of dominant copepod taxa across the sampling season, including juvenile stages (nauplii and copepodids), adult cyclopoids and adult calanoids for Lake Erie (NIA10), upper (NIA12) and lower Niagara River (NIA14) stations by date. Calanoid copepodids dominated density and biomass at all stations except in June.



**Figure 15.** Cladoceran and copepod eggs per individual comparing the above turbine station (NIA13) and below turbine station (NIA14) for the Niagara River by date.



**Figure 16.** Density in catch per unit effort (CPUE) (left) and biomass as CPUE·Mass·1000 (right) for each species of planktivorous fishes at DFO electrofishing transect stations from the Canadian side of the upper and lower Niagara River in 2015 (DFO SAR database). Emerald Shiner comprise the dominant density and biomass in the upper river, but Gizzard Shad dominate the biomass of the lower river.

**Appendix 1.** Dates and sampling sites for sonde profiles.

Date	Station	Single Point	Transect
05-Jun-14	NR 15	✓	
	NIA15	✓	
	NIA16	✓	
	NIA17	✓	
	NIA18	✓	
10-Jun-14	NIA19	✓	
	NIA13	✓	
	NIA14	✓	
	NIA18	✓	✓
	NIA4	✓	✓
12-Jun-14	NIA19	✓	
	NOTL	✓	
	NIA10	✓	
	NIA11	✓	
	NIA15	✓	
09-Jul-14	NIA12	✓	✓
	NIA18	✓	✓
	NIA4	✓	✓
	NIA10	✓	
	NIA11	✓	
10-Jul-14	NIA15	✓	
	NIA12	✓	
	NIA17	✓	
	NIA18	✓	
	NIA13	✓	

Date	Station	Single Point	Transect
30-Jul-14	NIA10	✓	
	NIA11	✓	✓
	NIA15	✓	
	NIA12	✓	✓
	NIA13	✓	
19-Aug-14	NIA14	✓	
	NIA18	✓	✓
	NIA4	✓	✓
	NIA10	✓	
	NIA11	✓	
10-Sep-14	NIA15	✓	
	NIA12	✓	✓
	NIA13	✓	
	NIA14	✓	
	NIA18	✓	✓
15-Oct-14	NIA4	✓	✓
	NIA10	✓	
	NIA11	✓	
	NIA15	✓	
	NIA12	✓	✓
	NIA13	✓	
	NIA14	✓	
	NIA18	✓	✓
	NIA4	✓	✓
	NIA10	✓	



