NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

# 2018 FINGER LAKES WATER QUALITY REPORT

## Summary of Historic Finger Lakes Data and the 2017-2018 Citizens Statewide Lake Assessment Program

November 2019


**Division of Water (DOW)**

**Finger Lakes Watershed Hub (FLWH)**

**615 Erie Boulevard, Syracuse, NY**

**Lake Monitoring and Assessment Section (LMAS)**

**625 Broadway, Albany, NY**


**www.dec.ny.gov**

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# Acknowledgements

The New York State Department of Environmental Conservation's (NYSDEC) Citizens Statewide Lake Assessment Program's (CSLAP's) expansion into the Finger Lakes was made possible by funding from the NYS Environmental Protection Fund-Ocean and Great Lakes Program. This funding allowed 22 sites on the 11 Finger Lakes to be added to the program in the spring of 2017. The program increased in 2018, with 6 additional sites on three of the largest lakes, Seneca, Cayuga, and Keuka. CSLAP in the Finger Lakes has allowed the NYSDEC to: (1) collect critical water quality data on these important natural resources, (2) assess contemporary water quality in the Finger Lakes in the context of recent and continuing water quality concerns, (3) make comparisons of the water quality between the lakes in 2017 and 2018, and (4) continue preliminary trend analyses for individual lakes over time.

A program as comprehensive as CSLAP does not function without the efforts of many hardworking and dedicated individuals. Many thanks to the NYS Federation of Lake Associations, Inc. (NYSFOLA), including manager of NYSFOLA and co-coordinator of CSLAP, Nancy Mueller. Since 2000, Nancy has served as the Assistant Program Coordinator and ensured day-to-day operation of the program. Also, the authors would like to express our appreciation to the entire NYSFOLA board of directors, Lou Feeney, Jan Andersen, and others for working with NYSDEC over the past three decades to shape CSLAP into one of the most successful citizen science programs in the country.

All the chemical analyses for CSLAP have been conducted at Upstate Freshwater Institute (UFI) since 2000. UFI has been incredibly accommodating during their tenure as the CSLAP laboratory, especially in its expansion to the Finger Lakes in 2017 and 2018.

All the contemporary data presented in this report was collected by volunteers. The CSLAP program would not exist if it weren't for the hundreds of volunteers that generously and tirelessly donate their time and resources in efforts to improve and preserve their lakes and watersheds. The NYSDEC would like to thank the lake associations of the Finger Lakes (below) for working with the Department as we continue to support CSLAP in the Finger Lakes.

- Conesus Lake Association
- City of Rochester (Hemlock and Canadice Lakes)
- Honeoye Valley Association and the Honeoye Lake Watershed Taskforce
- Canandaigua Lake Watershed Association
- Keuka Lake Association
- Seneca Lake Pure Waters Association
- Cayuga Lake Watershed Network
- Owasco Watershed Lake Association
- Skaneateles Lake Association
- Otisco Lake Preservation Association

Lastly, thank you to the NYSDEC Lake Management and Assessment Section (LMAS) and the Section Chief, Scott Kishbaugh, who has worked as the CSLAP program manager since 1986. CSLAP would not be the premier citizen science monitoring program that it is today without his hard work and dedication to improving the water quality of NYS lakes. In 2019, Scott retired from the NYSDEC. His tireless efforts laid the foundation for CSLAP and will allow us to continue this important program into the future.

## 2018 CSLAP Volunteers by Lake

| | |
|---|---|
| *Conesus Lake* | Chris Willoughby, Mike Parker, Ellen Hanafin, Karl Hanafin |
| *Hemlock Lake* | John Maier, Kathy Witzel, Britt Vanno, Dave Rowley, Greg Whitney |
| *Canadice Lake* | John Maier, Kathy Witzel, Britt Vanno, Dave Rowley, Greg Whitney |
| *Honeoye Lake* | Terry Gronwall, Dorothy Gronwall |
| *Canandaigua Lake* | Saralinda Hooker, Albert and Deirdre Crofton, Pamela Hart, Brendan Brady, Lindsay McMillan, Nadia Harvieux, and Rob Gray |
| *Keuka Lake* | Maria Hudson, Scott Drake, Stan Martin, Thom Love |
| *Seneca Lake* | Addison and Diane Mason, Jacob and Karen Welch, Larry and Susan Martin, Dan and Laurie Corbett, David Youst, Charles and Peter Hornsberger, Brian and Patricia Cusimano, Edward and Mary Ann Marks, Sayre Fulkerson |
| *Cayuga Lake* | Tom Casella, William Ebert, Don Sargent,<br>Shannon Barrett, Corinne Klohmann, Franny Lux, and Ed and Nancy Currier |
| *Owasco Lake* | Kate and Brian Brundage, Mark and Michelle Plis, Jeff Calkins |
| *Skaneateles Lake* | Barbara Delmonico, Bill Dean, Bob Dean, Jed Delmonico, Buzz Roberts, Deb Hole, Gretchen Roberts, Rich Hole |
| *Otisco Lake* | Jennifer Griffin and Ben Hardwick |

# Executive Summary

NYSDEC is responsible for reporting on the condition of water resources in New York State (NYS), including more than 16,000 lakes, ponds, and reservoirs, to meet state and federal monitoring requirements and address multiple data needs. Most lake management activities are locally-led initiatives in NYS but require collaboration between engaged lake residents and government officials to effectively evaluate and manage water quality problems.

The Citizens Statewide Lake Assessment Program (CSLAP) is a partnership between NYSDEC, NYSFOLA, and lake residents who help monitor and collect critical lake data in a manner consistent with other NYS programs. This information is used to understand individual lake conditions, to develop lake management plans, and to assist NYSDEC in meeting elements of its water quality reporting requirements under the Federal Clean Water Act (CWA) and NYS Environmental Conservation Law (ECL).

CSLAP volunteers monitored twenty-eight locations on the eleven Finger Lakes in the summer of 2018. Field data, user perception observations, and water quality samples including indicators of harmful algal blooms (HABs) were collected. Lake trophic state was evaluated and specialized forms of dissolved nutrients were successfully monitored on all lakes. Quality control results with paired field duplicate samples showed acceptable comparability between volunteers and NYSDEC staff, providing assurance that the data collected through CSLAP is of sufficient quality to aid NYSDEC in making accurate water quality assessments and management decisions.

In 2018, the Finger Lakes represented a moderate cross-section of the range of water quality conditions in NYS as compared to other CSLAP lakes (see Section 4, subsequently). The eleven Finger Lakes tended to have better water quality, compared with smaller lakes in the Finger Lakes region. Compared with other NYS CSLAP lakes in 2018 (Table E1), the Finger Lakes tended to have:

1. below average concentrations for total phosphorus, chlorophyll-a, and color;
2. clarity (Secchi depth) levels above average;
3. nitrogen concentrations below average in the western Finger Lakes and higher than average nitrogen concentrations in the eastern Finger Lakes;
4. higher than average chloride, calcium, pH, and specific conductivity; and

Phosphorus exhibited a strong, positive correlation with chlorophyll-a and an inverse correlation with Secchi disk depth in 2018. The relationship between these two metrics of water quality was similar to the relationship developed with NYSDEC data in the late 1990s for these lakes and with 2017 Finger Lake CSLAP data. Nitrogen to phosphorus ratios were high (> 20) for the mesotrophic and oligotrophic lakes for most observations. There were times, seasonally, for several lakes in which the ratio dropped below the threshold for P limitation. The N:P ratio for the eutrophic lakes suggested that either N or P could limit algal growth in these systems.

Table E1. Comparison of the Finger Lakes Relative to NYS Average Values for Key Water Quality Indicators in 2018.

| Lake | Current Trophic State | Total Phosphorus TP | Chlorophyll-a Chl-a | Secchi Disk Depth SD | Total Nitrogen TN | Oxidized Dissolved N $NO_X$ | Ammonia $NH_3$ | Calcium $Ca^{2+}$ | Chloride $Cl^-$ | pH | Color |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2018 NYS CSLAP** | Average | 0.021 | 8.66 | 3.3 | 0.536 | 0.041 | 0.047 | 15.8 | 34.4 | 7.33 | 14.5 |
| | Standard Dev. | (0.028) | (10.40) | (1.8) | (0.261) | (0.103) | (0.050) | (11.47) | (36.9) | (0.34) | (13.7) |
| **Conesus** | Mesotrophic | Below | Above | Below | Below | Below | Below | Above | Above | Above | Below |
| **Hemlock** | Mesotrophic | Below | Below | Above | Below | Below | Below | Above | Below | Above | Below |
| **Canadice** | Mesotrophic | Below | Below | Above | Below | Below | Below | Below | Below | Below | Below |
| **Honeoye** | Eutrophic | Above | Above | Below | Above | Below | Below | Above | Below | Below | Below |
| **Canandaigua** | Mesotrophic | Below | Below | Above | Below | Above | Below | Above | Above | Above | Below |
| **Keuka** | Mesotrophic | Below | Below | Above | Below | Above | Below | Above | Below | Above | Below |
| **Seneca** | Mesotrophic | Below | Below | Above | Above | Above | Below | Above | Above | Above | Below |
| **Cayuga** | Mesotrophic | Below | Below | Above | Above | Above | Below | Above | Above | Above | Below |
| **Owasco** | Mesotrophic | Below | Below | Above | Above | Above | Below | Above | Below | Below | Below |
| **Skaneateles** | Oligotrophic | Below | Below | Above | Above | Above | Below | Above | Below | Below | Below |
| **Otisco** | Mesotrophic | Below | Below | Below | Above | Above | Below | Above | Above | Above | Below |

Above = higher than the NYS average; Below = lower than the NYS average

Nitrogen was not strongly correlated with summer average chlorophyll-a in the Finger Lakes in 2018, reinforcing the paradigm that P mostly limits algal growth in these systems for most of the time during the growing season. A geographical pattern was observed for total nitrogen and $NO_X$ concentrations, in which values of these indicators were statistically lower in the western Finger Lakes compared with the eastern Finger Lakes. The geology, large size and volumes, and watershed management practices all play roles in influencing water quality of the Finger Lakes.

Chlorophyll-a in most lakes has improved or remained stable since the 1970s but has increased since the 1990s. Trends in water clarity have varied as well, but since the early 1900s clarity has decreased for most lakes. However, long term trends cannot yet be evaluated in these lakes, since most existing, external data from these lakes does not conform with NYSDEC's quality assurance standards. It is anticipated that the continuation of CSLAP sampling on all eleven Finger Lakes in future years will provide data to support more robust long-term trend analyses.

Trophic state evaluations are important limnological calculations that assess a lake's level of biological productivity. NYSDEC uses equations originally designed by Carlson (1997), modified to reflect NYS conditions and criteria. A summary of individual lake results, including an assessment of trophic state, is presented below.

## Conesus

Conesus Lake is a small Finger Lake with a surface area of 13.7 $km^2$ and volume of 157 million $m^3$. In 2018, major trophic state indicators were intermediate for total phosphorus (0.020 mg/L), chlorophyll-a (9.3 µg/L), and water clarity (Secchi disk depth of 2.6 m). Conesus Lake has low levels of total nitrogen and $NO_X$ (0.480 and 0.005 mg/L, respectively). Using current chlorophyll-a as metric of lake quality, Conesus's water quality has remained stable since the 1990s. The Conesus Lake Association maintains its own shoreline HABs surveillance program but HABs occurrences remain poorly documented by the NYSDEC. ***The 2017-2018 data suggests that Conesus Lake is meso-eutrophic (moderately to highly productive).***

## Hemlock

Hemlock Lake is a small Finger Lake serving as a drinking water supply for the City of Rochester. It has a surface area of 7.2 $km^2$ and volume of 105 million $m^3$. In 2018, major trophic state indicators were intermediate to low for total phosphorus (0.0080 mg/L) and for chlorophyll-a (3.5 µg/L), and intermediate for water clarity (Secchi disk depth of 3.8 m). Hemlock Lake has low levels of total nitrogen and $NO_X$ (0.345 and 0.027 mg/L, respectively). The City of Rochester reported algal blooms in the summer of 2018, although these were small and ephemeral, with no measured impact on drinking water quality. Using current chlorophyll-a as metric of lake quality, Hemlock's water quality has improved since the 1970s but remained stable since the 1990s. ***The 2017-2018 data suggests that Hemlock Lake remains oligo-mesotrophic (low to moderate levels of productivity).***

## Canadice

Canadice Lake is a small Finger Lake that also provides drinking water to the City of Rochester, with a surface area of 2.6 $km^2$ and volume of 42 million $m^3$. In 2018, major trophic state indicators were low for total phosphorus (0.008 mg/L) and chlorophyll-a (4.18 µg/L), and high for water clarity (Secchi disk depth of 4.5 m). Canadice Lake has low levels of total nitrogen and $NO_X$ (0.280 and 0.05 mg/L, respectively). Canadice's water quality has remained stable since the 1970s. There were no reported HABs on Canadice Lake in 2018. ***The 2017-2018 data suggests that Canadice Lake is oligo-mesotrophic (low to moderate levels of productivity).***

## Honeoye

Honeoye Lake is a small Finger Lake with a surface area of 7.1 $km^2$ and volume of 34 million $m^3$ but does not provide public drinking water. In 2018, major trophic state indicators were high for total phosphorus (0.033 mg/L) and for chlorophyll-a (27.5 µg/L) and low for water clarity (Secchi disk depth of 1.8 m). Honeoye Lake has relatively low levels of total nitrogen and $NO_X$ (0.619 and 0.06 mg/L, respectively). Honeoye experienced numerous harmful algal blooms in 2018 as reported by the Honeoye Lake Watershed Taskforce. Using current chlorophyll-a as metric of lake quality, Honeoye's water quality has declined since the 1990s and is currently similar to conditions in the 1970s. ***The 2017-2018 data suggests that Honeoye Lake remains eutrophic (highly productive).***

## Canandaigua

Canandaigua Lake is a large Finger Lake with a surface area of 42.3 $km^2$ and volume of 1,600 million $m^3$. In 2018, major trophic state indicators were low for total phosphorus (0.006 mg/L) and chlorophyll-a (2.3 µg/L) and high for water clarity (Secchi disk depth of 5.6 m). Canandaigua Lake has low levels of total nitrogen and $NO_X$ (0.330 and 0.050 mg/L, respectively). Canandaigua Lake had numerous reports of cyanobacteria blooms at numerous locations in the lake in the late summer as reported by the Canandaigua Lake Watershed Association and Watershed Council. Using current chlorophyll-a as metric of lake quality, Canandaigua's water quality has remained stable since the 1970s, but has degraded slightly since the late 1990s. ***Despite recent harmful algal blooms (HABs), the 2017-2018 data suggests that Canandaigua Lake remains oligo-mesotrophic (low to moderate levels of productivity).***

## Keuka

Keuka Lake has a surface area of 47 $km^2$ and volume of 1,400 million $m^3$. In 2018, major trophic state indicators were low total phosphorus levels (0.006 mg/L), low to intermediate chlorophyll-a levels (2.2 μg/L) and high water clarity (Secchi disk depth of 6.7 m). Keuka Lake has the low levels of total nitrogen (TN) and $NO_X$ (0.351 and 0.048 mg/L, respectively). The Keuka Lake Association reported small and ephemeral shoreline cyanobacteria blooms on the lake in 2018; blooms had not been reported to NYSDEC prior to 2017. Using current chlorophyll-a as metric of lake quality, Keuka's water quality has improved continually since the 1970s. ***The 2017 data suggests that Keuka Lake is oligo-mesotrophic (low to moderate levels of productivity).***

## Seneca

Seneca Lake is one of the largest Finger Lakes with a surface area of 175.4 $km^2$ and volume of 15,500 million $m^3$. In 2018, major trophic state indicators were intermediate for total phosphorus (0.011 mg/L), chlorophyll-a (5.4 μg/L), and water clarity (Secchi disk depth of 3.7 m). Seneca Lake has low levels of total nitrogen and $NO_X$ (0.551 and 0.241 mg/L, respectively). Using current chlorophyll-a as metric of lake quality, Seneca's water quality has improved since the 1970s, but degraded since the late 1990s and early 2000s. ***The 2017-2018 data suggests that Seneca Lake is mesotrophic (moderately productive).***

## Cayuga

Cayuga Lake is one of the largest Finger Lakes with a surface area of 172 $km^2$ and volume of over 9,300 million $m^3$. It is the longest Finger Lake (61.4 km) and has ~ 155 km of shoreline. In 2018, major trophic state indicators were intermediate for total phosphorus (0.013 mg/L), chlorophyll-a (4.1 μg/L), and water clarity (Secchi disk depth of 3.6 m). Cayuga Lake was the Finger Lake with the highest summer average total nitrogen and $NO_X$ concentrations (1.08 and 0.783 mg/L, respectively). In July and September, Cayuga Lake had numerous reports of cyanobacteria blooms at numerous locations in the lake, although blooms had not been well documented prior to 2017. Using current chlorophyll-a as metric of lake quality, Cayuga's water quality has degraded slightly relative to several key historical reference points: the 1970s, and the late 1990s. ***The 2017-2018 data suggests that Cayuga Lake remains mesotrophic (moderately productive).***

## Owasco

Owasco Lake is a medium-sized Finger Lake with a surface area of 26.7 $km^2$ and volume of 781 million $m^3$. In 2018, major trophic state indicators were intermediate for total phosphorus (0.008 mg/L), chlorophyll-a (3.4 μg/L), and for water clarity (Secchi disk depth of 3.7 m). Owasco Lake has elevated summer average total nitrogen and $NO_X$ concentrations (0.948 and 0.582 mg/L, respectively). From July through September, the Owasco Lake Watershed Association and Owasco Lake Watershed Inspection Program reported only a few isolated cyanobacteria blooms along the lake's shoreline. Using current chlorophyll-a as metric of lake quality, Owasco's water quality has remained stable relative to several key historical reference points: the 1970s, and the late 1990s. ***The 2017-2018 data suggests that Owasco Lake remains mesotrophic (moderately productive).***

## Skaneateles

Skaneateles Lake is a large Finger Lake with a surface area of 35.9 $km^2$ and volume of over 1,500 million $m^3$. In 2018, major trophic state indicators were low for total phosphorus (0.004 mg/L), chlorophyll-a (0.95 μg/L), and high for water clarity (Secchi disk depth of 8.5 m). Skaneateles Lake has low levels of total nitrogen and $NO_X$ (0.471 and 0.324 mg/L, respectively). Using current chlorophyll-a as metric of lake quality, Skaneateles's water quality has improved since the 1970s, but degraded slightly since the late 1990s. ***The 2017-2018 data suggests that Skaneateles Lake remains oligotrophic (low levels of productivity).***

## Otisco

Otisco Lake is a small Finger Lake with a surface area of 7.6 $km^2$ and volume of over 78 million $m^3$. In 2018, major trophic state indicators were intermediate-high for total phosphorus (0.015 mg/L), high for chlorophyll-a (5.9 µg/L), and intermediate for water clarity (Secchi disk depth of 2.5 m). Otisco Lake has intermediate levels of total nitrogen and $NO_X$ (0.568 and 0.215 mg/L, respectively). HABs were only sporadically reported in the lake in 2018 and have not been well documented in recent years. Using current chlorophyll-a as metric of lake quality, Otisco's water quality has degraded since the 1970s and 1990s. ***The 2017-2018 data suggests that Otisco Lake remains meso-eutrophic (moderately to highly productive).***

The Finger Lakes generally exhibited good water quality in 2018, however, ten of the eleven lakes experienced harmful algal blooms in 2018 of varying extents, duration, and toxicity. Recent research funded through the Governor's 2018 HAB Initiative have shown that the Finger Lakes represent ecological systems which provide conditions favorable for these blooms. While more research is needed to properly predict bloom triggers and forecast blooms, the underlying chemistry and water quality observations provided by CSLAP in the Finger Lakes is providing data necessary for understanding the nature of biological dynamics in the region. CSLAP data also provides information to assess future monitoring technologies including the use of field instruments and satellite image analysis to estimate lake chlorophyll-a concentrations. This data will be used in the development and implementation of HAB mitigation, nutrient reduction, and best management strategies.