## Appendix 2. Individual Niagara River plankton survey station sonde profile data for 2014.

Station	Date	Sounding (m)	EXO					FluoroProbe				Hydrolab			
			Range (m)	Chl (µg L <sup>-1</sup> )	Turb (FNU)	Temp (°C)	Cond (µS/cm)	Range (m)	Green	Blue- Green	Total (µg L <sup>-1</sup> )	Range (m)	Temp (°C)	SpCond (µS/cm)	DO (mg L <sup>-1</sup> )
NIA10	12-Jun	9.1	0-8.27	1.22	-0.99	15.31	231.32	0-8.62	0.000	0.021	0.021				
	09-Jul	9.2	0-8.87	0.70	2.75	21.88	268.01	--	--	--	--				
	10-Jul	9.1	0-6-9.3	0.64	0.95	22.01	271.48	0-9.44	0.000	0.000	0.000				
	30-Jul	--	--	--	--	--	--	0-9	0.000	0.007	0.633				
	19-Aug	9	0-8-9.4	0.79	6.23	20.99	278.77	0-3-9	0.000	0.000	0.024	0-9	21.00	241.23	8.38
	10-Sep	8.2	0-8.5	0.21	-0.30	22.04	269.00	0-8.4	0.00	0.00	0.00	0-8.3	22.01	253.98	7.88
	15-Oct	8.7	0-8.7	0.23	1.40	16.32	224.00	0-5.4	0.00	0.46	0.93	0-9.3	16.27	235.75	9.64
NIA11	12-Jun	6	0-4.9	1.06	-0.55	15.02	235.00	0-4.96	0.000	0.063	0.094				
	09-Jul	8.4	0-7.32	0.53	2.67	21.89	267.38	--	--	--	--				
	10-Jul	7.1	0-6.7	0.32	-0.03	22.07	273.29	0-6.69	0.000	0.001	0.001				
	30-Jul	--	0-5	0.41	0.12	21.15	278.82	0-4.6	0.080	0.000	0.520				
	19-Aug	--	0-9-4	0.78	0.09	21.09	275.38	0-2-3.5	0.503	0.193	1.573	0-8.5	20.99	185.85	8.54
	10-Sep	5.6-8.7	0-9.1	0.15	-1.79	22.06	268.47	0-8.8	0.00	0.00	0.00	0-7.6	22.04	253.12	7.79
	15-Oct	7.6	0-8.6	0.14	1.67	16.28	224.01	0-4.8	0.00	0.41	0.82	0-7.8	16.24	233.97	9.21
NIA12	12-Jun	5.2	0-5.11	0.73	-0.75	16.20	240.00	0-5.32	0.000	0.000	0.000				
	09-Jul	5.7	0-5.61	1.11	2.51	22.05	269.84	--	--	--	--				
	10-Jul	5.6	0-5.5	0.42	0.21	22.23	270.91	0-5.59	0.000	0.000	0.000				
	30-Jul	--	0-6	0.39	-0.10	21.51	279.47	0-5.8	0.069	0.025	0.427				
	19-Aug	5	0-1-6	0.27	-0.16	21.24	273.94	0-3-4.9	0.000	0.014	0.014	0-6	21.24	222.78	8.12
	10-Sep	4.8	0-5.9	0.02	-1.33	22.14	268.00	0-0.5	0.00	0.00	0.00	0-5.2	22.12	253.00	7.68
	15-Oct	5.3	0-5.6	0.60	2.80	16.23	223.00	0-8.8	0.00	0.22	0.98	0-5.6	16.17	235.34	9.83
NIA13	10-Jun	16-18	0-7-2.5	0.37	1.74	16.10	240.00	--	--	--	--				
	09-Jul	15.9	--	--	--	--	--	--	--	--	--				
	30-Jul	--	0-12.3	0.41	1.89	21.50	278.62	0-11	0.166	0.034	0.548				
	19-Aug	17.8	--	--	--	--	--	0-4-12	0.000	0.000	0.000	--	--	--	--
	10-Sep	17.6	0-13.4	0.07	0.05	22.32	270.00	0-12.9	0.00	0.00	0.00	0-7.6	22.29	248.20	9.66
	15-Oct	17.4	0-12.3	-0.04	2.53	16.38	225.00	n/a	0.179	0.393	1.039	0-10.5	16.43	190.58	11.10
NIA14	10-Jun	22-30	--	--	--	--	--	--	--	--	--				
	09-Jul	40	--	--	--	--	--	--	--	--	--				
	30-Jul	--	0-7.8	0.59	1.96	21.54	279.68	0-7.7	0.125	0.034	0.800				
	19-Aug	13.8	--	--	--	--	--	0-6-5.6	0.000	0.024	0.024	--	--	--	--
	10-Sep	25	0-10	0.21	-0.02	22.37	270.92	--	--	--	--	0-6.1	22.87	146.23	8.36
	15-Oct	18	0-6.2	0.16	2.08	16.32	226.00	n/a	0.00	0.38	1.32	0-12.7	16.61	156.59	10.20
NIA15	05-Jun	2	0-1.56	0.56	0.82	14.45	234.18	--	--	--	--				
	12-Jun	--	0-3.4	0.90	-0.13	15.14	235.24	0-3.64	0.000	0.010	0.010				
	09-Jul	--	0-3.85	0.56	3.28	21.90	268.00	--	--	--	--				
	10-Jul	--	0-3.7	0.34	0.31	22.15	272.89	0-3.7	0.000	0.000	0.000				
	30-Jul	--	0-3.7	0.61	0.19	21.28	277.55	0-3.4	0.320	0.000	0.780				
	19-Aug	--	0-1-3.5	0.58	2.40	21.39	276.00	0-2-3.4	0.000	0.096	0.255	--	--	--	--
	10-Sep	4.3	0-3.7	0.23	-1.54	22.08	268.00	0-3.6	0.00	0.00	0.00	--	--	--	--
NIA16	05-Jun	--	0-0.6	0.91	3.44	16.30	246.99	--	--	--	--				
NIA17	05-Jun	2	0-2.82	1.06	12.27	17.12	276.14	--	--	--	--				
	10-Jul	3-4	--	--	--	--	--	0-3.31	0.487	0.472	2.139				
NIA18	05-Jun	2	0-1.12	1.27	6.84	15.86	246.00	--	--	--	--				
	10-Jun	--	--	--	--	--	--	0-1.51	0.000	0.003	0.003				
	12-Jun	--	0-0.5	2.01	1.78	16.30	232.33	1.14-0	0.055	0.092	0.218				
	10-Jul	--	0-0.5	50.99	35.07	22.54	276.99	--	--	--	--				
NIA19	05-Jun	1.5	0-0.73	0.30	2.19	15.88	245.26	--	--	--	--				
	10-Jun	--	--	--	--	--	--	1-2.44	0.000	0.038	0.038				
NIA4	10-Jun	14.6	--	--	--	--	--	--	--	--	--				
	09-Jul	13.1	1.3-14.8	0.72	5.27	22.17	278.30	--	--	--	--				
	30-Jul	--	0-13	0.59	2.04	21.55	280.36	0-12.7	0.137	0.005	0.712				
	19-Aug	--	--	--	--	--	--	0.39-15	0.000	0.000	0.000	0-14.7	21.51	207.81	8.95
	10-Sep	13-14.8	--	--	--	--	--	0-11.4	0.00	0.00	0.00	0-13.9	22.37	226.65	8.60
	15-Oct	14	0-14.6	0.24	2.48	16.33	226.00	0-12.4	0.00	0.05	0.05	0-14.2	16.35	229.59	10.31
NOTL	10-Jun	--	--	--	--	--	--	0-18.67	0.000	0.041	0.041				
NR 15	05-Jun	--	0-1.09	23.95	2.53	13.85	230.62	--	--	--	--				