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# Acronym List

| | |
|---|---|
| 9EP | Nine Element Plan |
| ALSC | Adirondack Lake Survey Corporation |
| BG | Blue Green |
| C | Confirmed |
| Ca | Calcium |
| CALM | Consolidated Assessment and Listing Methodology |
| CDC | Centers for Disease Control |
| Chl-a | Chlorophyll a |
| Cl | Chloride |
| CSLAP | Citizens Statewide Lake Assessment Program |
| CWA | Clean Water Act |
| DBPs | Disinfection By-Products |
| DOC | Dissolved Organic Carbon |
| ECL | Environmental Conservation Law |
| ELAP | Environmental Laboratory Approval Program |
| HABS | Harmful Algal Blooms |
| HT | High Toxins |
| LCI | Lake Classification and Inventory |
| LCMS/MS | Liquid Chromatography-Mass Spectrometry |
| LN | Natural Logarithm |
| LOD | Level of Detection |
| LOQ | Level of Quantification |
| $NH_3$ | Ammonia |
| NOx | Oxidized Nitrogen |
| NYS | New York State |
| NYSDEC | New York State Department of Environmental Conservation |
| NYSDEC FLWH | New York State Department of Environmental Conservation Finger Lakes Watershed Hub – a section of four staff within the NYSDEC who focus on water quality in the Finger Lakes region |
| NYSDEC LMAS | New York State Department of Environmental Conservation Lake Management and Assessment Section |
| NYSDOH | NYS Department on Health |
| NYSFOLA | New York State Federation of Lakes Association, Inc. |
| OPRHP | Office of Parks, Recreation and Historic Preservation |
| QAMP | Quality Assurance Management Plan |
| QAPP | Quality Assurance Project Plans |
| QC | Quality Control |
| RPD | Relative Percent Difference |
| S | Suspicious |
| SC | Specific Conductance |
| SD | Secchi Disk |
| SM | Standard Method |
| SOP | Standard Operating Procedures |
| SUNY ESF | SUNY College of Environmental Science and Forestry |
| TDN | Total Dissolved Nitrogen |
| TDP | Total Dissolved Phosphorus |
| TMDL | Total Maximum Daily Load |
| TN | Total Nitrogen |

# Acronym List Continued

| | |
|---|---|
| TP | Total Phosphorus |
| TSI | Trophic State Index |
| UFI | Upstate Freshwater Institute |
| USEPA | United States Environmental Protection Agency |
| WHO | World Health Organization |
| WI/PWL | Waterbody Inventory/Priority Waterbodies List |

# Section 1: The Citizens Statewide Lake Assessment Program (CSLAP)

## CSLAP Background

There is a long history of water quality monitoring programs in New York State (NYS), starting with the State Conservation Department (predecessor to the NYS Department of Environmental Conservation, or NYSDEC) biological surveys from the 1920s and 1930s. The Adirondack Lake Survey Corporation (ALSC) conducted a study of more than 1,500 lakes in the Adirondacks, Catskills and surrounding areas primarily for evaluation of lake acidification in the 1980s. The NYSDEC Lake Classification and Inventory (LCI) survey has sampled more than 600 lakes since the early 1980s, and the NYSDEC Division of Fish and Wildlife conducts sampling of many lakes in support of fisheries management actions, including fish stocking. In addition to NYS programs, there have also been a myriad of academic and private studies of lakes throughout the state by various stakeholder groups ranging from infrequently sampled lakes to individual, high-profile lakes that are sampled year after year.

However, very few of these programs have been conducted consistently over multiple years, sampling at a frequency or duration capable of evaluating intra-(within) or inter-(between) annual trends in water quality on many lakes. Because most private or academic studies were narrowly focused on a particular waterbody prioritizing a specific issue, there has not been a holistic monitoring and assessment program dedicated to evaluating the health of the more than 16,000 lakes in NYS. Perhaps most importantly, very few of these programs were directed toward the large number of small lakes used daily by active lake communities and only a few of the professional programs took advantage of the local knowledge and experience of lake residents observing first-hand the daily and generational changes in their lakes. Including local stakeholders is vitally important to gaining an understanding of many individual lakes and, by extension, NYS lakes.

In 1983, NYS Federation of Lake Associations, Inc. (NYSFOLA) was organized to lobby NYS for a volunteer monitoring program to monitor and assess the water quality of NYS lakes like those in Wisconsin, Vermont, and Maine. In the mid-1980s, NYSDEC staff and the NYS Federation of Lake Associations, Inc. (NYSFOLA) proposed the development of a volunteer monitoring program to be used to supplement existing, professional monitoring efforts. NYSDEC Commissioner Henry Williams committed full support for the Citizens Statewide Lake Assessment Program (CSLAP), but initial efforts to secure funding for the program were unsuccessful.

In his 1986 State of the State address, NYS Governor Mario M. Cuomo provided his endorsement:

> *"I propose creating a program within the Department of Environmental Conservation to use trained volunteers to collect information on the State's water bodies. With this information, the Department can more effectively manage and protect our invaluable water resources." -Governor Mario M Cuomo*

With this endorsement and the support of several other organizations, CSLAP was established in 1986 by Jim Sutherland and Jay Bloomfield from the NYSDEC as a cooperative program between the NYSDEC and NYSFOLA, a non-profit coalition of lake associations, individual citizens, park districts, lake managers, and consultants dedicated to the preservation and restoration of lakes and their watersheds.

This program has expanded significantly over the last 30 years, and now serves as the primary long-term water quality monitoring network in NYS. CSLAP was codified in the state Environmental Conservation Law (ECL, in Article 17-0305) in 1988 to require NYSDEC to conduct the program.

## Why Does NYS Have CSLAP?

Information about the state of lakes, ponds and reservoirs in NYS is gathered in several ways. There are many lake sampling programs conducted throughout NYS by government agencies, academic institutions, consultants, and citizen scientists. Some of this data is collected to identify a specific water quality problem, in support of fish stocking, beach operation, or other resource management activity, or to support student or public education, ***while a primary use of lake data by the NYSDEC is to assess whether these lakes are meeting their best intended use***. The data generated from many of these programs are important, but there are enormous challenges in evaluating this information in a standardized way which is why the quality and consistency of the CSLAP program has been an invaluable and integral part of NYS efforts to monitor and assess water quality.

NYSDEC has two major lake monitoring programs: CSLAP and the Lake Classification and Inventory (LCI). These programs differ from each other, but both are unique among the various lake water quality monitoring programs conducted in NYS. These monitoring programs follow the NYSDEC requirements to use an ELAP certified lab and adhere to a strict state-approved Quality Assurance Project Plan (QAPP) or Quality Assurance Management Plan (QAMP) for the use of water quality data for several regulatory purposes, including lake assessments. For more information on LCI: https://www.dec.ny.gov/chemical/31411.html.

In addition to providing NYSDEC with monitoring and assessment data, CSLAP provides participating lake associations with the necessary data to develop lake and watershed management plans, gather information necessary to obtain lake management permits, and monitor the success of both in-lake and watershed-based management activities. CSLAP is a partnership between NYSDEC, in collaboration with NYSFOLA, and lake residents who help monitor and collect critical lake data in a manner consistent with other NYS programs. This information is used to understand lake conditions, to develop lake management plans, and to meet monitoring requirements mandated by the Federal Clean Water Act (CWA) and NYS Environmental Conservation Law (ECL).

## What Does CSLAP Do?

The Citizens Statewide Lake Assessment Program (CSLAP) has three major objectives:

(1) **collect** lake data for representative lakes throughout NYS,
(2) **identify** lake problems and changes in water quality over time, and
(3) **educate** the public about lake preservation, management and restoration.

**(1) Collect** – Trained CSLAP volunteers collect lake field data and collect water chemistry samples following approved methods. NYSDEC and NYSFOLA train volunteers from participating lake associations to collect water samples for several parameters designed to help evaluate nutrient enrichment conditions leading to excessive weed and algae growth. Every other week for 15 weeks, volunteers collect water samples at the deepest part of the lake, or at multiple sites on larger lakes, for lab analysis at a NYS Department of Health (NYSDOH) Environmental Laboratory Approval Program (ELAP) laboratory which allows them to be used in a variety of NYSDEC monitoring and assessment programs and management tools (including Total Maximum Daily Load [TMDL] analysis and Nine Element [9EP] planning). CSLAP lab sample analysis was conducted by the NYSDOH from 1986 to 2002, and by Upstate Freshwater Institute (UFI) starting in 2002.

Citizen scientists also record weather conditions, water temperature, water transparency, lake depth, and assessments of recreation and water quality of the lake and algal conditions based on the user's perception (Kishbaugh 1994). This snapshot of water quality based on “how the water looks” is extremely important in assessing water quality. Although subjective, visual assessments can be a very powerful tool for determining improvements or declines in water quality. In addition to water quality sampling, CSLAP volunteers collect information on freshwater harmful algal blooms (HABs), invasive species distribution, and aquatic plant surveys. HABs sampling through CSLAP forms the basis for one of the most extensive HABs surveillance and monitoring programs in the country, in support of a robust public education, outreach and notification system conducted by NYSDEC. Some CSLAP volunteers with access to multi-probe electronic meters also conduct depth profiles of field parameters.

**(2) Identify** – All CSLAP data and user perception information are added to the statewide lake database to help detect changes in water quality over time. The data also increases the total number of lakes that are sampled statewide and improves NYSDEC’s understanding of the overall water quality of NYS lakes. The data are used to report water quality information to federal, state, and local governments and to develop long term management/protection strategies and to monitor/propose management activities.

Regular lake monitoring keeps track of existing problems, detects threats to lakes before they become a problem, and helps evaluate lake condition patterns throughout NYS. Lake residents and trained volunteers can observe lake changes and compare them to "normal" conditions to detect emerging problems. The perspective of lakefront residents is even more important in documenting and tracking shoreline HABs and early introductions of invasive species.

HABs can be very ephemeral in many NYS lakes, with extreme variability in time and space. Finding and documenting these blooms, critically important to informing lake residents and visitors about public health threats, are extremely challenging in routine monitoring programs. Trained samplers look for blooms along the shoreline and respond to bloom reports from neighbors, which dramatically improves the ability of NYSDEC to understand bloom formation and protect public users of these lakes.

In addition, invasive species (plants and animals) are more easily managed, and in some cases eradicated, through a robust early detection program. CSLAP volunteers frequently report infestations of aquatic invasive species (AIS) in waterbodies that have not been previously seen in the lake. This significantly improves the ability for local lake managers including lake associations and other watershed partners to initiate local responses. A significant portion of the NYSDEC iMapInvasives inventory of AIS, documented in http://www.nyimapinvasives.org/, is derived from CSLAP samplers.

**(3) Educate** – Volunteers who participate in CSLAP gain a better understanding of lake ecology and the consequences of specific lake management practices. CSLAP volunteers have a strong commitment to conserve and protect lake resources, an important attribute since lake management in NYS is largely conducted at the local level. Volunteers help local communities better understand what is happening in the lake by sharing their knowledge and enthusiasm. Lake data collected by CSLAP volunteers educates lakefront property owners, lake users, and citizens, NYSDEC, contributes to water quality management plans and reports for CSLAP lakes, and supports many NYSDEC and local community programs and activities. For more information about CSLAP: https://www.dec.ny.gov/chemical/81576.html.

# Section 2: CSLAP in the Finger Lakes

## CSLAP 2018 Overview

All water quality measures used in CSLAP are documented in NYSDEC-approved Quality Assurance Management Plan (QAMP). A detailed summary of these measures can be found at http://www.dec.ny.gov /chemical/81849.html.

### Training

All CSLAP samplers are trained in standardized methods for collecting accurate and representative samples, consistent with the NYSDEC Lake Monitoring Standard Operating Procedures (http://www.dec.ny.gov /docs/water_pdf/sop20314.pdf). Specific sampling instructions are provided to the trained CSLAP samplers through several methods, including sampling training sessions conducted by NYSDEC and NYSFOLA, written sampling protocols (http://www.nysfola.org/cslap), instructional videos (http://www.dec.ny.gov/chemical/81849.html), sampling protocol quizzes (http://www.dec.ny.gov/docs/water_pdf/cslapquiz2.pdf ) and in-season "OOPS" sheets outlining specific problem areas to avoid sampling anomalies. In addition, NYSFOLA and the laboratory staff communicate directly with volunteers whenever issues with sample transport or field data occur. These training procedures are applied to all CSLAP lakes, not just the Finger Lakes, to provide standardization across all program lakes and to facilitate inter-lake comparisons.

Additionally, Finger Lakes Watershed Hub staff conducted field visits on the Finger Lakes during the 2017-2018 sampling season. Staff audited CSLAP volunteers at one site per lake. Staff performed visual assessments, collected field observations, and collected field duplicate samples using the volunteer's equipment. The results of these quality assurance audits are available in Section 4.

### Data and sample collection

The chemistry, locations, and sampling depths of the Finger Lakes sites are located in Table 1-2. CSLAP volunteer's complete user perception surveys on each trip which is important for assessing how the water and its surrounding appearance influence a user's perceived ability to recreate in and on the water. Evaluated through field perception forms (four question surveys completed during each sampling session), use impairment surveys link recreational lake use assessments to water quality data.

In all thermally stratified CSLAP lakes, surface and deep samples are collected in the deepest portion of the lake (open water). Since 1986, CSLAP samplers have used Kemmerer bottles to collect surface samples at a depth of 1.5 meters, and deeper water column samples. In most CSLAP lakes, deep-water samples are collected from 1.5 meters above the lake bottom in the deepest part of the lake. In the Finger Lakes, deep-water samplers were collected at shallower, metalimnetic depths to evaluate other important lake conditions. Surface and deep samples are transferred from the Kemmerer to collapsible containers in the field.

Open water HAB samples are collected through CSLAP even in the absence of any bloom conditions. This provides a long-term dataset to evaluate cyanobacterial abundance and levels of toxins throughout the spectrum of water quality conditions, including open water conditions with no visual evidence of blooms. If conditions at the site are consistent with a HAB (for example, appearing to resemble spilled paint, pea soup, green streaks, or dense concentrations of green dots), then surface skim samples are collected from the most intense part of the bloom. CSLAP volunteers also collect shoreline samples using the skim method if a bloom is present.

Field measurements include water clarity and temperature. Secchi disk transparency readings in CSLAP are measured using a standard limnological (black and white quartered, 20cm diameter) disk, with the Secchi disk transparency defined as the average of the depths of Secchi disk disappearance and reappearance in the water column. Water and air temperature are measured using a field thermometer, measured from the collapsible containers.

Instructions for completing standardized field forms are provided during all training sessions. Most CSLAP volunteers enter data on-line through a NYSFOLA-hosted web page (https://www.cslapdata.org/index.php ). Field data not entered by volunteers is entered into the database by the NYSFOLA program coordinator.

### Sample processing and preservation methods

Water samples are collected in the field and transferred to pre-labeled bottles provided by NYSDEC, NYSFOLA and UFI. Samples are identified using a standardized format.

Chlorophyll-a (Chl-a), (true) color, and cyanotoxins are field filtered in open water CSLAP samples, although cyanotoxins are analyzed from raw water samples when collected from concentrated shoreline blooms in CSLAP. Filters are placed in labeled vials, and Chl-a vials are wrapped in aluminum foil to prevent additional algae growth.

All CSLAP samples, except the raw water sample used for unextracted Chl-a measurements and cyanotoxins (field filter or raw water sample), are frozen overnight for next day shipping. All samples are accompanied by Request for Analysis/Chain of Custody forms signed by the samplers and laboratory staff receiving the sampling bottles.

### Sample shipping

Open water CSLAP sample bottles and filter vials are shipped to the contract lab inside Styrofoam coolers with ice packs using pre-paid shipping labels. Shoreline bloom samples from CSLAP samplers are shipped as whole water samples with ice packs and coolers directly to the contract lab, also using pre-paid shipping labels.

### Analytical methods

The field indicators measured through CSLAP or HABs programs are measured through standard limnological methods as governed by NYSDEC SOP 203-19 (Lake Monitoring Standard Operating Procedures); parameters with a laboratory equivalent are measured using methods approved by USEPA, Standard Methods, or some modification thereof. The laboratory water quality indicators measured through CSLAP are analyzed using accepted methodologies, as outlined in Table 1. Each of these laboratory analyses for which ELAP certification is available is analyzed using an ELAP approved method and are outlined in the CSLAP QAMP. Tables 3-4 describe the number of samples collected at the near-surface (1.5m) and deep sampling depths, respectively.

### Quality Assurance/Quality Control

Several quality control measures have been instituted in the field and/or laboratory through these monitoring programs, including:

- Training and procedure checks- as described above, a number of training techniques are used to assure sampling data accuracy. Each of these techniques involve feedback mechanisms- routine checks by CSLAP program staff, review of field and laboratory procedures to verify training techniques, sampler feedback, and periodic review of instructions

- Field measures- field duplicate samples were collected by Finger Lakes Watershed Hub staff at the surface of all eleven Finger Lakes again in 2018. In addition, NYSDEC provided interns to audit approximately thirty CSLAP volunteers in Central NY to assess field protocols and collect duplicate samples. Differences between volunteer samples and NYSDEC staff are presented in subsequent sections and have led to program improvements to assure quality data.
- Laboratory measures- UFI routinely conducts quality checks and deploy several quality measures outlined in the program QAMP, including enhanced staff training, data documentation, equipment calibration logs and checks, matrix duplicate and spike sampling, and laboratory control samples.
- Data review- laboratory staff and project managers review program data to assure the collection, transport, analysis and reporting of high-quality data in support of the NYSDEC program objectives and compliance with the approved QAPPs.

**Table 1.** Laboratory methods and other analytical method information for CSLAP parameters

| CSLAP Sample Type | Method | ELAP Certified? | Precision | Accuracy | LOD | LOQ |
|---|---|---|---|---|---|---|
| FIELD PARAMETERS | | | | | | |
| Secchi disk transparency | SOP #203-14 | NA | ± 0.1m | ± 0.1m | 0.1 m | same |
| Water temperature | SM 2550B | Yes | ± 1°C | ± 1°C | -5C | same |
| Lake perception | SOP #203-14 | NA | NA | NA | NA | NA |
| WATER CHEMISTRY PARAMETERS | | | | | | |
| Total phosphorus; TP (and Total Dissolved P; TDP) | SM 18-20 4500-P E | Yes | ±20% RPD | ±20% | 0.001 mg P/L | 0.0038 mg P/L |
| Soluble Reactive P (SRP) | SM 18-20 4500-P E | Yes | ±20% RPD | ±20% | 0.003 mg P/L | 0.0011 mg P/L |
| Nitrate+Nitrite; NOx | USEPA 353.2 Rev 2.0 | Yes | ±20% RPD | ±20% | 0.007 mg N/L | 0.029 mg N/L |
| Ammonia; $NH_3$ | USEPA 350.1 Rev 2.0 | Yes | ±20% RPD | ±20% | 0.015 mg N/L | 0.056 mg N/L |
| Total nitrogen; TN (and Total Dissolved N) | SM 20 4500-N C | Yes | ±20% RPD | ±20% | 0.09 mg N/L | 0.307 mg N/L |
| Chlorophyll-a-extracted; Chl-a | USEPA 445.0 Rev. 1.2 | NA | ±20% RPD | ±20% | 0.1 µg Chl/L | 0.3 µg Chl/L |
| pH | SM 18-20 4500 H+ B | Yes | ±20% RPD | ±20% | exempt | exempt |
| Specific conductance; SC | SM 18-20 2510 B | Yes | ±20% RPD | ±20% | 10 umho/cm | 10 umho/cm |
| True color | SM 18-20 2120 B | Yes | ±20% RPD | ±20% | 1 pCU | 5 pCU |
| Calcium; $Ca^{2+}$ | USEPA 200.7 | Yes | ±20% RPD | ±20% | 0.2 mg/L | 0.7 mg/L |
| Chloride; $Cl^-$ | SM 4500-Cl-97, -11 | Yes | ±20% RPD | ±20% | 100 µg/l Cl/L | 100 µg/l Cl/L |

**Table 1 (cont.).** Laboratory methods and other analytical method information for CSLAP parameters

| CSLAP Sample Type | Method | ELAP Certified? | Precision | Accuracy | LOD | LOQ |
|---|---|---|---|---|---|---|
| HAB PARAMETERS | | | | | | |
| Chlorophyll-a-unextracted | Bbe Moldaenke, 2014 | NA | ± 0.01 µg/L | ± 0.01 µg/L | 0.05 µg/L | same |
| Bluegreen chlorophyll-a unextracted | Bbe Moldaenke, 2014 | NA | ± 0.01 µg/L | ± 0.01 µg/L | 0.05 µg/L | same |
| Microcystin | USEPA 546 | Yes | | | 0.3 µg/l | same |
| Anatoxin-a | USEPA 545 – LCMS/MS | NA | | | 0.027 µg/l | same |
| Cylindrospermopsin | USEPA 545 – LCMS/MS | NA | | | 0.318 µg/l | same |

ELAP Certified? = certified through the Environmental Laboratory Approval Program as per 40 CFR Part 136; SM = Standard Methods; EPA = EPA approved methods

**Table 2.** 2018 CSLAP Finger Lakes monitoring locations and descriptions

| Lake | Site | Lake Depth (m) | Lat. (°) | Lon. (°) | Secondary Sampling Depth (m) |
|---|---|---|---|---|---|
| **Conesus Lake (CO)** | 1 | 12 | 42.812 | -77.712 | 9 |
| | 2 | 18 | 42.755 | -77.712 | 12 |
| **Hemlock Lake (HE)** | 1 | 11 | 42.773 | -77.615 | 9 |
| | 2 | 27 | 42.720 | -77.611 | 18 |
| | 3 | 11 | 42.682 | -77.600 | 9 |
| **Canadice Lake (CA)** | 1 | 24 | 42.717 | -77.568 | 18 |
| **Honeoye Lake (HO)** | 1 | 7 | 42.765 | -77.512 | 5.5 |
| | 2 | 9 | 42.751 | -77.509 | 7.5 |
| **Canandaigua Lake (CG)** | 1 | 54 | 42.821 | -77.276 | 15 |
| | 2 | 78 | 42.719 | -77.313 | 15 |
| **Keuka Lake (KE)** | 1 | 51 | 42.550 | -77.150 | 18 |
| | 2 | 55 | 42.489 | -77.155 | 18 |
| | 3 | 40 | 42.550 | -77.102 | 18 |
| **Seneca Lake (SE)** | 1 | 35 | 42.771 | -76.950 | 18 |
| | 2 | 17 | 42.585 | -76.898 | 18 |
| | 3 | 145 | 42.690 | -76.922 | 18 |
| | 4 | 175 | 42.453 | -76.887 | 18 |
| **Cayuga Lake (CY)** | 1 | 18 | 42.818 | -76.726 | 9 |
| | 2 | 50 | 42.555 | -76.598 | 18 |
| | 3 | 3.5 | 42.470 | -76.515 | - |
| | 4 | 110 | 42.714 | -76.730 | 18 |
| | 5 | 2 | 42.919 | -76.740 | - |
| **Owasco Lake (OW)** | 1 | 34 | 42.845 | -76.516 | 9 |
| | 2 | 48 | 42.795 | -76.493 | 9 |
| **Skaneateles Lake (SK)** | 1 | 35 | 42.918 | -76.415 | 15 |
| | 2 | 83 | 42.802 | -76.292 | 18 |
| **Otisco Lake (OT)** | 1 | 19 | 42.875 | -76.296 | 9 |
| | 2 | 19 | 42.856 | -76.274 | 9 |