### Appendix 3. Niagara River station NLET water chemistry by date.

Date	Station	Chl. a µg.L <sup>-1</sup>	TP µg.L <sup>-1</sup>	SRP µg.L <sup>-1</sup>	TKN mg.L <sup>-1</sup>	NO <sub>3</sub> +NO <sub>2</sub> <sup>-</sup> mg.L <sup>-1</sup>	NH <sub>3</sub> mg.L <sup>-1</sup>	POC mg.L <sup>-1</sup>	PON mg.L <sup>-1</sup>	DIC mg.L <sup>-1</sup>	DOC mg.L <sup>-1</sup>	SiO <sub>2</sub> mg.L <sup>-1</sup>	Na <sup>+</sup> mg.L <sup>-1</sup>	Mg <sup>+2</sup> mg.L <sup>-1</sup>	K <sup>+</sup> mg.L <sup>-1</sup>	Ca <sup>+2</sup> mg.L <sup>-1</sup>
Jun-06	NIA10	0.835	11.9	0.7	0.244	0.256	0.013	0.195	0.034	21.1	2.8	0.33	12.4	8.95	1.58	34.2
	NIA12	1.006	13.1	1.9	0.224	0.245	0.018	0.141	0.023	20.7	2.5	0.32	12.4	8.96	1.59	34.2
	NIA13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	NIA4	1.693	15.3	1.7	0.284	0.310	0.018	0.289	0.051	21.3	2.7	0.40	12.9	8.89	1.59	33.9
Jul-09	NIA10	1.710	755.0	772.0	0.261	0.144	0.019	0.285	0.045	21.2	41.6	0.47	11.1	8.60	1.69	33.5
	NIA12	1.680	19.2	9.9	0.273	0.165	0.030	0.298	0.049	21.0	2.5	0.46	10.8	8.66	1.61	33.3
	NIA13	2.499	25.3	9.8	0.255	0.181	0.025	0.288	0.046	20.9	2.6	0.46	10.9	8.62	1.60	33.4
	NIA4	1.925	19.5	6.8	0.265	0.195	0.039	0.349	0.055	21.0	2.6	0.54	11.8	8.66	1.63	33.6
Jul-30	NIA10	1.172	13.5	2.8	0.225	0.187	0.014	0.182	0.028	21.7	2.9	0.49	11.4	8.86	1.52	34.2
	NIA12	0.490	7.8	2.9	0.221	0.182	0.017	0.136	0.018	21.6	2.9	0.48	11.3	8.82	1.50	34.0
	NIA13	0.711	18.5	5.7	0.245	0.192	0.027	0.163	0.021	21.5	2.7	0.53	11.4	8.73	1.52	33.8
	NIA4	1.140	23.5	11.1	0.285	0.196	0.039	0.341	0.047	21.6	2.9	0.53	11.5	8.74	1.55	33.9
Aug-19	NIA10	1.162	13.5	3.3	0.260	0.144	0.012	0.229	0.038	22.4	2.6	0.39	11.1	8.95	2.18	33.9
	NIA12	0.801	16.1	8.5	0.421	0.139	0.019	0.172	0.028	22.3	2.3	0.36	10.8	8.93	1.63	33.7
	NIA13	0.974	12.6	3.8	0.271	0.144	0.015	0.206	0.031	22.2	2.5	0.38	11.1	8.88	1.58	33.5
	NIA4	1.297	13.7	4.4	0.262	0.154	0.022	0.275	0.042	22.6	2.5	0.39	11.1	8.96	1.61	33.9
Sep-10	NIA10	1.309	24.3	12.9	0.255	0.092	0.020	0.278	0.048	22.3	2.6	0.34	10.5	9.03	1.46	34.4
	NIA12	1.031	13.3	5.8	0.250	0.095	0.021	0.160	0.024	22.2	2.5	0.26	10.4	9.05	1.46	34.3
	NIA13	1.192	9.4	2.4	0.249	0.098	0.016	0.206	0.028	22.0	2.5	0.28	10.4	9.02	1.46	34.2
	NIA4	1.579	10.9	2.2	0.252	0.105	0.019	0.213	0.031	22.2	2.5	0.31	10.6	9.03	1.47	34.4
Oct-15	NIA10	1.665	12.8	6.0	0.239	0.111	0.025	0.698	0.047	22.9	2.4	0.43	10.5	8.88	1.56	33.8
	NIA12	1.194	12.8	6.7	0.232	0.109	0.024	0.601	0.053	22.7	2.3	0.37	10.3	8.78	1.54	33.5
	NIA13	1.215	19.1	13.1	0.251	0.116	0.023	0.651	0.044	22.7	2.5	0.38	10.4	8.78	1.56	33.5
	NIA4	1.527	24.4	13.8	0.250	0.129	0.029	0.726	0.073	22.9	2.3	0.42	10.8	8.91	1.57	33.9
Mean ± SE	NIA10	1.31±0.14	15.2±2.3	5.14±2.1	0.247±0.006	0.156±0.024	0.017±0.002	0.31±0.08	0.040±0.003	21.9±0.3	2.66±0.09	0.41±0.03	11.2±0.2	8.88±0.06	1.67±0.11	33.9±0.1
	NIA12	1.03±0.16	13.7±1.6	5.95±1.3	0.270±0.031	0.156±0.022	0.022±0.002	0.25±0.07	0.033±0.006	21.8±0.3	2.50±0.09	0.38±0.03	11.0±0.3	8.87±0.06	1.56±0.03	33.9±0.2
	NIA13	1.32±0.31	17.0±2.8	6.96±2.0	0.254±0.004	0.146±0.018	0.021±0.002	0.30±0.09	0.034±0.005	21.9±0.3	2.56±0.04	0.41±0.04	10.8±0.2	8.81±0.07	1.54±0.02	33.8±0.2
	NIA4	1.53±0.11	17.9±2.2	6.67±2.0	0.266±0.006	0.182±0.030	0.028±0.004	0.37±0.07	0.050±0.006	21.9±0.3	2.58±0.08	0.43±0.04	11.5±0.3	8.87±0.06	1.57±0.02	34.0±0.1
Mean ± SE	FE *		14.7±2.2	1.94±0.5	0.31±0.011	0.166±0.017	0.024±0.002			21.3±0.2	2.62±0.05	0.47±0.05	11.2±0.3	8.75±0.04	1.55±0.01	33.4±0.2
	NOTL*		26.0±6.9	3.88±0.4	0.33±0.000	0.179±0.014	0.022±0.002			21.9±0.2	2.61±0.03	0.48±0.04	11.0±0.2	8.75±0.04	1.54±0.02	33.4±0.2