**Table 3.** Summary (Number of Samples) of surface water quality and assessment data collected in 2018

| Lake | Temp.[1] | Clarity | Chl-a | TP | TDP | SRP | TN | TDN | NOx | $NH_3$ | SC | pH | Color | Cl- | $Ca^{2+}$ | Algal ID | User Perception |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Conesus** | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 15 | 16 | 16 | 4 | 4 | 16 | 16 |
| **Hemlock** | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 6 | 6 | 21 | 21 |
| **Canadice** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 1 | 2 | 6 | 6 |
| **Honeoye** | 16 | 16 | 16 | 15 | 16 | 16 | 16 | 16 | 16 | 16 | 14 | 16 | 16 | 4 | 4 | 16 | 16 |
| **Canandaigua** | 17 | 17 | 17 | 14 | 17 | 17 | 17 | 17 | 17 | 17 | 15 | 16 | 17 | 4 | 3 | 17 | 17 |
| **Keuka** | 20 | 20 | 20 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 20 | 19 | 21 | 6 | 4 | 21 | 20 |
| **Seneca** | 32 | 32 | 32 | 28 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 8 | 8 | 32 | 32 |
| **Cayuga** | 39 | 39 | 39 | 37 | 39 | 39 | 38 | 39 | 38 | 39 | 39 | 38 | 39 | 10 | 10 | 39 | 39 |
| **Owasco** | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 13 | 15 | 15 | 4 | 4 | 15 | 15 |
| **Skaneateles** | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 14 | 3 | 4 | 14 | 14 |
| **Otisco** | 16 | 16 | 16 | 15 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 4 | 3 | 16 | 16 |
| **Total** | **212** | **212** | **212** | **202** | **213** | **213** | **212** | **213** | **212** | **213** | **204** | **209** | **213** | **54** | **52** | **213** | **212** |

[1] Air and water temperature; [2] Microcystin, Anatoxin, Cylindrospermopsin as well as congener analysis at SUNY ESF in 2018

**Table 4.** Summary (Number of Samples) of deep sample water quality data collected in 2018

| Lake | Temp.[1] | Clarity | TP | TDP | SRP | TN | TDN | $NH_3$ |
|---|---|---|---|---|---|---|---|---|
| **Conesus** | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 3 |
| **Hemlock** | 21 | 21 | 19 | 21 | 21 | 21 | 21 | |
| **Canadice** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | |
| **Honeoye** | 16 | 16 | 16 | 15 | 16 | 15 | 16 | 2 |
| **Canandaigua** | 17 | 17 | 17 | 17 | 17 | 17 | 17 | |
| **Keuka** | 20 | 20 | 20 | 21 | 21 | 21 | 21 | |
| **Seneca** | 32 | 32 | 31 | 31 | 32 | 32 | 32 | 2 |
| **Cayuga** | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 3 |
| **Owasco** | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 2 |
| **Skaneateles** | 14 | 14 | 13 | 14 | 14 | 14 | 14 | |
| **Otisco** | 16 | 16 | 15 | 16 | 16 | 16 | 16 | |
| **Total** | 197 | 197 | 192 | 196 | 198 | 197 | 198 | 12 |

[1] Air and water temperature

# Section 3: Background of the Finger Lakes

## Introduction

The Finger Lakes of Central New York (Figure 1) share some similarities and limnological features but are different and unique in several important ways. They share a similar climate (cold snowy winters, a brief spring and a warm summer), geology (mostly shale, with some sandstone and limestone bands), relatively simple shape and orientation (elongated, in the N-S direction with the exception of Y-shaped Keuka). They all drain from the south to the north and are in the Lake Ontario watershed. The lakes vary significantly in maximum depth (~ 9m for Honeoye vs ~ 200 m for Seneca; Table 5), surface area (Canadice Lake at 2.7 square kilometers [$km^2$] to Seneca Lake at 176 $km^2$), and volume – Seneca Lake has 400 times the volume of Honeoye and more than the other ten lakes combined. These differences in size and depth influence fundamental limnological properties such as thermal stratification, light penetration, water column interaction with the sediments, water chemistry, and biology and therefore, play critical roles in influencing individual lake ecology.

Some Finger lakes have watersheds that are predominately forested, which is not markedly different from a century ago and others have watersheds dominated by agriculture. Industry and urban development varies throughout the Finger Lakes basin (see Individual Lake Chapters). Except for Hemlock and Canadice, all Finger Lakes have at least partially developed shorelines. They support a variety of uses, ranging from drinking water sources (except Honeoye), fishing, swimming, and other forms of recreation, although the Rochester drinking water supplies (Canadice and Hemlock Lakes) experience less recreational pressure due to protective watershed restrictions.

**Table 5.** Physical characteristics of the Finger Lakes

| Lake | Mean Depth (m) | Max Depth (m) | Length (km) | Shoreline Length (km) | Surface Area ($km^2$) | Watershed Area ($km^2$) | WA:LA$^+$ | Volume ($10^6$ $m^3$) | Elevation above MSL$^{++}$ (m) |
|---|---|---|---|---|---|---|---|---|---|
| **Conesus** | 11.5 | 18.0 | 12.6 | 29 | 13.0 | 182 | 14.0 | 149 | 249 |
| **Hemlock** | 13.6 | 27.5 | 10.8 | 27 | 8.4 | 111 | 13.2 | 114 | 276 |
| **Canadice** | 16.4 | 25.4 | 5.1 | 12 | 2.7 | 32 | 11.9 | 44 | 334 |
| **Honeoye** | 4.9 | 9.2 | 6.6 | 17 | 7.3 | 104 | 14.3 | 36 | 245 |
| **Canandaigua** | 38.8 | 83.5 | 24.9 | 66 | 42.6 | 482 | 11.3 | 1,653 | 210 |
| **Keuka** | 30.5 | 55.8 | 31.6 | 96 | 47.3 | 464 | 9.8 | 1,441 | 218 |
| ***Seneca** | 88.6 | 198 | 56.6 | 127 | 175.6 | 1,838 | 10.5 | 15,556 | 136 |
| ****Cayuga** | 54.5 | 133 | 61.4 | 170 | 172.5 | 1,870 | 10.8 | 9,399 | 116 |
| **Owasco** | 29.3 | 54 | 17.9 | 43 | 27.5 | 515 | 18.7 | 806 | 217 |
| **Skaneateles** | 43.5 | 90.5 | 24.2 | 55 | 35.3 | 189 | 5.3 | 1,535 | 263 |
| **Otisco** | 10.2 | 20.1 | 8.7 | 24 | 8.9 | 110 | 12.3 | 91 | 240 |

* excluding Keuka Lake watershed; ** excludes Seneca River watershed; + watershed to lake surface area ratio; ++ mean sea level

As with much of the northeast in the last 250 years, the region experienced industrialization, alterations to land use and changes to its hydrology. Most of the original forests were felled, wastewater was discharged into the lakes, increased development led to more runoff, and soil loss from agricultural practices found its way into the lakes. Cultural eutrophication – the increase in lake productivity produced by an unnatural input of nutrients – was apparent in all the lakes by the 1970s, when nuisance algal blooms were documented by the USEPA, although it is not known if these blooms produced toxins. Water quality improved in the late part of the 20$^{th}$ century, in large part due to implementation of Clean Water Act requirements and regulations, and the resulting improvements to wastewater treatment.

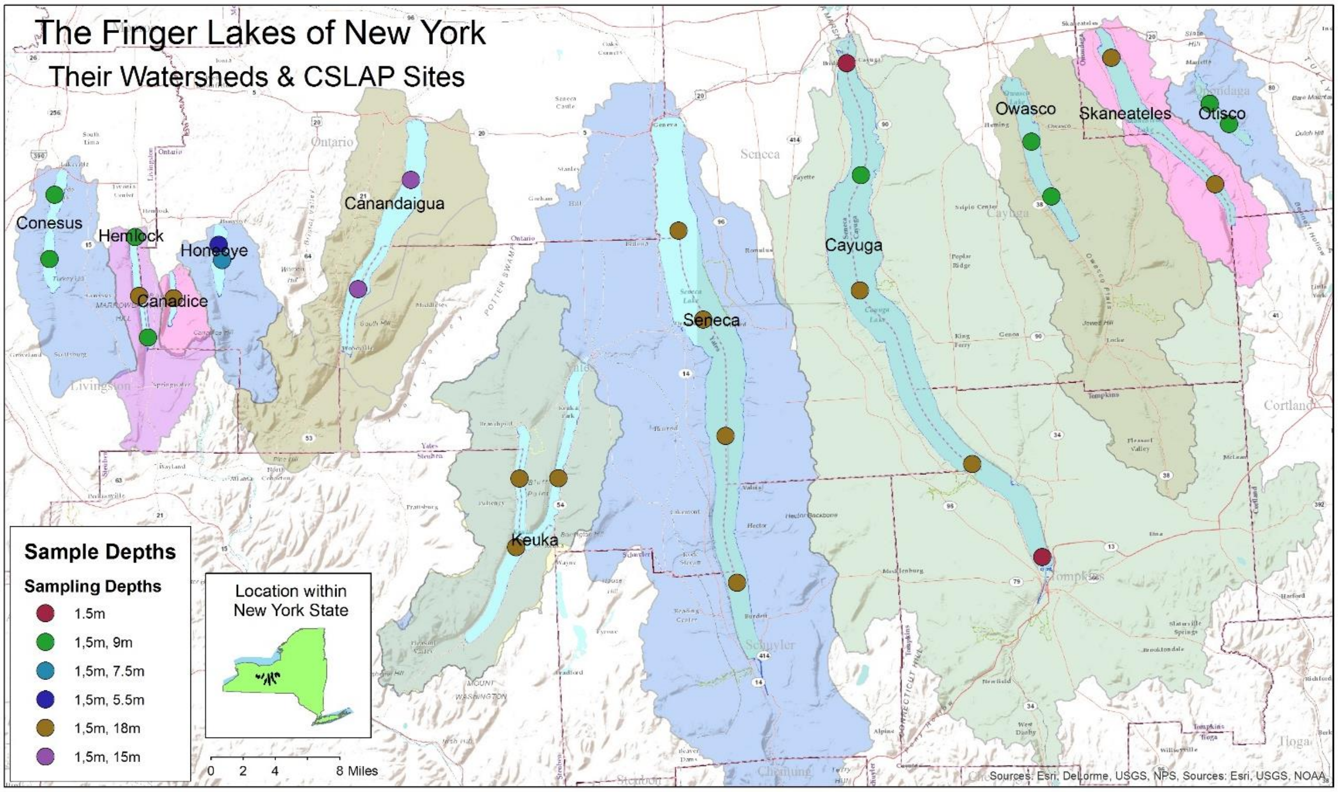



**Figure 1 .** Map of the Finger Lakes Region in Central New York including 2018 Finger Lake CSLAP sites.

The lakes and rivers of the region supply drinking water to more than 2 million people. Groundwater is only a minor component of municipal public water supply, due to the low porosity and permeability of most of the region's Silurian and Devonian bedrock. Groundwater does serve private wells in much of the rural parts of the region. Except for Honeoye Lake, all the Finger Lakes are used as public drinking water supplies, serving 1.5 million customers. The lakes are also used extensively for private water supplies, via individual lake intakes or shoreline wells, although NYSDOH does not recommend this practice.

The eleven Finger lakes represent some of the largest lakes in New York in term of surface area, depth, and volume, which plays an important role in the water quality of these systems. A lake's morphology (size and shape) and orientation influences thermal stratification and the degree to which the photic zone (the part of the upper waters where light is available to algae and plants) interacts with the bottom sediments. Assimilative capacity, the ability of a waterbody to receive nutrient inputs and maintain water quality, is heavily influenced by lake morphology and nutrient inputs. In the 1960s, researchers determined that water quality and trophic state in lakes is a result of external loading inputs relative to the lake's depth, surface area and residence time (Vollenweider 1970). Nutrient inputs to lakes are directly influenced by watershed characteristics such as slopes, soil types, land use, cultural practices, population density. In addition, legacy nutrient loading has led to phosphorus accumulation in the bottom sediments, which are released into the water during the summer in some lakes. In the Finger Lakes, Schaffner and Olgesby (1978) found that the water quality of the Finger Lakes was driven by phosphorus inputs relative to the size of the epilimnion of lakes. They also described the statistical relationships between phosphorus loading, lake TP concentration, chlorophyll concentrations, and Secchi disk clarity.

## Water Quality Classifications

All waters in NYS are assigned a letter classification that denotes their best uses. Letter classes such as AA, A, B, C, and D are assigned to fresh surface waters, and SA, SB, SC, I, and SD to saline (marine) surface waters. Best uses include: source of drinking water, swimming, boating, fishing, and shell fishing. The letter classifications and their best uses are described in Table 6.

**Table 6.** Water quality classifications on NYS and the designated best use

| Classification | Best Use |
|---|---|
| **Class AA** | The best usages are a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish and wildlife propagation and survival.<br>This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary, to remove naturally present impurities, meet or will meet NYSDOH drinking water standards and are or will be considered safe and satisfactory for drinking water purposes. |
| **Class A** | The best usages are a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish and wildlife propagation and survival.<br>This classification may be given to those waters that, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary, to reduce naturally present impurities, meet or will meet NYSDOH drinking water standards and are or will be considered safe and satisfactory for drinking water purposes. |
| **Class B** | Best usage is primary and secondary contact recreation and fishing. These waters shall be suitable for fish, shellfish and wildlife propagation and survival. |
| **Class C** | Best usage is fishing. These waters shall be suitable for fish, shellfish and wildlife propagation and survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes. |
| **Class D** | Best usage is fishing. Due to such natural conditions as intermittency of flow, water conditions not conducive to propagation of game fishery, or stream bed conditions, the waters will not support fish propagation. These waters shall be suitable for fish, shellfish and wildlife survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes. |

**The *symbol (T),* appearing in an entry in the classification means that the classified waters are trout waters. The *symbol (TS),* appearing in an entry in classification means that the classified waters in that specific item are trout spawning waters.

The Waterbody Inventory/Priority Waterbodies List (WI/PWL) is an inventory of water quality assessments that characterize known/and or suspected water quality issues and determine the extent of designated use support in a waterbody. It is instrumental in directing water quality management efforts to address water quality impacts and in tracking progress toward their resolution. In addition, the WI/PWL provides the foundation for the development of the state Section 303(d) List of Impaired Waters, a USEPA program that dictates the development of nutrient budgets and proposed actions to reduce specific inputs or impacts and restore and protect designated uses.

The WI/PWL assessments reflect data and information drawn from numerous NYSDEC programs (e.g. CSLAP) as well as other federal, state and local government agencies, and other partners. All data and information used in these assessments has been evaluated for adequacy and quality as per the NYSDEC Consolidated Assessment and Listing Methodology (CALM; https://www.dec.ny.gov/ chemical/36730.htm). The NYSDEC CALM provides a "rulebook" for conducting assessments and impaired water listing decisions. These rules are based on assessing designated uses against existing water quality standards and guidance values indicating "how much is too much?" of a water quality indicator before designated uses are impacted. For more information on NYSDEC CALM see http://www.dec.ny.gov/docs/water_pdf/asmtmeth09.pdf

CSLAP data, collected under a standardized quality control program, provides current and valuable data to properly assess and update WI/PWLs for NYS Lakes.

WI/PWLs for Conesus, Hemlock, Canadice and Honeoye Lakes can be found in the Lower Genesee River Sub-Basin listing at http://www.dec.ny.gov/chemical/36744.html. WI/PWLs for Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco Lakes can be found in the Oswego River/Finger Lakes Basin (West) listing at http://www.dec.ny.gov/chemical/36737.html. Table 7 provides the most recent PWL information for each of the Finger Lakes.

**Table 7.** Water quality classifications and current status of the Finger Lakes

| Lake | Segment | Classification | WI/PWL Status | Management Status | Primary Impairment | Primary Pollutant |
|---|---|---|---|---|---|---|
| **Conesus (2018)** | Entire Lake | AA | Impaired | Strategy underway | Primary and secondary recreation | Elevated nutrient loads, aquatic vegetation growth |
| **Hemlock (2015)** | Entire Lake | AA(T) | No Known Impacts | No action needed* | N/A | N/A |
| **Canadice (2016)** | Entire Lake | AA(TS) | Impaired | Strategy underway | Fish consumption | PCBs |
| **Honeoye (2018)** | Entire Lake | AA | Impaired | Strategy underway | Primary and secondary recreation | Nutrients (phosphorus) |
| **Canandaigua (2007)** | Entire Lake | AA(TS) | Threatened | Strategy underway | Water supply Threatened | N/A |
| **Keuka (2015)** | Entire Lake | AA(TS) | No Known Impacts | No action needed* | N/A | N/A |
| **Seneca (2016)** | North | B(T) | No Known Impacts | No action needed* | N/A | N/A |
| | Middle | AA(TS) | Threatened | Protection Strategy Needed | Water supply Threatened | N/A |
| | South | B(T) | Threatened | Strategy underway | Water supply Threatened | N/A |
| **Cayuga (2018)** | Northern End | B(T) | Minor Impacts | Strategy underway | Primary and secondary recreation | Algal/plant growth and invasive species |
| | Mid-North | A(T) | Minor Impacts | Strategy underway | Primary and secondary recreation | Algal/plant growth and invasive species |
| | Mid-South | AA(T) | Minor Impacts | Strategy underway | Primary and secondary recreation | Algal/plant growth and invasive species |
| | Southern End | A | Impaired | Strategy underway | Primary and secondary recreation | Nutrients (phosphorus), silt/sediment |
| **Owasco (2018)** | Entire Lake | AA(T) | Impaired | Strategy underway | Primary and secondary recreation | Pathogens |
| **Skaneateles** | Entire | AA | Minor | Strategy | Primary and | Harmful Algal |

| Lake | Segment | Classification | WI/PWL Status | Management Status | Primary Impairment | Primary Pollutant |
|---|---|---|---|---|---|---|
| **(2018)** | Lake | | Impacts | underway | secondary recreation | Blooms |
| **Otisco (2007)** | Entire Lake | AA | Minor Impacts | Protection Strategy Needed | Aquatic life | Low dissolved oxygen levels |

**Although no actions are required by USEPA to address water quality impacts, local communities may have developed protection strategies to maintain high quality conditions.*

## Emerging Threat: Harmful Algal Blooms

Like other NYS lakes, the Finger Lakes continue to face water quality challenges from climate change, agricultural run-off, emerging contaminants, stormwater flows, aging infrastructure, septic impacts, and the effects of cyanobacterial blooms (often called Harmful Algal Blooms, or "HABs").

Several Finger Lakes have experienced HABs periodically since at least 2012, the first year of a formal process for NYSDEC cyanobacteria bloom documentation (https://www.dec.ny.gov/chemical/77118.html). HABs were detected in all 11 Finger Lakes in 2017 and in ten in 2018. More details about HAB occurrences in the Finger Lakes are provided in Section 6. However, since surveillance networks have been established in only a few of these lakes in recent years, it is likely that the frequency, extent and duration of HABs in the Finger Lakes have not been well documented, historically.

In his 2018 State of the State address, Governor Andrew M. Cuomo announced a $65 million, four-point initiative to aggressively combat HABs in New York, with the goal of identifying contributing factors fueling HABs, and implementing innovative strategies to address their causes and protect water quality. Under this initiative, the Governor's Water Quality Rapid Response Team focused strategic planning efforts on 12 priority lakes across New York that have experienced or are vulnerable to HABs. The five Finger Lakes identified as priority lakes as part of this Initiative were Conesus, Honeoye, Cayuga, Owasco and Skaneateles Lakes.

The Governor's Team brought together national, state, and local experts at four regional summits which focused on conditions that were affecting the waters and contributing to HABs formation, and immediate and long-range actions to reduce the frequency and/or treat HABs. Although the 12 selected lakes are unique and represent a wide range of conditions, the goal was to identify factors that lead to HABs in specific water bodies, and apply the information learned to assist other lakes facing similar threats. The Rapid Response Team, national stakeholders, and local steering committees worked together collaboratively to develop science-driven HAB Action Plans for each of the 12 lakes to reduce the sources of pollution that trigger algal blooms. The HAB Action Plans for these five Finger Lakes (and each of the 12 priority lakes) document water quality conditions, bloom extent, and factors that contribute to these blooms (https://on.ny.gov/HABsAction).

## Previous Investigations

The eleven Finger Lakes have been intensively studied by numerous researchers for well over a century. In early twentieth century, Birge and Juday published their study "A Limnological Study of the Finger Lakes of New York" (Birge and Juday 1914). Their famous quote regarding the uniqueness and complexity of the lakes still holds true today with the emergence of new problems and challenges, including HABs.

> *"It is probable that there is no group of lakes in the world which offer the limnologist [lake scientist] such opportunities for working out the problems of his science"*
> *- E.A. Birge and C. Juday, 1914*

Since Birge and Juday, there have been numerous scientific studies, biological assessments, ecological process studies, and monitoring programs of the Finger Lakes from storied limnologists and world renowned academic researchers to local stakeholder groups and citizen scientists. To date the most comprehensive look at the Finger Lakes remains Bloomfield's compilation, "The Lakes of New York State: The Ecology of the Finger Lakes" published in 1978. Anyone interested in the history of the Finger Lakes basin should review this publication. There are too many water quality studies to mention in this report, but the Finger Lakes Watershed Hub (NYSDEC FLWH) is currently compiling sources (post 1980) of Finger Lake data and reports to consolidate these important resources in one central location.