\* Environment Canada Niagara River Monitoring Program sampled weekly June-Oct, 2014 for upper river Fort Erie (FE) and lower river Niagara-on-the-Lake (NOTL) stations.

**Appendix 4.** Niagara River phytoplankton species biomass (mg m<sup>-3</sup>) by station and date.  
Taxonomic groups are: (1) Cyanophyta, (2) Chlorophyta, (3) Euglenophyta, (4) Chrysophyta, (5) Bacillariophyta, (6) Cryptophyta, (7) Dinophyceae.

### **NIA10**

<b>Group</b>	<b>Name</b>	<b>July 9</b>	<b>July 30</b>	<b>Aug 19</b>	<b>Sept 10</b>	<b>Oct 15</b>
<b>1</b>	<i>Anabaena lemmermannii</i>			10.22		
	<i>Aphanizomenon flos-aquae</i>			8.51		
	<i>Aphanocapsa delicatissima</i>	0.13	0.30	2.08	2.76	1.39
	<i>Aphanocapsa elachista</i>			0.11	0.03	
	<i>Aphanocapsa holsatica</i>		0.56	0.88	0.67	0.22
	<i>Aphanocapsa incerta</i>				1.37	
	<i>Aphanothece nidulans</i>		1.09	0.89	6.04	0.12
	<i>Cylindrospermopsis raciborskii</i>		0.54			
	<i>Microcystis aeruginosa</i>					0.11
	<i>Pseudanabaena galeata</i>		0.26			18.28
	<i>Pseudanabaena limnetica</i>	1.38	2.74	0.36	4.63	
	<i>Pseudanabaena mucicola</i>		0.29			
	<i>Synechococcus elongatus</i>	0.03			0.05	
	<i>Synechococcus</i> sp 1	0.05	0.49	5.17	2.42	
	<i>Synechocystis</i> sp.					1.11
	Unknown Cyanophyte	1.78	2.59	3.78	5.86	0.98
<b>2</b>	<i>Ankistrodesmus falcatus</i>			0.36		
	<i>Chlamydomonas</i> sp.	0.33	0.43	2.80	3.31	5.19
	<i>Coelastrum microporum</i>		2.05		0.63	
	<i>Coelastrum pseudomicroporum</i>		0.69			
	<i>Monomastix minuta</i>				0.28	
	<i>Monoraphidium arcuatum</i>	0.44				1.89
	<i>Monoraphidium capricornutum</i>	2.86	0.18	0.12	0.42	
	<i>Oocystis parva</i>	0.88	3.55			
	<i>Scenedesmus bijuga</i>		0.08	0.36	0.62	1.24
	<i>Scenedesmus quadricauda</i>		0.11		0.38	
	<i>Scenedesmus serratus</i>					0.03
	<i>Sphaerocystis schroeteri</i>	13.16				
	<i>Stichococcus bacillaris</i>			0.10		
	Unknown Chlorophyte	0.04	0.10	1.06	5.08	2.06
<b>4</b>	<i>Chromulina</i> sp.	1.05	0.44	0.78	0.55	0.11
	<i>Chrysochromulina parva</i>	1.31	0.25	3.45	1.76	1.97
	<i>Dinobryon</i> sp.	15.76	1.53		3.06	1.23
	<i>Dinobryon bavaricum</i>			0.08		
	<i>Dinobryon sertularia</i>			1.48		
	<i>Dinobryon sociale americana</i>		0.58			
	<i>Mallomonas</i> sp.		3.63			
	<i>Ochromonas</i> sp.			24.70	0.36	
	Unknown Chrysophyte					0.96
	<i>Uroglena</i> sp.				1.32	1.18
<b>5</b>	<i>Achnanthes minutissima</i>	0.64				
	<i>Asterionella formosa</i>		0.93			
	<i>Aulacoseira crenulata</i>					2.78
	<i>Aulacoseira muzzanensis</i>	13.16				
	<i>Cocconeis pediculus</i>		18.10			
	<i>Cyclotella atomus</i>			0.38	5.21	2.10
	<i>Cyclotella comensis</i>	0.89			2.25	11.97
	<i>Cyclotella comensis</i> 1	5.16	0.52	1.05	3.14	1.33