This report refers to several previous investigations, or monitoring by NYS directly, whereby the water quality of all eleven Finger Lakes were monitored consistently and systematically. The studies referenced here provide historical context and comparison to the 2018 CSLAP data are:

(1) **Bloomfield 1978 –** Historic review of the history, geology, and ecology of the Finger Lakes. The water quality component referenced in this volume relied heavily on the work of Schaffner and Oglesby (1978), and includes a mix of academic and government studies,

(2) **Callinan 2001 –** the Water Quality of the Finger Lakes conducted in the late 1990s by NYSDEC which comprehensively monitored and assessed the surface and hypolimnion (deep portion) of the Finger Lakes for metrics of trophic state (total phosphorus, chlorophyll-a, Secchi disk clarity), nitrogen, alkalinity, metals, chloride, temperature, and dissolved oxygen,

(3) **Callinan et al. 2013** – a regional study of trophic state metrics, dissolved organic carbon and drinking water quality of 21 NYS lakes by NYSDEC, including all Finger Lakes, conducted over the 2004-2007 interval, for the purpose of evaluating drinking water threats, and

(4) **2017 Finger Lakes Region Lakes Report –** a comprehensive review of CSLAP and LCI data from the Finger Lakes region. This report contains lake results from smaller lakes, ponds and reservoirs (not the eleven Finger Lakes) in the Finger Lakes basin, to provide some geographic context for evaluating water quality conditions in the Finger Lakes.

**(5) 2017 Finger Lakes Water Quality Report**

# Section 4: Major Water Quality Indicators

The water quality and overall health of a lake ecosystem can be assessed visually, determined with field measurements, or evaluated through chemical analyses. CSLAP employs all three techniques in monitoring and assessment of lake conditions. The individual lake chapters in Section 9 of this report provide the condition estimates for all 28 sites monitored in the Finger Lakes in 2018. As indicated in Tables 2-4, the programs were slightly different between lakes, so the results described in this report will be limited to ***summer average values (defined as June through September) for the open water, surface samples*** for indicators common to all lakes.

This approach provides consistency, not only for these lakes in 2018, but for the traditional approach for evaluating NYS surface waters and trophic state (Section 5). It is also important to note that this look into current water quality of the Finger Lakes is limited to two years. The Individual Lake chapters Contain a summary of historical NYSDEC data available for these lakes. While this report refers to several investigations of water quality for comparison to 2018, **the authors would like to qualify any apparent changes described here should be viewed cautiously – with large lake systems like the Finger Lakes, multiple years of data are required for accurate assessments** of trend. The 2017-2018 data sets presented in this report are brief snapshots, highly dependent on the environmental conditions specific to these two years and any apparent changes in water quality over time will become clearer with the addition of subsequent data. Summer average lake values for all water quality indicators are presented in Table 8.

## Summer Average Conditions: Major Water Quality Parameters

### Total Phosphorus (TP)

In most temperate freshwater systems, including the Finger Lakes, **phosphorus** is the nutrient most often limiting algal growth

Trophic status is driven primarily by phosphorus, since phosphorus usually limits the amount of algae growth in temperate freshwater lakes. There are multiple forms of phosphorus, and the amount of soluble, "available" phosphorus often dictates additional growth of algae. However, these other forms are difficult to monitor and can vary significantly between water, algal cells, and sediment, often within very short timeframes. The primary measure of phosphorus is referred to as "total" phosphorus (TP), which measures all forms of phosphorus in a sample. It is recorded as milligrams per liter (mg/L), or parts per million (ppm). Concentrations less than 0.010 mg/L are generally indicative of oligotrophic lakes (low nutrient, low biological production), and low susceptibility for excessive algae growth and harmful algal blooms, at least within large portions of the lake. Concentrations above 0.020 mg/L indicate an increasing susceptibility to widespread or frequent shoreline blooms and are typical of eutrophic lakes (high nutrient, highly biologically productive). Measurements between these thresholds are generally typical of mesotrophic lakes. In 1993, NYSDEC designated a TP threshold of 0.020 mg/L as the state guidance value associated with poor aesthetic quality.

In 2018, 151 NYS CSLAP lake sites were analyzed for TP. The summer average TP ranged from 0.003 to 0.275 mg/L (Figure 2a). The interquartile range (IQR; range between the $25^{th}$ and $75^{th}$ percentiles) was 0.008 to 0.023 mg/L with a median statewide concentration of 0.012 mg/L (mean = 0.021 mg/L).

Summer average TP concentrations in the eleven Finger Lakes (Figure 2b) varied between 0.004 (Skaneateles) and 0.033 mg/L (Honeoye), meaning that the minimum and maximum concentrations in the Finger Lakes were outside the NYS interquartile range. Several lakes were at or below the $25^{th}$ percentile of NYS lakes in 2018 (TP < 0.008 mg/L). Conesus, Cayuga, and Otisco summer average TP exceeded the NYS median (greater than 0.012 mg/L) but were lower than NYS average for TP (0.021 mg/L). In addition, two lakes (Conesus and Honeoye) reached or exceeded NYS recreational guidance value for TP (0.020 mg/L) and Honeoye exceeded the 75th percentile of NYS lakes in 2018. Figure 3 shows the geographical distribution of TP in the Finger Lakes.

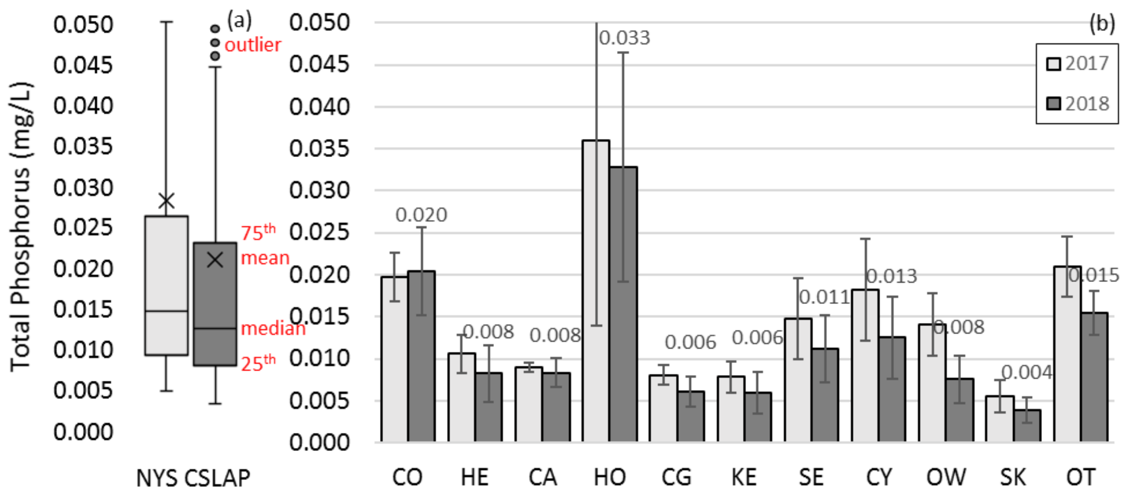



**Figure 2.** Summer average, open water, surface TP concentrations (mg/L) in 2017 and 2018: (a) in all NYS CSLAP lakes and (b) in the 11 Finger Lakes (the X axis is ordered from left to right proceeding from west to east). In panel (a) the upper and lower edges of the box show 3rd and 1st quartile ranges, upper and lower whiskers show 1st and 4th quartile, central line is the median, "X" marks the mean, and circles represent outliers for all NYS lakes. In panel (b), bar height and numbers show the average for each lake, error bars are ±1 standard deviation for each of the Finger Lakes.

**Table 8.** 2018 Summer average (June 1 through September 30) conditions of surface samples by lake with variability statistics

| Lake | Temp. (°C) | SD (m) | Chl-a (µg/L) | TP (mg/L) | TDP (mg/L) | SRP (mg/L) | TN (mg/L) | TDN (mg/L) | $NO_X$ (mg/L) | $NH_3$ (mg/L) | pH | SC (µS/cm) | Color (CU) | $Cl^-$ (mg/L) | $Ca^{2+}$ (mg/L) | %BGA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO** | 24.1 | 2.6 | 9.31 | 0.020 | 0.009 | 0.001 | 0.480 | 0.408 | 0.005 | 0.021 | 7.6 | 410 | 5 | 51.5 | 29.6 | 32% |
| | (2.4) | (0.8) | (5.0) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.0) | (0.0) | (0.4) | (38.2) | (2.7) | (10.6) | (2.2) | |
| **HE** | 22.4 | 4.1 | 3.50 | 0.008 | 0.004 | 0.000 | 0.345 | 0.263 | 0.027 | 0.018 | 7.5 | 273 | 5 | 33.3 | 20.3 | 4% |
| | (2.7) | (0.6) | (1.2) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.0) | (0.0) | (0.4) | (23.1) | (2.4) | (4.7) | (2.8) | |
| **CA** | 23.6 | 4.5 | 4.18 | 0.008 | 0.004 | 0.000 | 0.280 | 0.214 | 0.005 | 0.015 | 7.4 | 233 | 5 | | 15.0 | 26% |
| | (2.5) | (1.6) | (2.7) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.0) | (0.0) | (0.3) | (12.8) | (2.2) | | (1.8) | |
| **HO** | 23.3 | 1.8 | 27.50 | 0.033 | 0.017 | 0.002 | 0.619 | 0.521 | 0.006 | 0.040 | 7.6 | 259 | 7 | 29.5 | 18.6 | 71% |
| | (1.8) | (0.8) | (21.1) | (0.0) | (0.0) | (0.0) | (0.2) | (0.1) | (0.0) | (0.0) | (0.6) | (24.9) | (2.7) | (5.6) | (2.0) | |
| **CG** | 23.3 | 5.6 | 2.31 | 0.006 | 0.003 | 0.001 | 0.376 | 0.305 | 0.076 | 0.013 | 7.6 | 403 | 3 | 45.7 | 30.9 | 22% |
| | (2.0) | (1.4) | (1.0) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.1) | (0.0) | (0.4) | (35.7) | (2.3) | (0.6) | (5.5) | |
| **KE** | 23.5 | 6.7 | 2.23 | 0.006 | 0.002 | 0.001 | 0.351 | 0.272 | 0.048 | 0.015 | 7.8 | 315 | 4 | 27.6 | 23.5 | 29% |
| | (2.0) | (1.1) | (0.8) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.0) | (0.0) | (0.5) | (44.5) | (2.0) | (11.4) | (4.3) | |
| **SE** | 21.5 | 3.7 | 5.43 | 0.011 | 0.007 | 0.001 | 0.551 | 0.485 | 0.214 | 0.031 | 7.7 | 639 | 3 | 126.1 | 32.1 | 3% |
| | (2.5) | (1.0) | (2.3) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.1) | (0.0) | (0.3) | (100.5) | (2.2) | (14.4) | (1.7) | |
| **CY** | 21.8 | 3.6 | 4.07 | 0.013 | 0.005 | 0.001 | 1.080 | 0.977 | 0.783 | 0.024 | 7.6 | 431 | 3 | 48.7 | 26.4 | 9% |
| | (2.9) | (0.9) | (1.3) | (0.0) | (0.0) | (0.0) | (0.2) | (0.3) | (0.1) | (0.0) | (0.3) | (40.0) | (2.3) | (6.1) | (6.9) | |
| **OW** | 23.4 | 3.7 | 3.40 | 0.008 | 0.004 | 0.000 | 0.948 | 0.838 | 0.582 | 0.022 | 7.5 | 273 | 3 | 20.6 | 31.6 | 1% |
| | (2.0) | (0.8) | (1.8) | (0.0) | (0.0) | (0.0) | (0.2) | (0.3) | (0.2) | (0.0) | (0.4) | (50.4) | (1.9) | (7.8) | (4.3) | |
| **SK** | 22.5 | 8.5 | 0.95 | 0.004 | 0.002 | 0.001 | 0.563 | 0.471 | 0.334 | 0.017 | 7.4 | 280 | 1 | 21.4 | 28.8 | 30% |
| | (2.2) | (1.4) | (0.4) | (0.0) | (0.0) | (0.0) | (0.1) | (0.1) | (0.0) | (0.0) | (0.3) | (23.4) | (1.1) | (0.6) | (2.1) | |
| **OT** | 23.8 | 2.5 | 5.94 | 0.015 | 0.005 | 0.000 | 0.568 | 0.489 | 0.215 | 0.025 | 7.8 | 360 | 5 | 38.5 | 32.9 | 20% |
| | (2.7) | (0.6) | (2.5) | (0.0) | (0.0) | (0.0) | (0.2) | (0.2) | (0.1) | (0.0) | (0.4) | (51.9) | (3.0) | (3.9) | (6.3) | |

* all parenthetic values represent one standard deviation difference from the summer average

The eleven Finger Lakes were very low in TP, compared with smaller lakes and ponds in the broader Finger Lakes basin. In the "2017 Finger Lakes Regional Lakes Report" (NYSDEC 2017) the average TP for all the lakes in the region was 0.075 mg/L and ranged from 0.013 to ~ 0.150 mg/L.

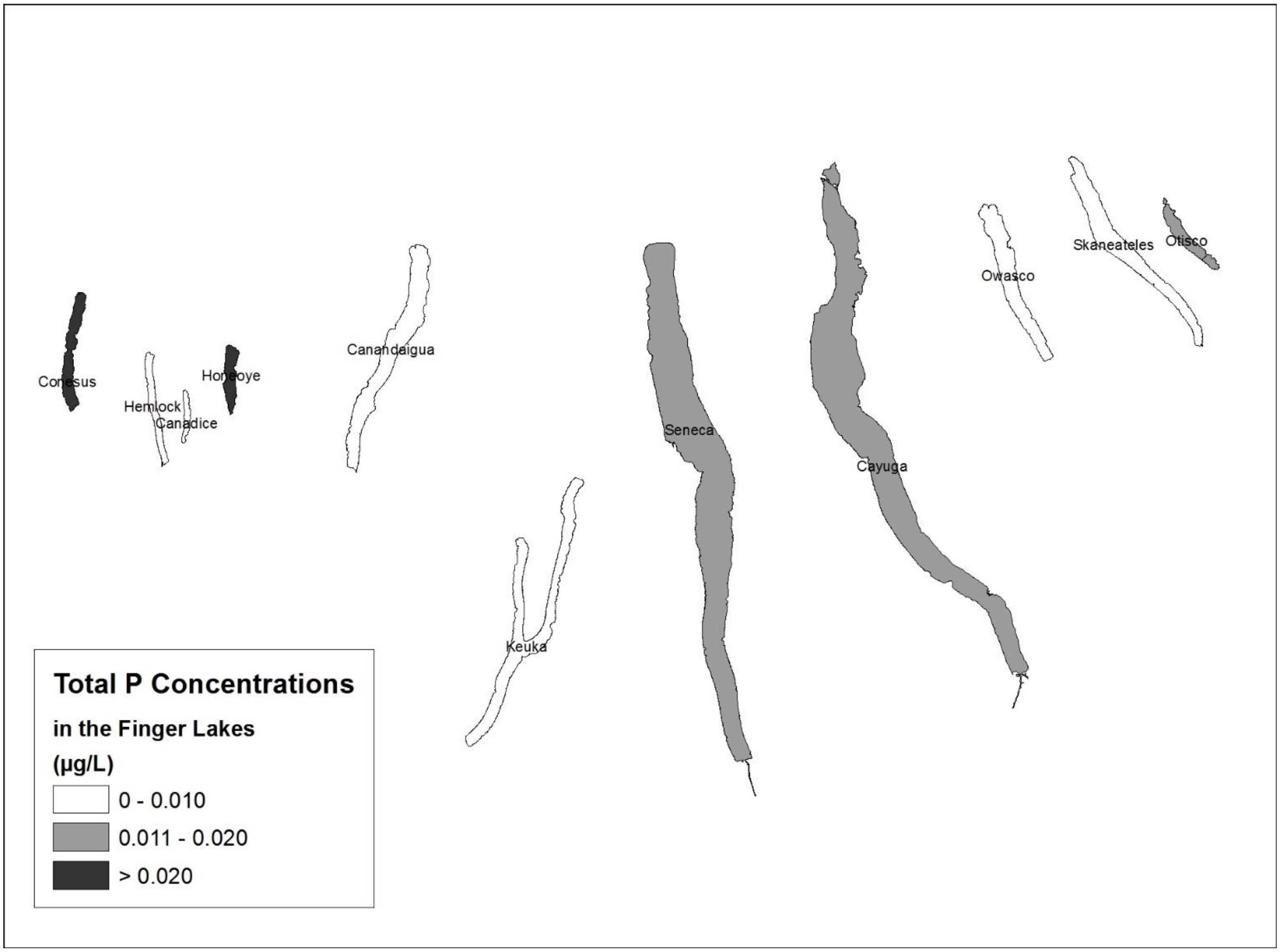



**Figure 3.** Distribution in lake average TP concentration in the Finger Lakes in 2018. Shading corresponds to NYSDEC trophic criteria for TP.

Previous investigations of TP in the Finger Lakes are presented in Figures 4a and 4b. Hemlock, Canadice, Owasco and Skaneateles Lakes have seen little change in their TP concentrations since the 1970s. In contrast, Honeoye and Otisco Lakes have experienced notable increases since the 1970s. Honeoye TP has increased from 0.019 mg/L to ~ 0.033 mg/L in 2017-2018 (roughly double) while Otisco Lake summer average TP has more than doubled since the 1970s (Bloomfield 1978). Some lakes, notably Canandaigua, Keuka, Seneca, and Cayuga, exhibited decreases in TP from the 1970s to the late 1990s. For Cayuga and Seneca, 2017-2018 TP concentrations have increased to near 1970's concentrations since the late 1990s. Skaneateles, Keuka, Hemlock and Canadice Lake TP concentrations have remained relatively stable since the late 1990s. The TP concentration in Owasco Lake has increased slightly since the 1990s but current TP values are within 0.002 mg/L of the data presented in Bloomfield 1978.

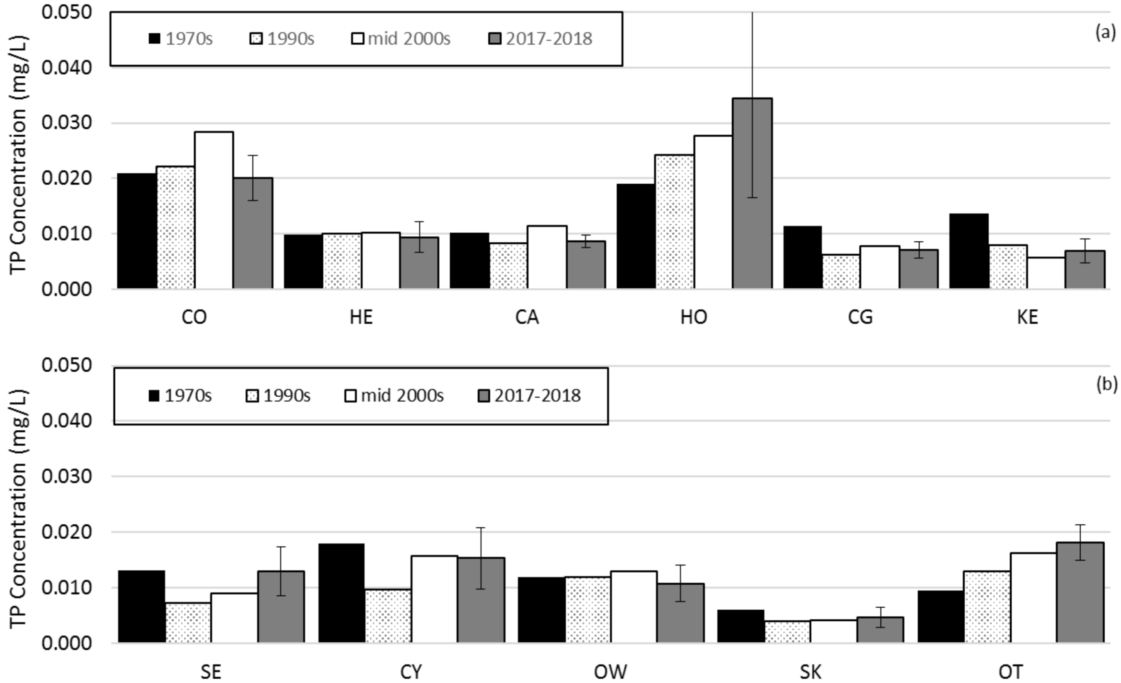



**Figure 4.** TP concentrations (mg/L) in the Finger Lakes from the 1970s (Bloomfield 1978), 1990s (Callinan 2001), mid 2000s (Callinan et al. 2013) and 2017-2018 average for: (a) the western lakes and (b) the eastern lakes. Note that the TP values from the 1970s were from winter samples.

## Chlorophyll-*a* (Chl-a)


Filamentous Green Algae

What most people refer to as "algae" is actually a highly diverse group of photosynthetic microscopic organisms referred to broadly as "phytoplankton" that include floating, suspended, and benthic forms. The broader term also includes photosynthesizing cyanobacteria that were once referred to as blue-green algae, but generally does not include macroalgae, more frequently (and mistakenly) considered to be "weeds." The amount of algae, or biomass, in a lake or pond can appear to be dominated by any of these forms, but suspended phytoplankton usually represents much of the biomass, and thus serves as the base for the overall aquatic food chain. This is also the form most commonly analyzed in monitoring programs.