	<i>Cyclotella ocellata</i>				2.20	6.76
	<i>Cyclotella pseudostelligera</i>	1.40	0.38	0.38		
	<i>Fragilaria crotonensis</i>			39.83	6.56	54.32
	<i>Navicula cryptotenella</i>	3.84				
	<i>Nitzschia gracilis</i>			2.66		
	<i>Nitzschia intermedia</i>	9.46				
	<i>Nitzschia palea</i>			1.44		
	<i>Nitzschia recta</i>	11.23	4.37			11.07
	<i>Rhoicosphenia curvata</i>				4.19	
	<i>Stephanodiscus alpinus</i>		18.14			32.77
	<i>Stephanodiscus medius</i>		12.31	12.85		
	<i>Stephanodiscus parvus</i>	11.91				
	<i>Synedra filiformis</i>		0.74			
<b>6</b>	<i>Cryptomonas erosa</i>	1.70				23.34
	<i>Rhodomonas minuta</i>		1.44		1.03	1.71
	<i>Rhodomonas minuta nannoplanctica</i>	10.94	12.57	28.73	23.82	20.52
<b>7</b>	<i>Gymnodinium</i> sp 2				1.79	
<b>Total</b>		<b>109.52</b>	<b>91.99</b>	<b>154.60</b>	<b>91.78</b>	<b>206.74</b>

### **NIA13**

	<b>Name</b>	<b>July 9</b>	<b>July 30</b>	<b>Aug 19</b>	<b>Sept 10</b>	<b>Oct 15</b>
<b>1</b>	<i>Aphanocapsa delicatissima</i>			0.17	0.35	0.19
	<i>Aphanocapsa elachista</i>		0.07	0.60		0.03
	<i>Aphanocapsa holsatica</i>			0.97		
	<i>Aphanocapsa incerta</i>			0.50	0.92	
	<i>Aphanothece nidulans</i>				0.65	0.39
	<i>Chroococcus minimus</i>				0.32	
	<i>Lyngbya</i> sp.		16.19			
	<i>Lyngbya birgei</i>				450.24	
	<i>Microcystis aeruginosa</i>				11.26	
	<i>Phormidium</i> sp.					0.44
	<i>Pseudanabaena</i> sp.		2.30	0.83	0.18	0.04
	<i>Pseudanabaena galeata</i>					4.16
	<i>Pseudanabaena limnetica</i>		2.07	0.77	0.56	0.52
	<i>Synechococcus elongatus</i>		0.10			
	<i>Synechococcus</i> sp 1	0.77	1.72	1.32	1.58	0.06
	<i>Synechocystis</i> sp.		0.03	0.08	0.65	0.10
	Unknown Cyanophyte	0.62	3.69	1.47	1.70	1.11
<b>2</b>	<i>Chlamydomonas</i>	5.47	0.10	1.19		2.46
	<i>Coelastrum microporum</i>					1.05
	<i>Lagerheimia quadriseta</i>					0.28
	<i>Monoraphidium capricornutum</i>	0.15	0.12	0.08	0.17	0.06
	<i>Scenedesmus bijuga</i>		1.42			0.56
	<i>Scenedesmus denticulatus</i>			0.23		
	<i>Scenedesmus quadricauda</i>					0.27
	<i>Scenedesmus serratus</i>				0.11	
	Unknown Chlorophyte	0.64	0.59	0.66	1.09	0.06
<b>3</b>	<i>Euglena</i> sp.				4.64	
<b>4</b>	<i>Chromulina</i> sp.	0.28	0.13		0.40	
	<i>Chrysochromulina parva</i>	1.85		1.06	0.37	0.25
	<i>Dinobryon</i> sp.	1.54				
	<i>Mallomonas</i> sp.				1.06	0.96
	<i>Ochromonas</i> sp.			2.93	0.28	

5	<i>Achnanthes delicatula</i>					0.15
	<i>Achnanthes minutissima</i>	2.08				0.71
	<i>Cocconeis neodiminuta</i>	0.76				
	<i>Cocconeis pediculus</i>	35.47	2.94	2.75		
	<i>Cocconeis placentula lineata</i>	6.09	11.07	1.72	3.42	
	<i>Cyclotella atomus</i>				1.24	0.43
	<i>Cyclotella comensis</i>	3.81				
	<i>Cyclotella ocellata</i>					0.79
	<i>Cymbella caespitosa</i>					1.99
	<i>Diatoma vulgaris vulgaris</i>					9.25
	<i>Fragilaria capucina vaucheriae</i>			1.58		
	<i>Fragilaria construens</i>		14.18			
	<i>Fragilaria crotonensis</i>	11.08				16.76
	<i>Gomphonema olivaceum</i>	10.38				
	<i>Gomphonema parvulum</i>				0.51	
	<i>Navicula cryptotenella</i>		1.77	0.88	1.42	0.27
	<i>Navicula pupula</i>					1.39
	<i>Navicula salinarum</i>				4.56	
	<i>Navicula tripunctata</i>		8.51			
	<i>Navicula viridula rostellata</i>			4.73		1.32
	<i>Nitzschia dissipata</i>					3.70
	<i>Nitzschia gracilis</i>			2.47		
	<i>Nitzschia palea</i>			0.91		1.00
	<i>Nitzschia perminuta</i>					0.46
	<i>Nitzschia recta</i>		9.37		4.26	2.02
	<i>Stephanodiscus parvus</i>	3.94				
	<i>Synedra filiformis</i>					0.67
6	<i>Cryptomonas erosa</i>		3.08	2.53	0.59	0.85
	<i>Rhodomonas minuta</i>		1.44	1.03	2.06	
	<i>Rhodomonas minuta</i>	5.13	9.23	12.82	8.79	3.85
	<i>nannoplantica</i>					
7	<i>Gymnodinium</i> sp 2					1.05
	<i>Gymnodinium</i> sp 3	3.08				
<b>Total</b>		<b>93.13</b>	<b>90.12</b>	<b>44.30</b>	<b>503.38</b>	<b>59.66</b>

#### NIA4

	Name	July 9	July 30	Aug 19	Sept 10	Oct 15
1	<i>Aphanocapsa delicatissima</i>			0.28	0.30	0.23
	<i>Aphanocapsa elachista</i>			2.43	0.06	0.02
	<i>Aphanocapsa holsatica</i>		1.00	1.40	0.80	0.19
	<i>Aphanothece nidulans</i>		0.64	0.41	3.21	0.72
	<i>Heteroleibleinia</i> sp.				13.86	
	<i>Merismopedia punctata</i>				5.11	
	<i>Oscillatoria</i> sp.				2.67	
	<i>Pseudanabaena</i> sp.			0.16	0.18	0.40
	<i>Pseudanabaena acicularis</i>				1.13	
	<i>Pseudanabaena galeata</i>					10.22
	<i>Pseudanabaena limnetica</i>		1.11		0.42	1.50
	<i>Pseudanabaena mucicola</i>		0.66			
	<i>Synechococcus elongatus</i>	0.06	4.01	0.14	0.06	
	<i>Synechococcus</i> sp 1	0.37	1.74	0.62	2.28	0.26
	<i>Synechocystis</i> sp.			1.35	0.48	0.06
	Unknown Cyanophyte	1.72	2.74	4.31	2.26	0.76