As with TP, trophic status can be determined by measurements of suspended phytoplankton. This can be achieved in several ways, such as cell count, but is most frequently quantified by the measurement of chlorophyll *a* (Chl-a), a photosynthetic pigment found in all freshwater phytoplankton, including cyanobacteria. Chl-a readings less than 2 parts per billion (or micrograms per liter; µg/L) are generally indicative of oligotrophic lakes. Readings above 8 parts per billion are typical of eutrophic lakes that are susceptible to persistent water quality problems. Readings between these thresholds are generally typical of mesotrophic lakes.

NYSDEC has not formally adopted a target Chl-a threshold (water quality standard or guidance value) for lakes and ponds, but NYS research has identified that Chl-a concentrations greater than 10 µg/L can result in reduced water clarity, degradations in aesthetic and recreational water quality, and increased frequency of open water and shoreline algal blooms (NYSDEC 2010).

Chl-a was highly variable in NYS CSLAP lakes in 2018 with summer average values ranging from less than 1 to greater than 100 µg/L (Figure 5a). The interquartile range was 2.3 to 10.2 µg/L with a median statewide concentration of 4.2 µg/L (mean = 9.3 µg/L).

Skaneateles, Canandaigua and Keuka Lakes had the lowest Chl-a concentrations, averaging at or below 2.3 µg/L in 2018 (i.e., less than the 25th percentile of CSLAP lakes). Honeoye had the highest average concentration, of 27.5 µg/L, significantly higher than the next most productive Finger Lake, Conesus (9.3 µg/L; Figure 5b). Conesus, Honeoye, Seneca, and Otisco all had Chl-a values greater than the NYS median (4.2 µg/L). These values fall in the expected range given the TP levels for these lakes, as expected given the strong relationship between phosphorus and chlorophyll in most NYS lakes (see the section "Relationships Between Major Trophic Indicators" later in this document).

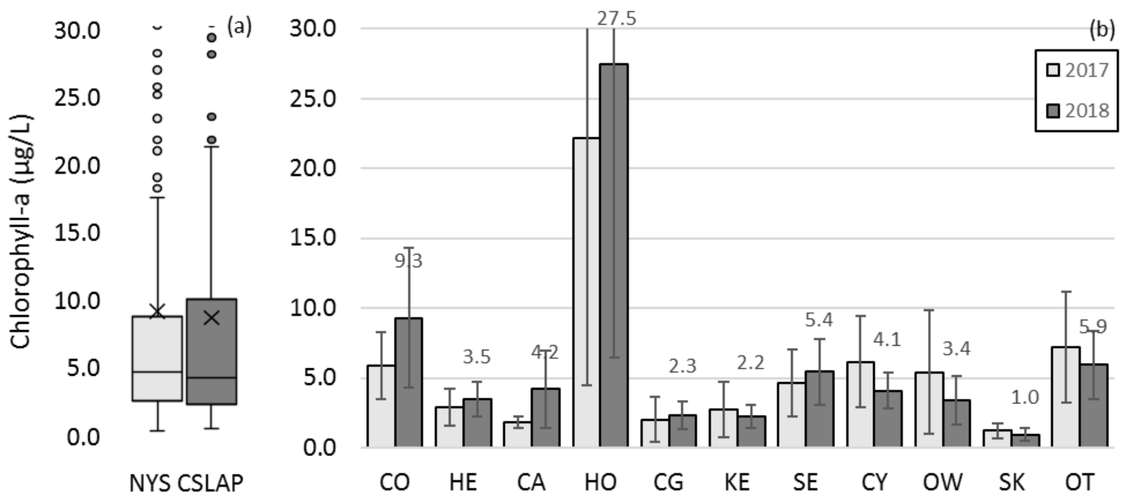



**Figure 5.** Summer average, open water, surface Chl-a concentrations (µg/L) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

Average Chl-a for the lakes in the Finger Lakes region listed in the 2017 Finger Lakes Region Lakes Report (CSLAP and LCI lakes from 2012-2016) was 32 µg/L and ranged in summer average Chl-a from 3 to 160 µg/L (NYSDEC 2017). Other than Honeoye Lake, Chl-a levels in the Finger Lakes were substantially lower than the smaller lakes and ponds in the region. The discussion of historical changes in Chl-a will be reserved for the Trophic State discussion in Section 5.

### Secchi Disk Clarity (SD)

Secchi disk

The transparency of the water- "how clear is it?"- is one of the fundamental measures of water quality, due to its relationship with other limnological indicators such as algal production, and the connection between water transparency and public use. Water transparency, also referred to as water clarity, is closely connected to the amount of suspended and dissolved material in the water. The suspended material is comprised of both phytoplankton and suspended particles, and the dissolved material relates to brownish color imparted by dissolved organic matter. In most deep lakes, like the Finger Lakes, water clarity is very closely related to phytoplankton, while in shallower lakes, water clarity is influenced by algae, suspended sediment, and natural brownness.

The Secchi disk was invented by Angelo Secchi, the Director of the Vatican Observatory, to measure the clarity of the water in the Mediterranean Sea. For freshwater use, the Secchi disk is a black and white quadrant disk, 20 cm in diameter affixed to a tape measure. The disk is lowered through the water column to estimate the depth of water clarity. This simple and economical design has been used since 1865 as an indirect method of measuring the clarity of water in lakes all over the world. The device was also used in the Finger Lakes by the earliest researchers (Birge and Juday) in 1910.

As with TP and Chl-a, trophic status can be assessed by measurements of water clarity. Water clarity readings greater than about 5 meters are generally indicative of oligotrophic lakes. Readings less than 2 meters indicate eutrophic conditions. Readings between these thresholds are generally typical of mesotrophic lakes. NYSDEC has not formally adopted a target water clarity threshold (water quality standard or guidance value) for lakes and ponds, although NYSDOH will not site a new swimming beach unless water clarity exceeds 4 feet (or about 1.2 meters).

As with TP and Chl-a, Secchi disk clarity measurements were also highly variable in 2018 CSLAP lakes. Summer average clarity ranged from less than 1 to 8.5 m with an interquartile range of 1.7 to 4.5 m. The median statewide Secchi depth was 3.0 m (mean = 3.3 m; Figure 6a). The Secchi depth measurement range for the Finger Lakes varied between 1.8 m (Honeoye) and 8.5 m (Skaneateles). Skaneateles and Keuka Lakes had the greatest average lake clarity, with both having Secchi disk depths greater than 6 m (Figure 6b).

Conesus, Honeoye, and Otisco Lakes had SD lower than the state's median value of 3.0 m (2.6 m, 1.8 m, and 2.5 m, respectively). Canandaigua and Canadice had clarity values greater than the state's 75$^{th}$ percentile (> 4.5 m).

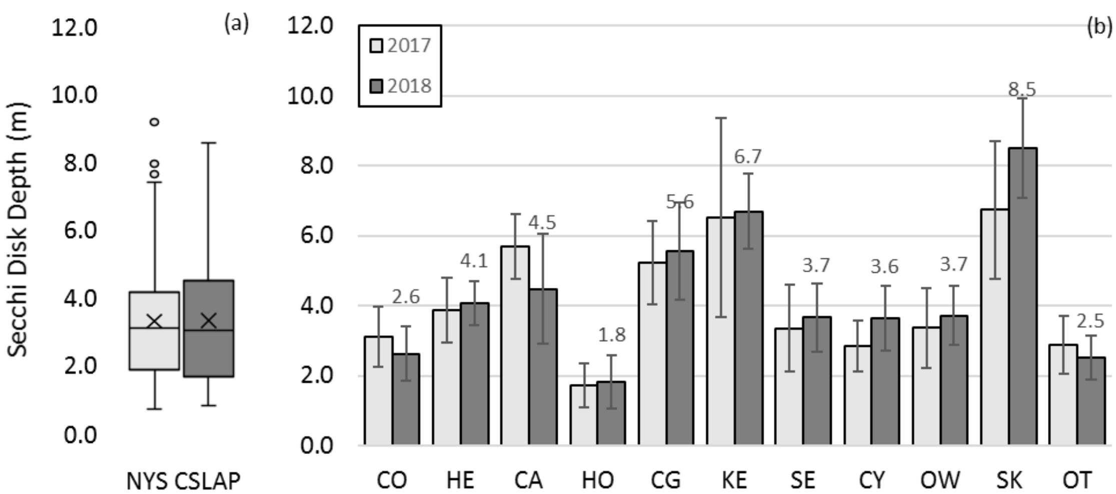



**Figure 6.** Secchi Disk depth (m) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

The eleven Finger Lakes generally had much higher clarity compared with smaller lakes and ponds in the Finger Lakes region (NYSDEC 2017). Average Secchi disk depth in the smaller lakes was 1.8 m with a range between 0.4 and 3.5 m.

The Finger Lakes have a long history of Secchi disk measurements, starting in the early 1900's with the classic limnological investigations of Birge and Juday (1914). Trends in water clarity have varied between lakes: some lakes have severely degraded in clarity, while others had higher contemporary clarity in 2017-2018 compared with the early 20$^{th}$ century (Figure 7). Despite differences in magnitude of changes, most lakes have experienced the same general trend since the turn of the last century: (1) water clarity degradation from 1910 to the 1970s, (2) improvements in clarity from the 1970s to the late 1990s – but with the 1990s rarely being clearer than 1910, (3) minor changes (both positive or negative) from the late 1990s to the mid-2000s and to 2017-2018.

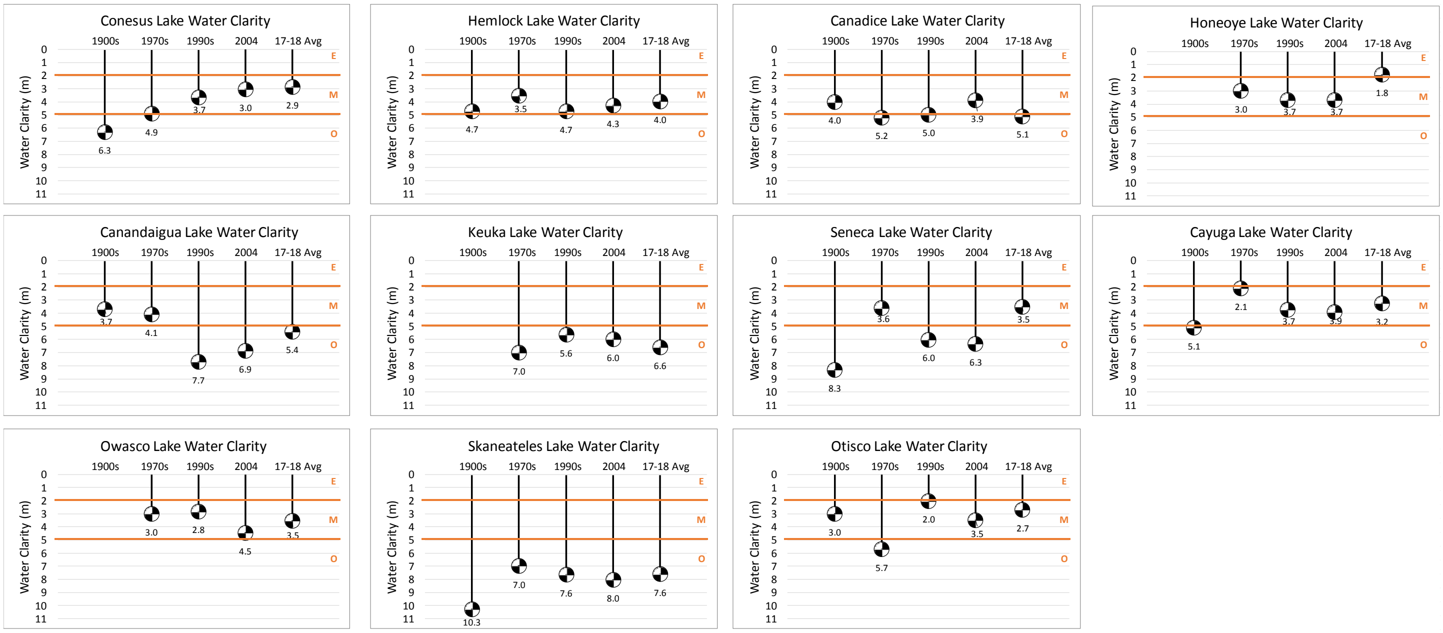



**Figure 7.** Summer average SD (m) for the Finger Lakes from 1910 (Birge and Juday 1914 [if available], Bloomfield 1978, Callinan 2001, 2013) to 2017 and 2018. The panels are arranged from west to east, starting the upper left. Note the letters correspond to trophic state boundaries for SD; E – eutrophic, M – mesotrophic, and O – oligotrophic.

## Relationships Between Major Trophic Indicators

Surface Chl-a observations were positively correlated with TP concentrations in NYS lakes in 2018. That is as TP concentrations increased, Chl-a concentrations also increased. The relationship was strong with summer average TP explaining 79% ($R^2$, also called the coefficient of determination, a metric of statistical fit-see box on the right) of the variability in summer average Chl-a for individual observations (Figure 8). At TP concentrations near the NYS guidance value (0.020 mg/L), Chl-a concentrations varied from ~ 1 µg/L to > 10 µg/L indicating that while TP is an important in promoting algal growth: (1) TP is a composite measurement that includes dissolved forms and non-algal particles such as resuspended sediment and (2) factors other than TP (e.g., light, temperature, and grazing pressure) are important in determining Chl-a concentrations in NYS lakes. The relationship between TP-Chl-a for the Finger Lakes was consistent with the NYS TP-Chl-a relationship as all the Finger Lakes values were within the scatter of the larger pool of NYS lakes (Figure 8). Most Finger Lakes had observations above the best-fit line indicating that these lakes had higher Chl-a levels for their respective TP concentrations in 2018 compared with other NYS lakes.

> The $R^2$ is also called the coefficient of determination. The $R^2$ can range from 0 to 1 with a 0 indicating the predictor (for example, TP) explains 0 percent of the variation in the response variable (for example, Chl-a). An $R^2$ of 1 would mean that the predictor explains 100% of the variability in the response. $R^2$ values of greater than 0.7 typically indicate a strong relationship.

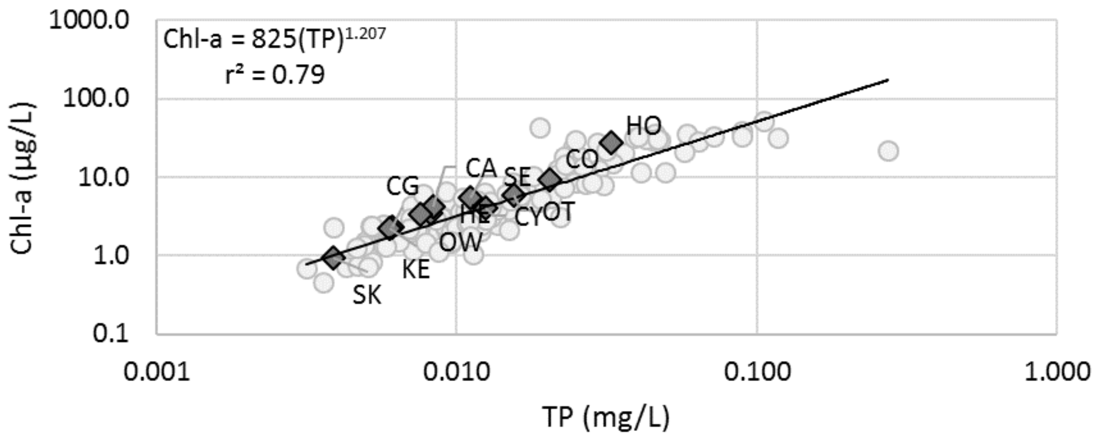



**Figure 8.** Relationship between summer average TP concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2018 NYS CSLAP dataset (gray circles) with the Finger Lakes as diamonds. Note the scale is log-log with the NYS statistical best-fit relationship is presented (solid line).

Chl-a concentrations were negatively correlated with Secchi disk depth (Figure 9). That is, as Chl-a increased, Secchi disk depth generally decreased. The relationship for all CSLAP observations was strong with Chl-a explaining 70% of the variability in clarity. Secchi disk depth was highly variable at all levels of Chl-a concentration. At Chl-a concentrations of 4 µg/L, clarity measurements less than ~2 m (eutrophic) and greater than 6 m (oligotrophic) were observed. This is not unexpected given that many factors regulate water clarity in a lake, including: (1) type of algal community, (2) water color and dissolved organic matter, (3) sediment laden runoff from the watershed following intense rain storms, (4) resuspended nearshore sediments transported to the open water during wind events, and (5) internal production of calcium carbonate (i.e., whiting events). In addition, these relationships are less robust when Chl-a measurements are very low and within the range of variability in the analytical tests. Like TP-Chl-a, the relationship between Chl-a-SD for the Finger Lakes was consistent with the NYS Chl-a-SD relationship (Figure 9). All the Finger Lakes had slightly better clarity for a given Chl-a concentration in 2018 compared with other NYS lakes.

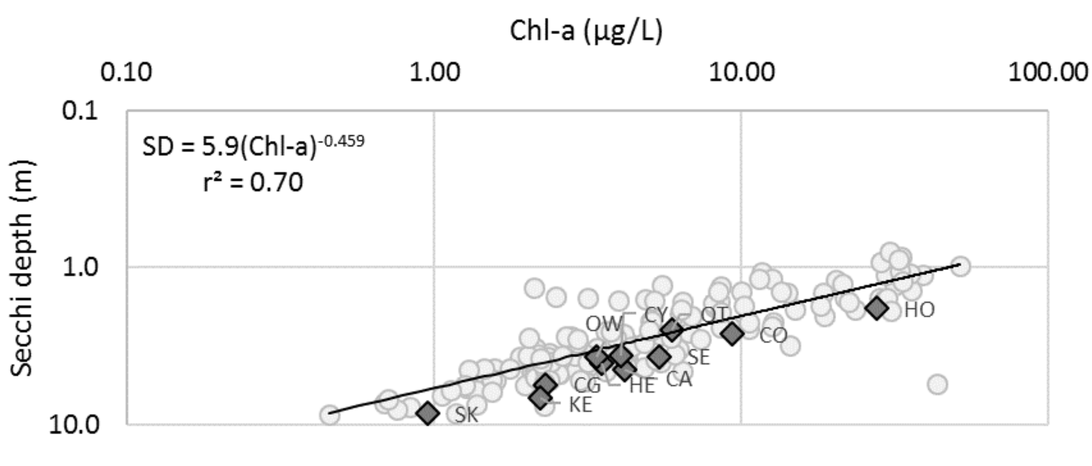



**Figure 9.** Relationship between Chl-a concentrations (µg/L) and Secchi disk clarity (m) for all paired observations in the 2018 CSLAP dataset (gray circles) with the Finger Lakes as diamonds. Note the scale is log-log with the NYS statistical best-fit relationship is presented (solid line).

TP was a good predictor of Secchi disk clarity in all 2018 NYS lakes (Figure 10) with the overall relationship similar to Chl-a-SD (Figure 9). Because TP includes all types of P in the sample (algal and suspended sediment), it is not unexpected that TP by itself would be a good predictor of clarity, especially in moderate to low biological production ecosystems. In NYS lakes in 2018, TP explained 72% of the variability in Secchi depth. The relationship between TP-SD for the Finger Lakes was consistent with the NYS TP-SD.

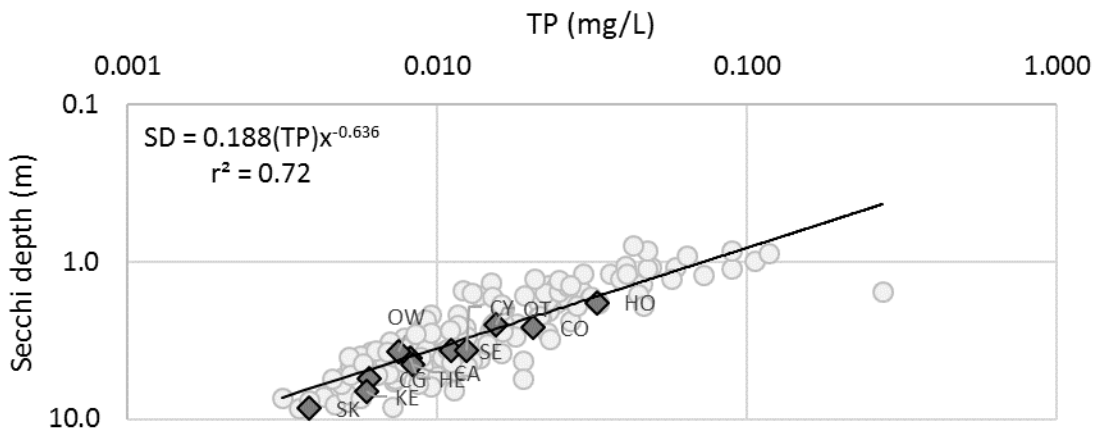



**Figure 10.** Relationship between TP concentrations (mg/L) and Secchi disk clarity (m) for all paired observations in the 2018 CSLAP dataset (gray circles) with the Finger Lakes as diamonds. Note the scale is log-log with the NYS statistical best-fit relationship is presented (solid line).

Figure 11a shows the relationships between the summer average values of TP and Chl-a for the Finger Lakes in 2018. On a summer average basis, open water TP explained 94% of the variability in open water Chl-a. The relationship between phosphorus and algae has been well established, going back to at least the 1950s. The P-limitation mechanism was elegantly highlighted in the pioneering work by Dr. David Schindler in the Canadian Experimental Lakes Area in the 1970s (Schindler 1977). This research, confirmed by many studies in the following decades, formed the basis for the foundational principle of lake management linking phosphorus limitation with algae control. In many lakes, phosphorus serves as the primary limiting factor controlling algae growth during the summer growing season- increasing phosphorus, particularly soluble phosphorus, will increase algae levels. Interestingly, the 2018 relationship between TP-Chl-a for the Finger Lakes appears to have changed very little since the late 1990s (Figure 11b; Callinan 2001).