2	<i>Chlamydomonas</i> sp.	0.30	0.27	14.56	7.13	1.22
	<i>Chlorogonium</i> sp.				0.34	
	<i>Coelastrum microporum</i>			6.65	1.14	
	<i>Lagerheimia quadriseta</i>				0.05	
	<i>Monomastix minuta</i>					0.14
	<i>Monoraphidium arcuatum</i>					0.50
	<i>Monoraphidium capricornutum</i>		0.10	0.15	0.18	
	<i>Oocystis parva</i>				0.20	1.27
	<i>Pyramichlamys dissecta</i>				3.18	
	<i>Scenedesmus bijuga</i>			0.93	0.25	0.72
	<i>Scenedesmus denticulatus</i>					1.90
	<i>Scenedesmus quadricauda</i>			0.40		
	<i>Scenedesmus serratus</i>				0.18	0.22
	<i>Stichococcus bacillaris</i>	0.09			0.05	
	<i>Tetracystis pulchra</i>					16.45
	Unknown Chlorophyte	0.54	0.43	14.41	3.71	0.38
4	<i>Chromulina</i> sp.	0.04	1.11	0.28	0.11	
	<i>Chrysochromulina parva</i>	1.31	0.41	1.85	1.72	0.70
	<i>Dinobryon</i> sp.		2.14		1.18	
	<i>Mallomonas</i> sp.			5.03	1.02	
	<i>Ochromonas</i> sp.			75.89	4.02	
	Unknown Chrysophyte			3.74		
	<i>Uroglena</i> sp.					3.11
5	<i>Achnanthes minutissima</i>				1.33	
	<i>Cocconeis pediculus</i>	48.70	14.19			18.99
	<i>Cocconeis placentula lineata</i>		2.13	1.30	0.64	
	<i>Cyclostephanos invisitatus</i>			4.16		1.22
	<i>Cyclotella atomus</i>				1.77	0.14
	<i>Cyclotella comensis</i>		1.31		3.15	0.47
	<i>Cyclotella comensis 1</i>	2.66		1.66	0.33	
	<i>Cyclotella michiganiana</i>			2.13	1.54	
	<i>Cyclotella ocellata</i>	1.41				4.11
	<i>Fragilaria crotonensis</i>			162.14		
	<i>Gomphonema pumilum</i>	1.29				
	<i>Navicula</i> sp.			0.51		
	<i>Navicula cryptotenella</i>			1.23	1.83	
	<i>Nitzschia heufleriana</i>	21.42				
	<i>Nitzschia palea</i>			1.80	1.97	0.81
	<i>Nitzschia recta</i>	2.30				
	<i>Skeletonema potamos</i>	12.26	21.75	0.87	8.62	
	<i>Stephanodiscus alpinus</i>					59.36
	<i>Stephanodiscus binderanus</i>			38.47		
	<i>Stephanodiscus medius</i>					7.42
6	<i>Cryptomonas erosa</i>	7.11		4.43	5.25	2.89
	<i>Rhodomonas minuta</i>				0.72	2.06
	<i>Rhodomonas minuta nannoplantica</i>	6.84	6.41	4.49	11.80	6.23
7	<i>Gymnodinium</i> sp 2				2.66	
	<i>Peridinium umbonatum</i>					1.28
<b>Total</b>		<b>108.77</b>	<b>62.16</b>	<b>358.17</b>	<b>99.66</b>	<b>145.95</b>