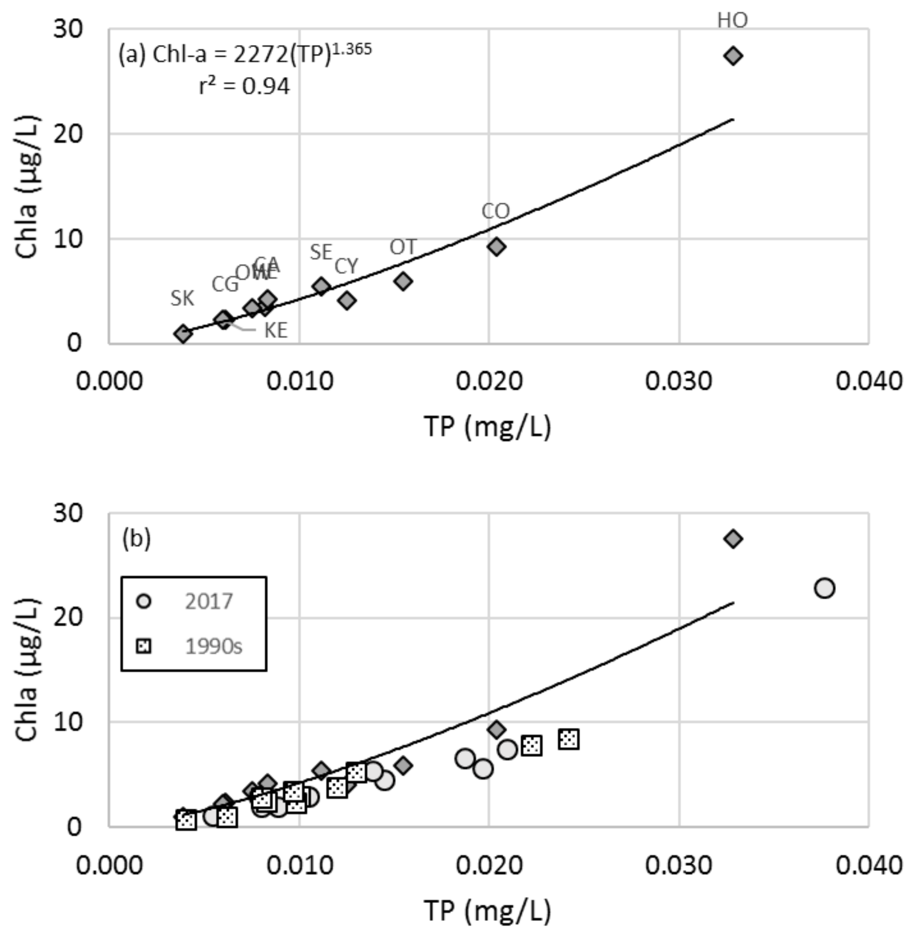



**Figure 11.** Relationships between major trophic state metrics for lake summer average values for: (a) TP (mg/L) – Chl-a (µg/L) in 2018, (b) TP (mg/L) – Chl-a (µg/L) in previous years. 2018 Finger Lakes as diamonds.

The relationship between summer average Chl-a and Secchi depth was strong in 2018 with open water Chl-a explaining more approximately 90% of the variation in clarity (Figure 12a). As with TP-Chl-a, the relationship between Chl-a-SD appears to have changed very little since the late 1990s (Figure 12b; Callinan 2001), indicating the influence of algal growth on clarity in these lakes on a seasonal scale.

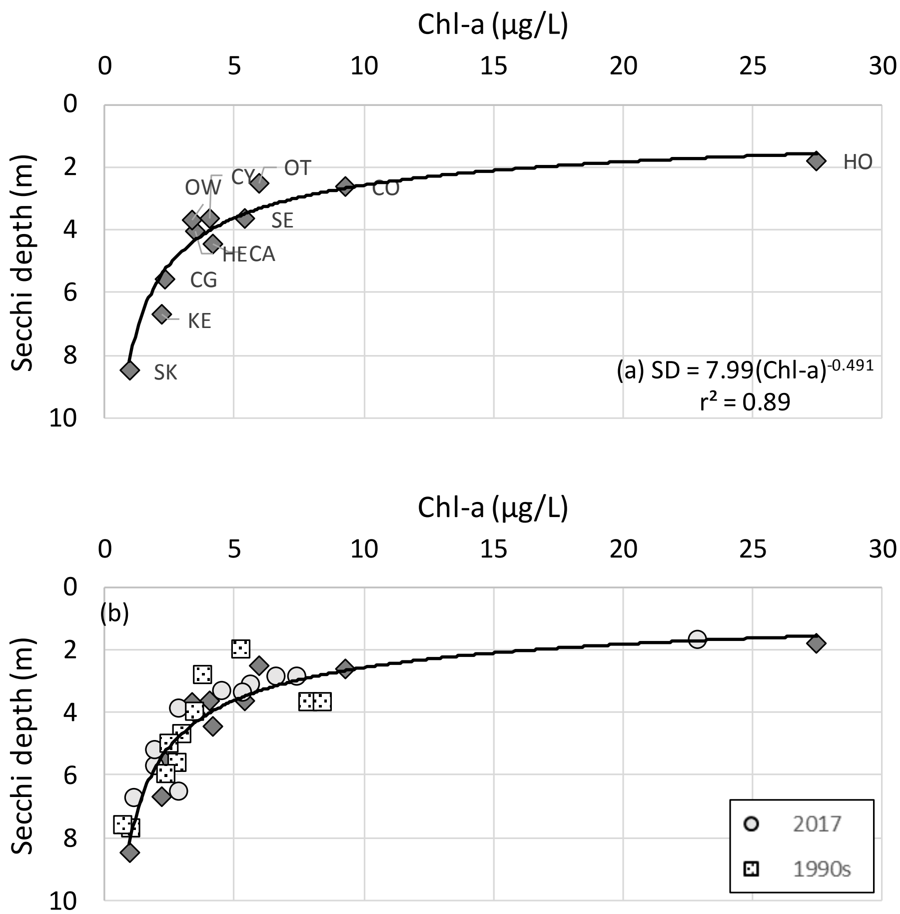



**Figure 12.** Relationships between major trophic state metrics for lake summer average values for: (a) Chl-a (μg/L) – SD (m) in 2018, (b) Chl-a (μg/L) – SD (m) in previous years. 2018 Finger Lakes as diamonds.

Summer average TP explained approximately 92% of the variation in clarity in the Finger Lakes in 2018 (Figure 13a). As with, the other major trophic indicator relationships, the contemporary relationship between TP-SD was very similar to the late 1990s (Figure 13b; Callinan 2001) indicating: (1) the role of TP influencing algal growth and therefore, clarity in the Finger Lakes and (2) the effect of the inorganic TP forms, like suspended sediment, on Secchi depth.

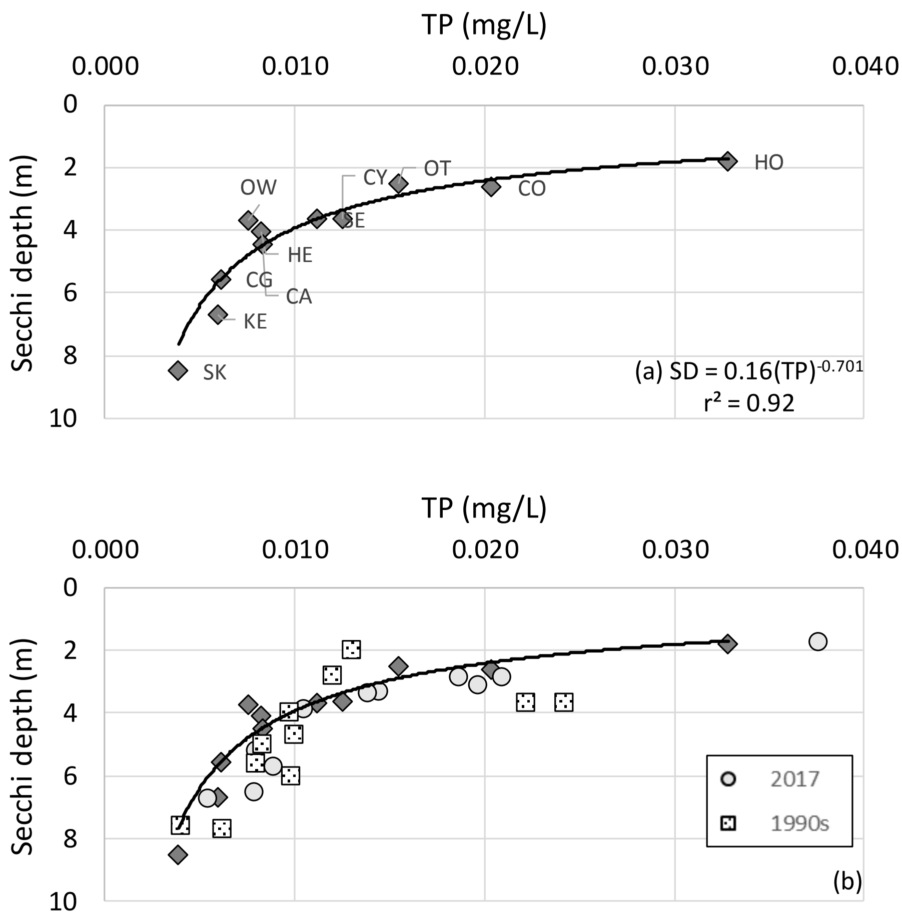



**Figure 13.** Relationships between major trophic state metrics for lake summer average values for: (a) TP (mg/L) – SD (m) in 2018, (b) TP (mg/L) – SD (m) in previous years. 2018 Finger Lakes as diamonds.

## Total Nitrogen (TN)

Several forms of nitrogen are collected and analyzed in the CSLAP program. These forms include nitrate + nitrite (NOx), ammonia ($NH_3$) and total nitrogen (TN). The role of nitrogen in cyanobacteria biomass and cyanotoxins has come under intensive study in recent years. The empirical relationship between any specific nitrogen form and Chl-a is not as strong as the relationship between TP and Chl-a in most NYS lakes. A preliminary investigation of the 2012-2017 CSLAP dataset as part of Governor Cuomo's HABs Initiative in 2018, showed a strong relationship between HABs production and phosphorus rather than nitrogen. However, the specific role of nitrogen, phosphorus, and other bloom "triggers" for any individual lake may be specific to that lake.

Nitrate ($NO_3$) is a form of nitrogen that is available for biological uptake, including uptake by algae. It is more easily analyzed as $NO_X$, or nitrate + nitrite. Nitrite ($NO_2$) is rarely found in surface waters and can be created as an intermediate step in denitrification; the conversion of nitrate into nitrogen gas in the absence of oxygen. Nitrite can be toxic to aquatic life, though it readily converts to nitrate (or other forms of nitrogen) in the presence of oxygen. Toxic levels of nitrite are rarely found in surface waters, although elevated nitrite levels may be found in highly anoxic waters near the bottom of some lakes. Nitrate can be a limiting nutrient for some forms of green algae and may be an important nutrient in some regions of the state, such as Long Island. Nitrate can be an important component of wastewater, stormwater, fertilizers, and soil erosion. Therefore, it can be an indirect surrogate for pollutant loading to lakes, although elevated nitrate readings may be natural in some parts of the state. The oxidized forms of nitrogen $NO_3$, $NO_2$, NO and $N_2O$ are collectively referred to as $NO_X$.

Ammonia is a form of nitrogen produced from nitrogen gas by nitrogen fixation and through the degradation of organic matter generated through several biological processes. It is toxic to aquatic organisms and (to a much lesser extent) humans at concentrations occasionally found in lake water, particularly at high pH or in the absence of oxygen (such as occasionally found in the bottom waters of productive lakes). High ammonia readings may also be a sign of pollution such as stormwater runoff, wastewater treatment plant effluent, or may indicate persistent problems with deoxygenated water.

Total nitrogen is the sum of all component forms of nitrogen—NOx + total Kjeldahl nitrogen (or TKN, which is equal to total ammonia + organic nitrogen). It can also be computed as an independent laboratory analysis, without first analyzing the nitrogen components, as is done by UFI through CSLAP.

There are no water quality standards for total nitrogen, although in some lakes, TN levels above 0.6 mg/L may indicate eutrophic conditions (NYSDEC 2017). The NYS water quality standard for ammonia is 2 mg/L adopted to protect aquatic life (although lower standards for pH dependent forms of ammonia are applied to trout waters), but this is very rarely reached in surface water samples. Elevated ammonia in bottom waters may be an indication of deoxygenation, often in response to excessive algae or other eutrophication measures. The $NO_3$ drinking water standard in NYS is 10 mg/L; this is well above the readings found in NYS lakes. For both NOx and ammonia, readings above 0.300 mg/L could be considered elevated, although elevated nitrogen levels in some lakes may be associated with natural conditions and therefore, not necessarily indicative of water quality problems.

Summer average TN values were extremely variable in NYS CSLAP lakes ranging from 0.209 to 1.479 mg/L (Figure 14a). The interquartile range was 0.348 to 0.641 mg/L with a median statewide concentration of 0.445 mg/L (mean = 0.536 mg/L). TN concentrations in the eleven Finger Lakes were also highly variable, ranging between 0.280 mg/L (Canadice) and 1.080 mg/L (Cayuga) as presented in Figure 14b.

With regards to TN, an interesting geographical pattern was observed, not seen with TP, Chl-a, or SD. Except for Honeoye Lake, all lakes from Keuka – west had summer average TN values less than the NYS mean (< 0.536 mg/L; Figure 14b). The five eastern lakes (Seneca to Otisco) had elevated TN values when compared to the NYS lakes (Figure 14a) and the western Finger Lakes, ranging from 0.551 mg/L to ~1.000 mg/L.

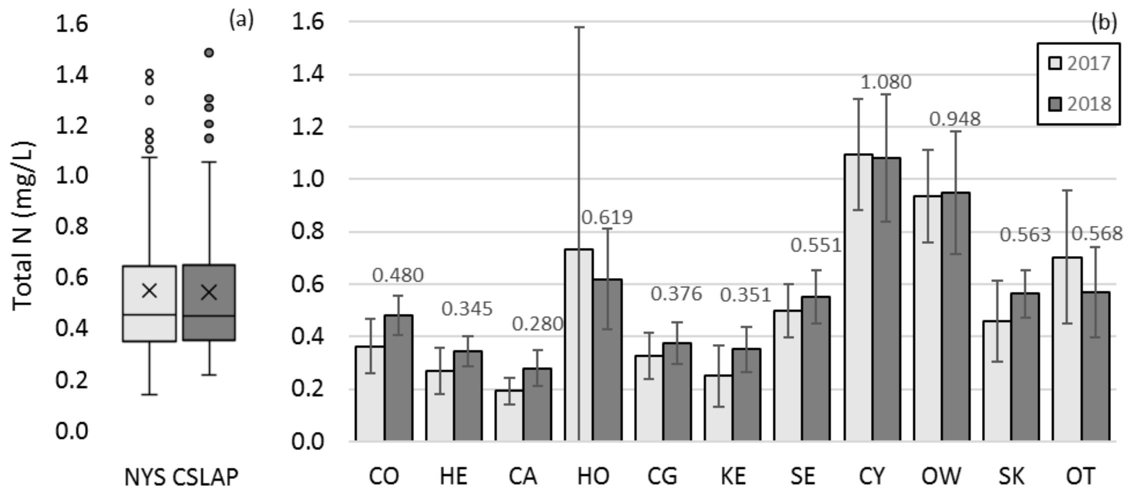



**Figure 14.** Summer average, open water, surface TN concentrations (mg/L) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

## Relationships Between TN, Chl-a, and Clarity

Surface Chl-a observations were positively correlated with TN concentrations in NYS lakes in 2018, although the relationship was weak and extremely variable with TN only explaining 61% of the variability in Chl-a for NYS lakes (Figure 15). The relationship between TN-Chl-a for the Finger Lakes was consistent with the NYS TN-Chl-a relationship as all the Finger Lakes values were within the scatter of the larger pool of NYS lakes (Figure 15). Cayuga, Owasco, and Skaneateles had observations well below the best-fit line indicating that these lakes had lower Chl-a levels for their respective TN concentrations compared with other NYS lakes.

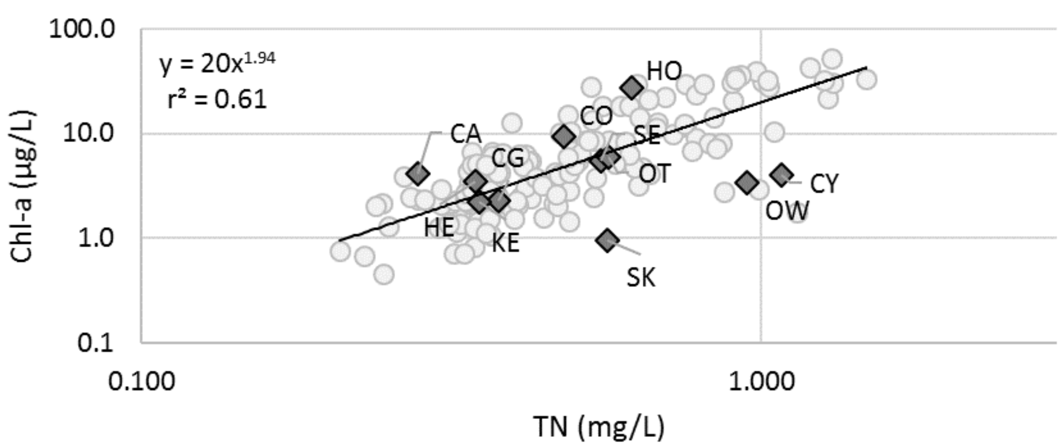



**Figure 15.** Relationship between summer average TN concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2018 NYS CSLAP dataset (gray circles) with the Finger Lakes as diamonds. Note the scale is log-log with the NYS statistical best-fit relationship is presented (solid line).

Figure 16a shows the relationships between summer average TN and Chl-a in the Finger Lakes in 2018. TN was positively correlated with algal growth in the Finger Lakes in 2018, although TN was a poor predictor of summer average Chl-a in these lakes ($R^2$=0.02). The relationship between TN and Chl-a was much weaker than the relationship between TP and Chl-a ($R^2$=0.94; Figure 11a). These observations support the current paradigm of phosphorus promoting algal growth in the Finger Lakes. In fact, as will be discussed subsequently, most of the TN in the Finger Lakes is in soluble forms and therefore would be expected to be somewhat disconnected to primary production and water clarity, since it has not been taken up by algae. As noted earlier, atmospheric nitrogen may be providing a constant source of nitrogen for algal communities dominated by nitrogen-fixing cyanobacteria such as *Dolichospermum* and *Aphanizomenon.*

Figure 16b shows the relationships between the summer average values of TN and Secchi disk clarity in the Finger Lakes in 2018. Generally, TN was correlated with algal growth in the Finger Lakes but was a poor predictor of clarity ($R^2$=0.10). The relationship between TN and SD was much weaker than the relationship between TP and SD (Figure 13a; $R^2$=0.92). TN, unlike TP does not have a strong particulate mineral phase.

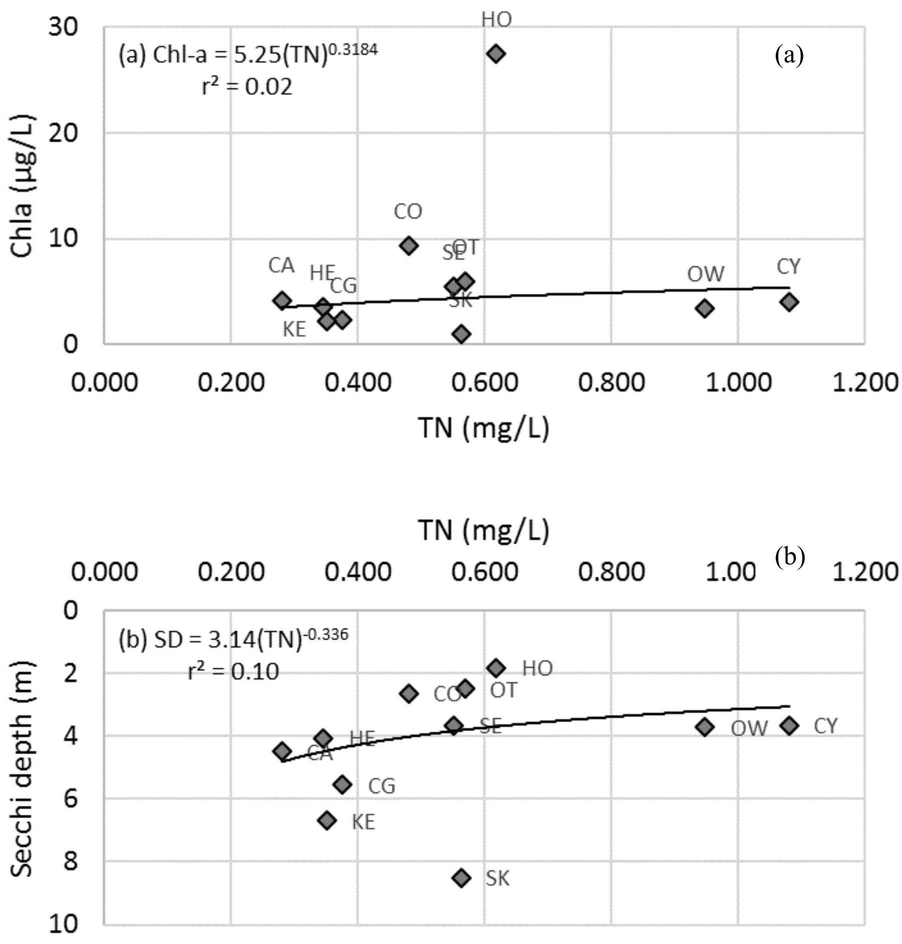



**Figure 16.** Relationships between: (a) summer average TN (mg/L) – Chl-a (µg/L) and (b) TN (mg/L) – Secchi disk clarity (m) in the Finger Lakes in 2018.

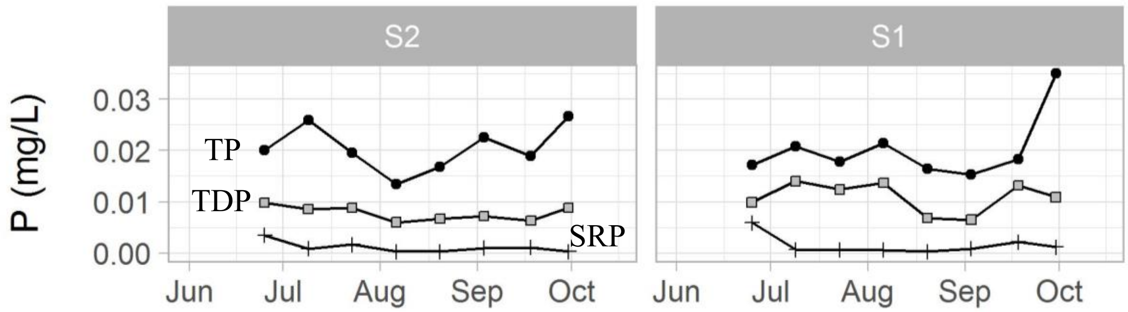
## Seasonal Patterns in Forms of Phosphorus

The seasonal patterns in P varied within and between lakes in 2018 (Figure 17). The proportion of TP that was dissolved (TDP), varied between lakes as well; ranging from ~ 10% of TP in some samples to more than 90% in others. In general, soluble reactive P (SRP) was low in the open-water with concentrations ranging from less than detection to 0.0061 mg/L. This is not unexpected given the high rate of uptake of this from of P by phytoplankton.

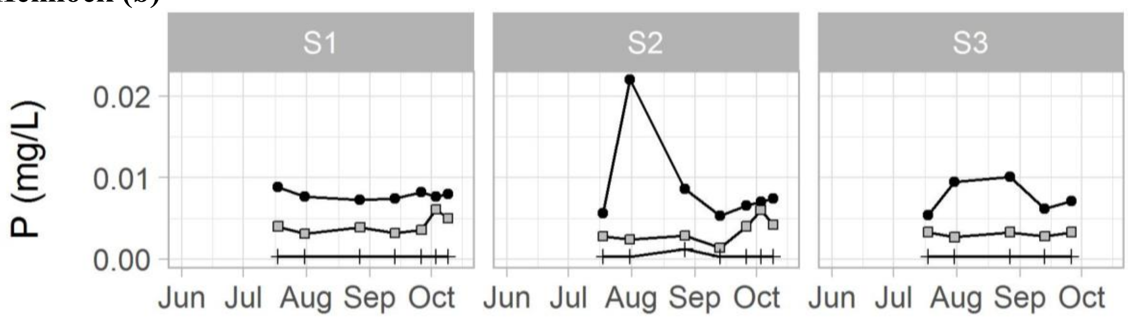
The summary below is a brief characterization of lake P patterns for each of the Finger lakes in 2018. For more detail, see Figure 17.

| Lake | Summary |
|---|---|
| Conesus Lake | • TP fairly constant throughout the season, slight increase in late summer<br>• TDP fairly constant in 2018, varied between 30-70% of TP<br>• SRP was low in 2018, ranging from less than LOD to 0.006 mg/L<br>• No major differences between sites |
| Hemlock Lake | • Large spike in TP in late July (S2) – reason is unknown<br>• TDP was ~ 50% of TP, and ranged from 10% of TP to 85% of TP<br>• All SRP samples were less than detection |
| Canadice Lake | • TP, TP increased throughout the summer<br>• TDP ranged from 22% of TP to 89% of TP<br>• SRP samples were less than detection in early summer, increased to 0.009 mg/L in late summer |
| Honeoye Lake | • TP, TDP increased throughout the summer<br>• TDP ranged from 20% of TP to 77% of TP<br>• SRP were high, averaging 0.0016 in 2018 (maximum was 0.006 mg/L) |
| Canandaigua Lake | • TP, TDP variable throughout the summer, large crash in TP at S2 in August<br>• TDP ranged from 20% of TP to 76% of TP<br>• SRP started low, increased throughout the summer |
| Keuka Lake | • TP, TDP variable throughout the summer, TP increased from July through September<br>• TDP ranged from 13% of TP to 90% of TP<br>• SRP mostly less than detection |
| Seneca Lake | • Patterns were variable between sites<br>• TDP ranged from 20% of TP to 94% of TP<br>• SRP mostly less than detection, maximum value was 0.0022 mg/L |
| Cayuga Lake | • Patterns were variable between sites<br>• TP was mostly low in the spring, increased in summer and declined in fall<br>• TDP ranged from 11% of TP to 89% of TP<br>• SRP was mostly low, highest at site S5 |
| Owasco Lake | • TP was fairly constant throughout the summer, there was a large spike at S2 in July<br>• TDP ranged from 24% of TP to 88% of TP<br>• SRP mostly less than detection |
| Skaneateles Lake | • Patterns were variable between sites<br>• TDP ranged from 19% of TP to 97% of TP<br>• SRP was high in the spring at S1, SRP mostly less than detection throughout the summer |
| Otisco Lake | • TP was fairly constant throughout the summer<br>• TDP ranged from 12% of TP to 46% of TP<br>• SRP mostly less than detection throughout the summer, with a small spike in mid-August |

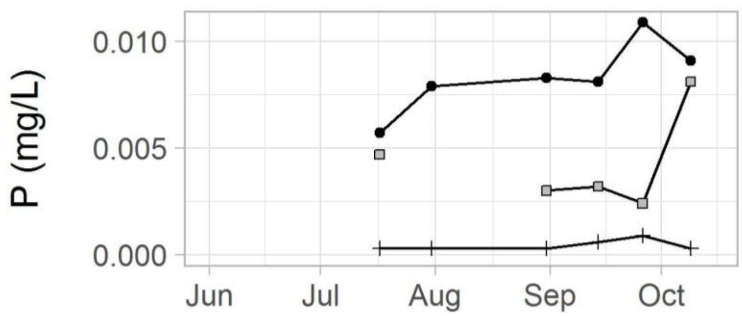
**Conesus (a)**




**Hemlock (b)**




**Canadice (c)**




**Honeoye (d)**

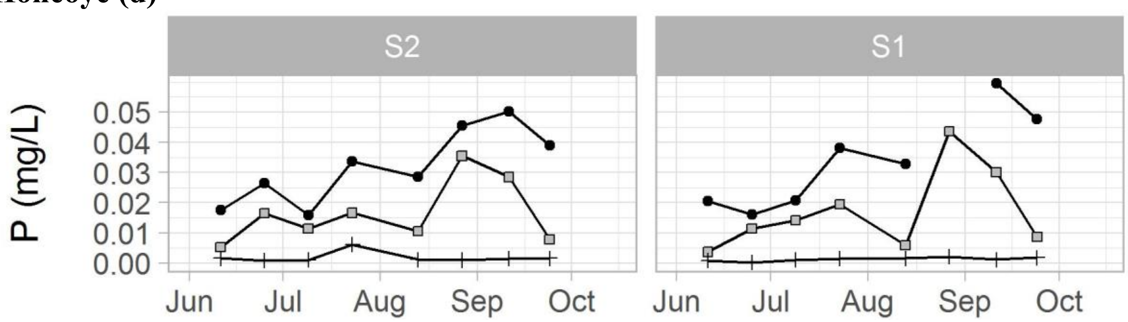
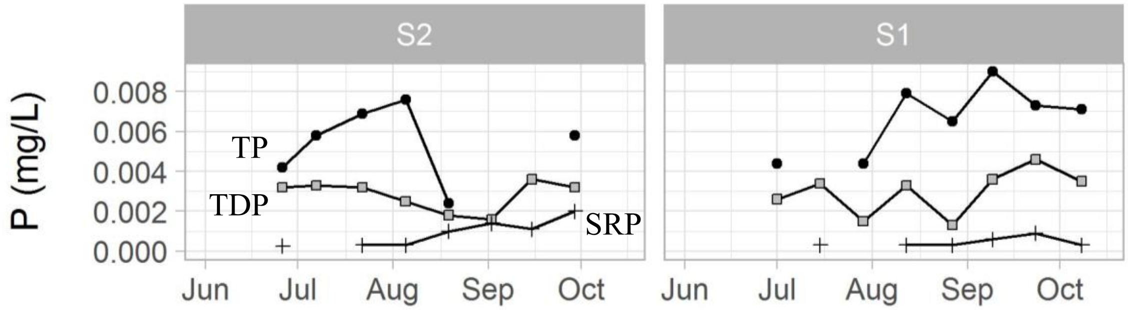
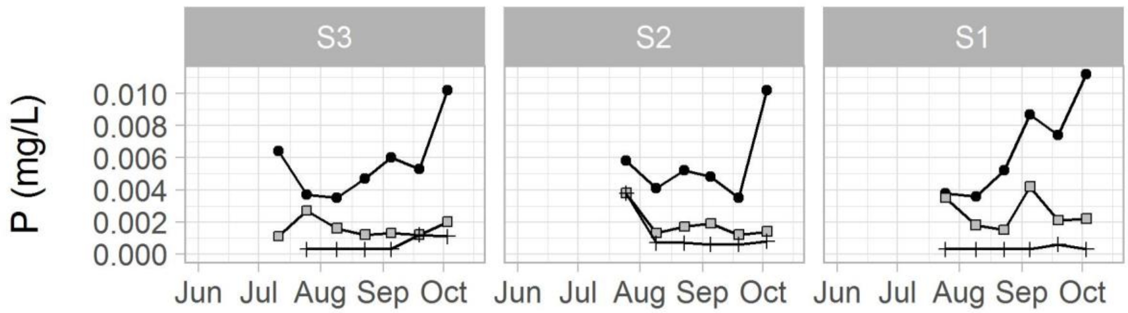



**Figure 17.** 2018-time series of forms of P (mg/L) in the Finger Lakes by station: (a) Conesus, (b) Hemlock, (c) Canadice, (d) Honeoye. Panels arranged from south to north (left to right). TP – black circles, TDP – gray squares, SRP – crosses.

**Canandaigua (e)**




**Keuka (f)**




**Seneca (g)**

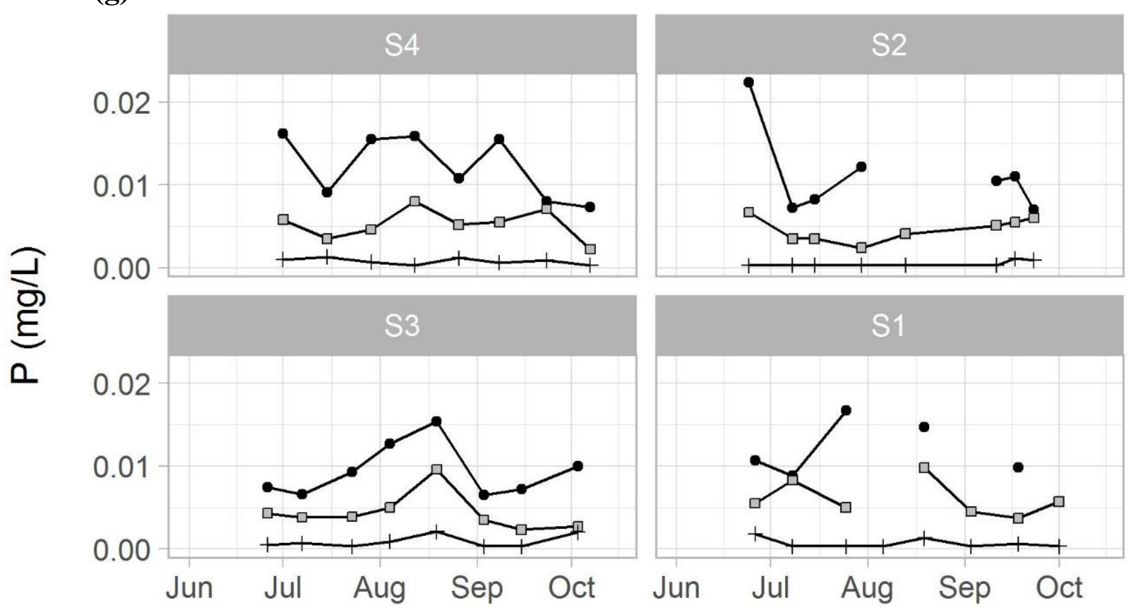
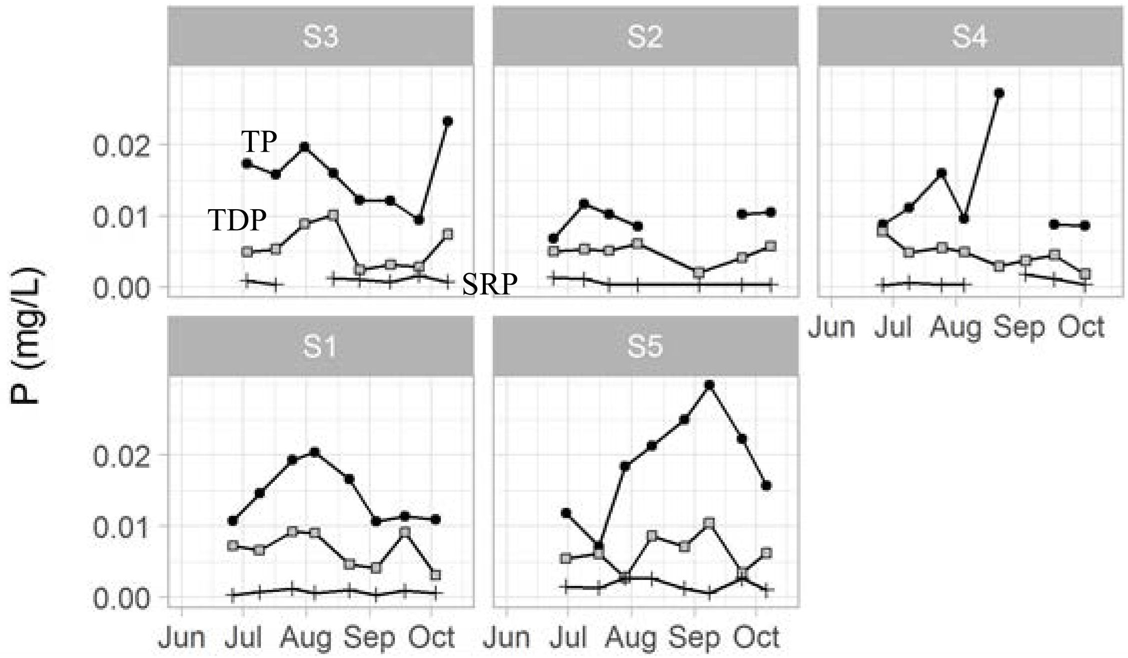
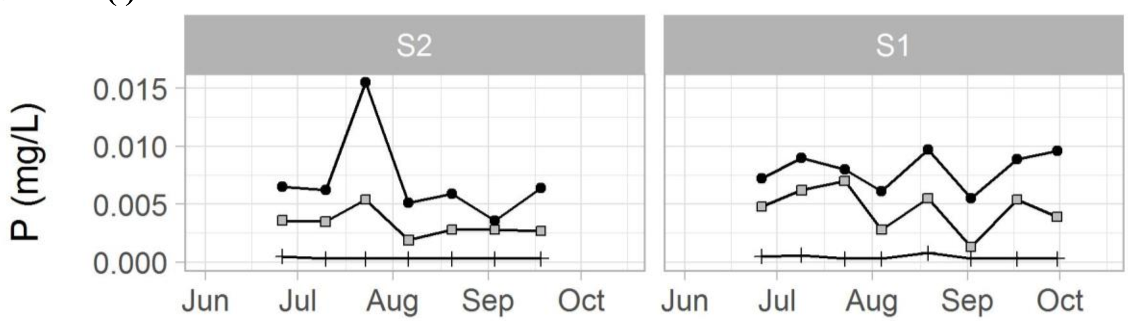



**Figure 17 continued.** 2018-time series of forms of P (mg/L) in the Finger Lakes by station: (e) Canandaigua, (f) Keuka, (g) Seneca. Panels arranged from south to north (left to right). TP – black circles, TDP – gray squares, SRP – crosses.

**Cayuga (h)**




**Owasco (i)**




**Skaneateles (j)**


**Figure 17 continued.** 2018-time series of forms of P (mg/L) in the Finger Lakes by station: (h) Cayuga, (i) Owasco, (j) Skaneateles. Panels arranged from south to north (left to right). TP – black circles, TDP – gray squares, SRP – crosses.

**Otisco (k)**

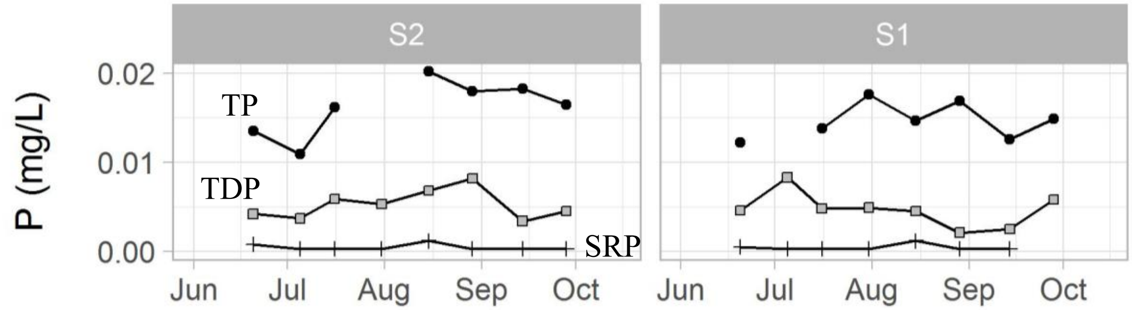



**Figure 17 continued.** 2018-time series of forms of P (mg/L) in the Finger Lakes by station: (k) Otisco. Panels arranged from south to north (left to right). TP – black circles, TDP – gray squares, SRP – crosses.

## Seasonal Patterns in TN:TP Ratios

The ratio between TN and TP, referred to as the N:P ratio, may influence the extent and type of algae growth, and may have relevance for the production of both cyanobacteria biomass and cyanotoxins. For example, a low N:P ratio provides a selective advantage to nitrogen-fixing types of cyanobacteria such as *Dolichospermum*. The ratio of N:P also is an important limnological analysis that can lend insight to whether N or P are limiting algal growth. These ratios often referred to as the Redfield ratios named after the scientist that pioneered this work in the 1930s. Thus, from a physiological perspective, aquatic plants (algae) require significantly less phosphorus than carbon and/or nitrogen.

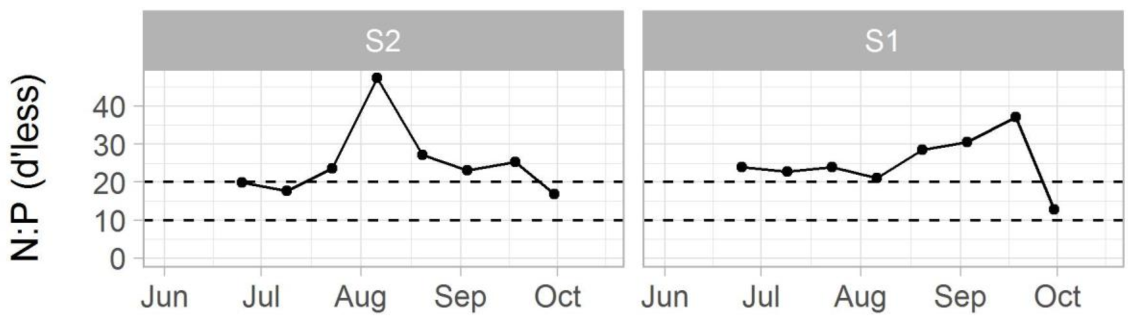
Previous empirical investigations have found that freshwater ecosystems with N:P ratios > 20 – phosphorus is most likely the limiting nutrient. Lakes with N:P < 10 – nitrogen is most likely the limiting nutrient and when N:P is between 10-20 it is difficult to determine the limiting nutrient. When N:P is between 10-20, limitation depends upon other factors such as light availability, presence/absence of nitrogen-fixing algae (cyanobacteria), and the forms of nutrients present (Thomann and Mueller, 1987).

The summary below is a brief characterization of lake P patterns for each of the Finger lakes in 2018. For more detail, see Figure 18.

| Lake | Summary |
|---|---|
| Conesus Lake | • N:P ratio varied between 12-47<br>• Likely co-limitation on N, P at times |
| Hemlock Lake | • N:P was greater than 19 for the 2018 season,<br>• Likely P limited |
| Canadice Lake | • N:P was greater than 19 for the 2018 season,<br>• Likely P limited |
| Honeoye Lake | • N:P ratio varied between 9-30, less than 20 for multiple observations, less than 10 in September<br>• Likely co-limitation on N, P at times |
| Canandaigua Lake | • N:P ratio varied between sites in 2018<br>• S1 was high in the spring and declined throughout the summer<br>• Seasonally varied between 38-121<br>• P limited |

| Lake | Summary |
|---|---|
| Keuka Lake | • N:P was high in the early summer (> 50), declined to ~ 20 in September<br>• P limited |
| Seneca Lake | • N:P ratio varied between sites in 2018<br>• N:P ratio varied between 24-103, was mostly high in the spring and declined through early September |
| Cayuga Lake | • N:P ratio varied between sites in 2018<br>• N:P ratio varied between 12-229, was mostly high in the spring and declined through early September<br>• S5 had low N:P which was between 10-20 in September<br>• Mostly P limited, some co-limitations |
| Owasco Lake | • N:P was > 50 all season<br>• P limited |
| Skaneateles Lake | • N:P was > 50 all season<br>• P limited |
| Otisco Lake | • N:P ratio varied between 18-75, was mostly high in the spring and declined through early September<br>• Mostly P limited, some co-limitation in late summer |

**Conesus (a)**




**Hemlock (b)**

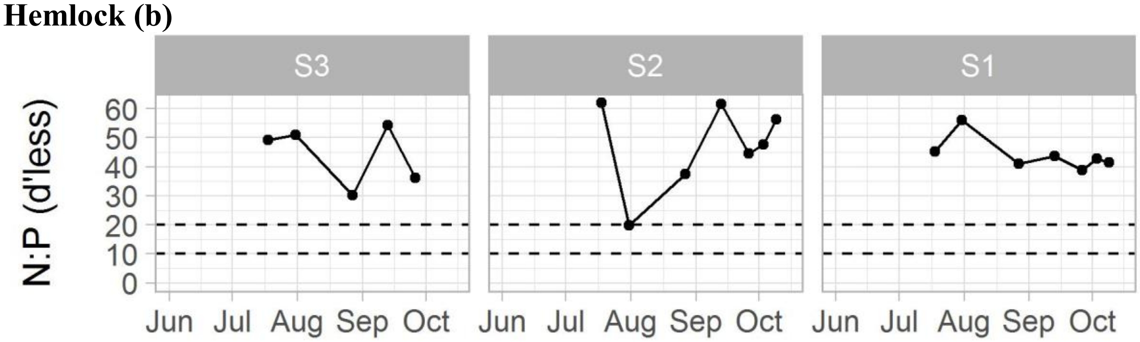
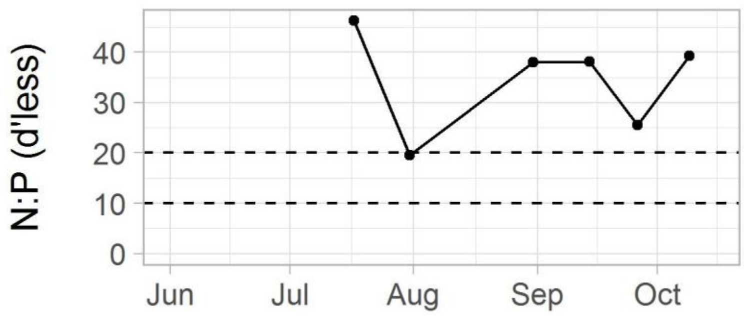
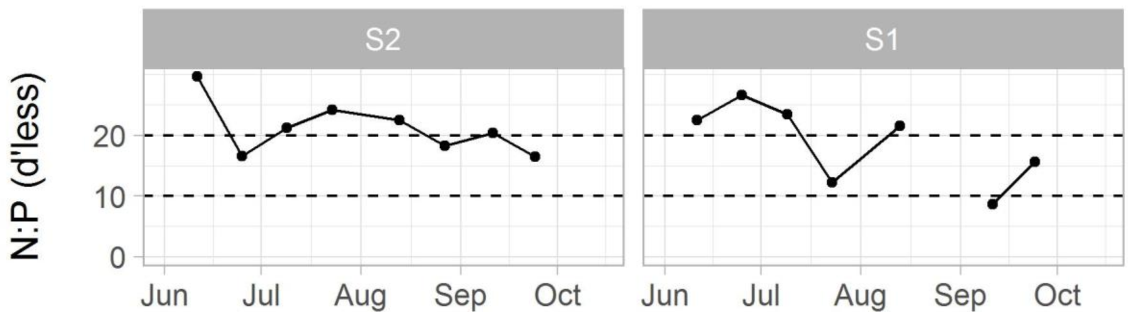



**Figure 18.** 2018-time series of N:P (dimensionless) in the Finger Lakes by station: (a) Conesus, and (b) Hemlock. Panels arranged from south to north (left to right).

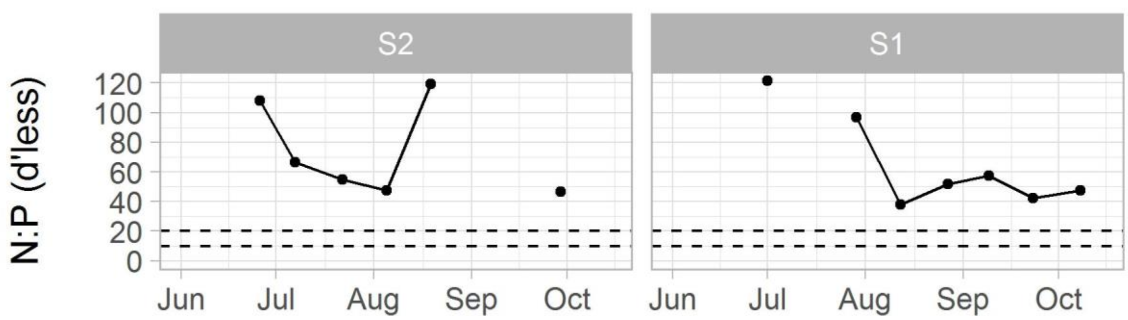
**Canadice (c)**




**Honeoye (d)**




**Canandaigua (e)**




**Keuka (f)**

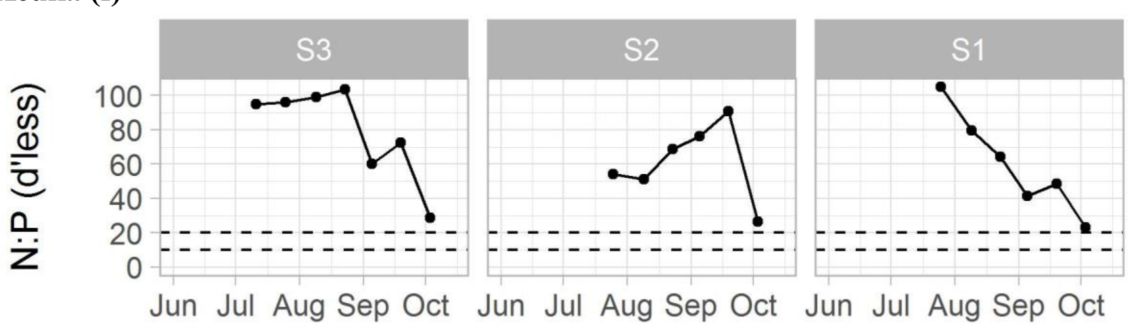
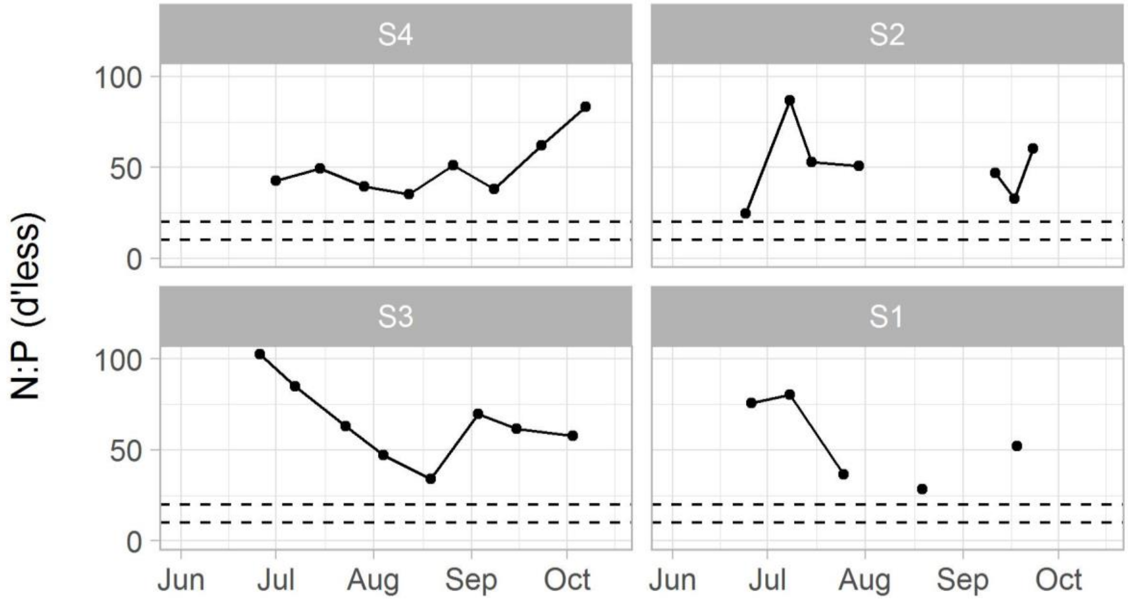



**Figure 18 continued.** 2018-time series of N:P (dimensionless) in the Finger Lakes by station: (c) Canadice, (d) Honeoye (e) Canandaigua, and (f) Keuka. Panels arranged from south to north (left to right).

**Seneca (g)**




**Cayuga (h)**

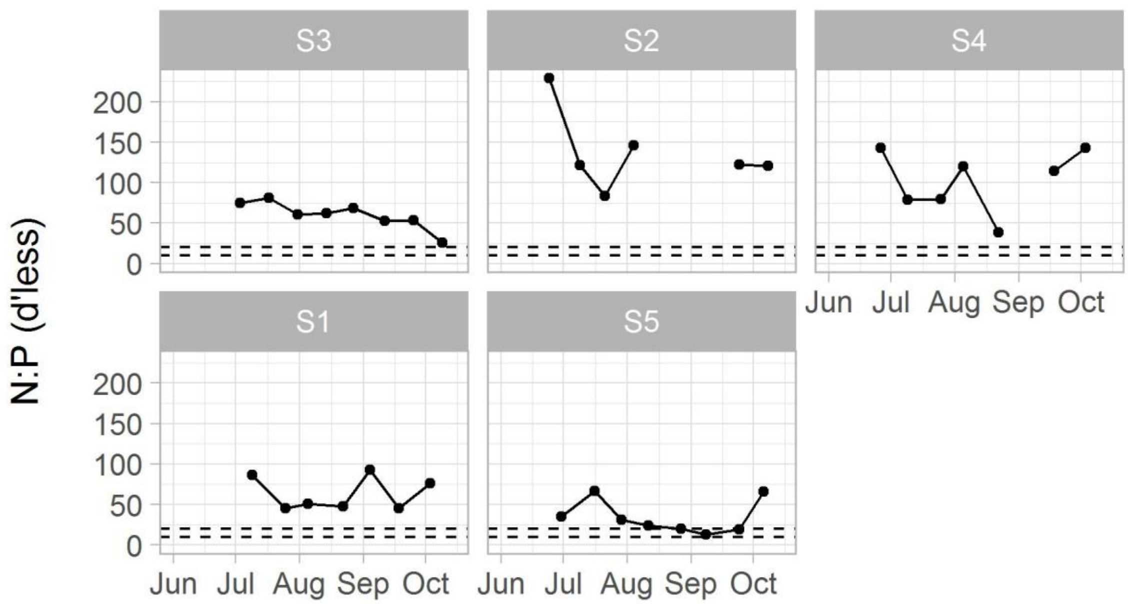
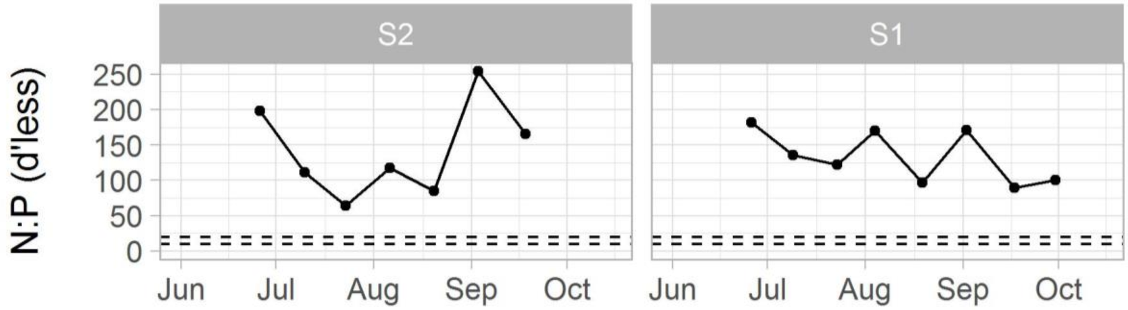
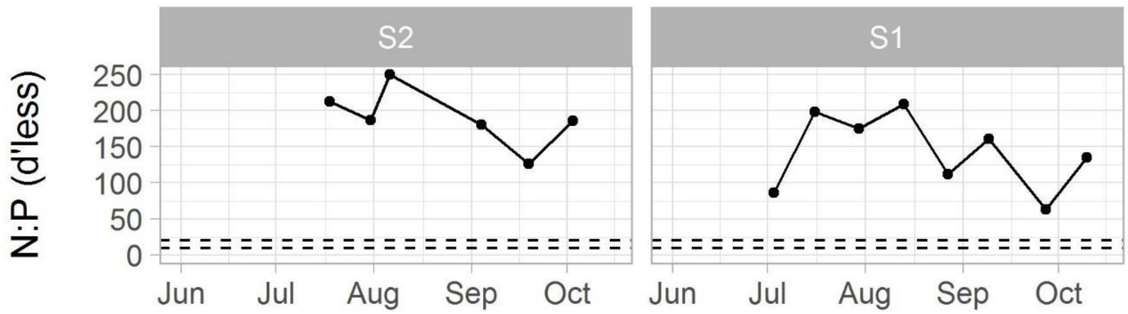



**Figure 18 continued.** 2018-time series of N:P (dimensionless) in the Finger Lakes by station: (g) Seneca and (h) Cayuga, Panels arranged from south to north (left to right).

**Owasco (i)**




**Skaneateles (j)**




**Otisco (k)**

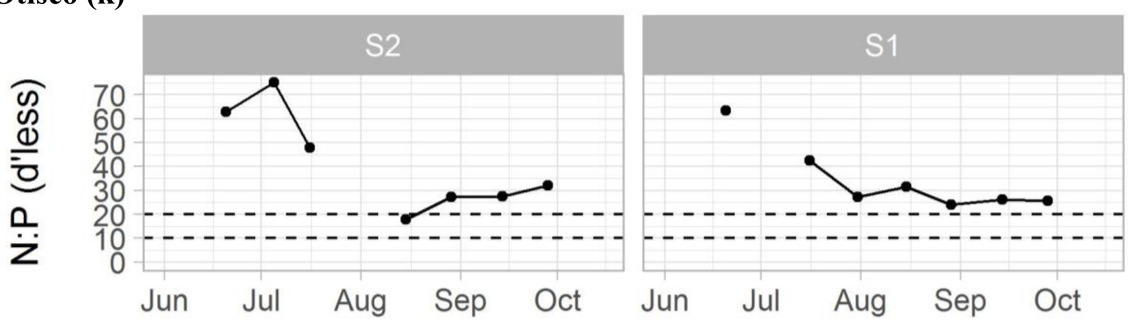


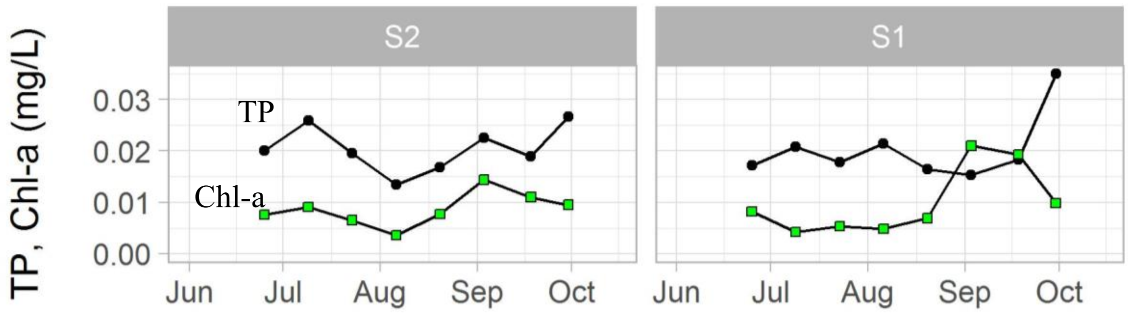

**Figure 18 continued.** 2018-time series of N:P (dimensionless) in the Finger Lakes by station: (i) Owasco, (j) Skaneateles, and (k) Otisco. Panels arranged from south to north (left to right).

## Seasonal Patterns in TP, Chl-a, and Secchi Depth

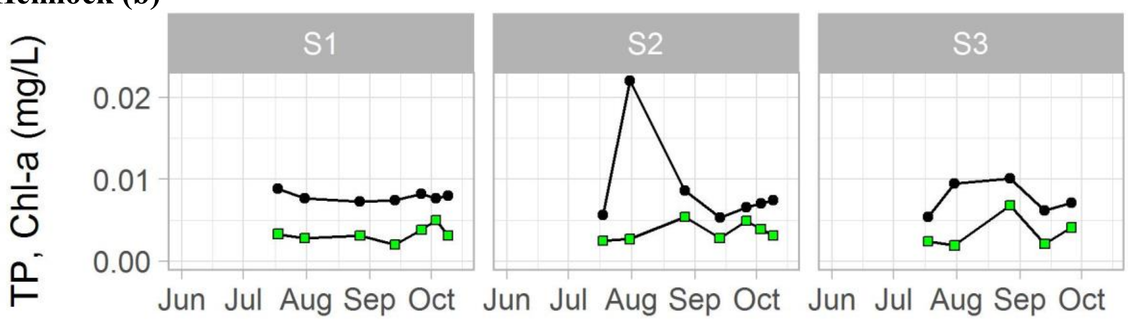
Seasonal patterns in Chl-a and SD (shown in the individual lake chapters) were variable within and between the Finger Lakes in 2018. In general, patterns in Chl-a tracked the patterns in P. The summary below is a brief characterization of lake TP and Chl-a patterns for each of the Finger lakes in 2018. For more detail, see Figure 19.

| Lake | Summary |
|---|---|
| Conesus Lake | • TP, Chl-a patterns were similar at both sites<br>• Summer average Chl-a was 9.3 µg/L and varied between 3.6-21 µg/L |
| Hemlock Lake | • TP and Chl-a patterns were fairly constant through the season<br>• Summer average Chl-a was 3.5 µg/L and varied between 2 and 6.8µg/L |
| Canadice Lake | • Chl-a patterns tracked patterns in TP<br>• Chl-a was low in early summer and increased through September<br>• Summer average Chl-a was 4.3 and ranged from 0.9 – 7.5 µg/L |
| Honeoye Lake | • Chl-a patterns tracked patterns in TP<br>• Chl-a was low in early summer and increased through September<br>• Summer Chl-a ranged between 3.7-71 µg/L (mean was 27.5 µg/L) |
| Canandaigua Lake | • Chl-a was low in early summer and increased through September<br>• Chl-a ranged from 0.2 – 4.2 µg/L; average was 2.3 µg/L |
| Keuka Lake | • Chl-a patterns tracked patterns in TP<br>• Chl-a was low in early summer and increased through September<br>• Summer Chl-a ranged between <1-3.6 µg/L (mean was 2.2 µg/L) |
| Seneca Lake | • Chl-a patterns tracked patterns in TP but were variable between sites<br>• Summer Chl-a ranged between 1-11.5 µg/L (mean was 5.4 µg/L) |
| Cayuga Lake | • Chl-a patterns tracked patterns in TP<br>• Chl-a was fairly constant at the southern sites (S3-S4)<br>• Chl-a was low in early summer and increased through September at S1-S5<br>• Summer Chl-a ranged between 2.1-10.1 µg/L (mean was 4.5 µg/L) |
| Owasco Lake | • Chl-a patterns tracked patterns in TP<br>• Chl-a was low in early summer and increased slightly through September<br>• Summer Chl-a ranged between 0.1-6.3 µg/L (mean was 3.4 µg/L) |
| Skaneateles Lake | • Chl-a was low in early summer and increased very slightly through September<br>• Summer Chl-a ranged between 0.3-1.6 µg/L (mean was 0.95 µg/L) |
| Otisco Lake | • Chl-a was variable in 2018<br>• Summer Chl-a ranged between 1.1-10 µg/L (mean was 5.9 µg/L) |

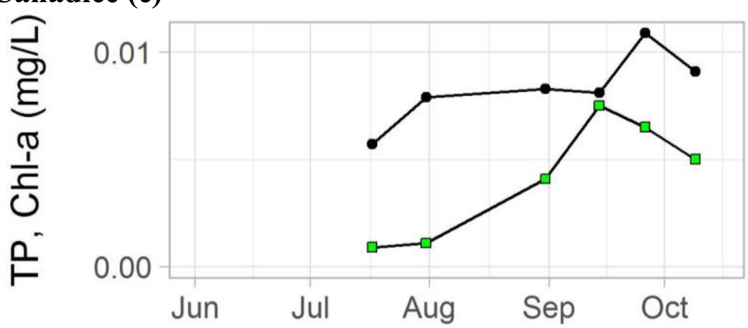
**Conesus (a)**




**Hemlock (b)**




**Canadice (c)**




**Honeoye (d)**

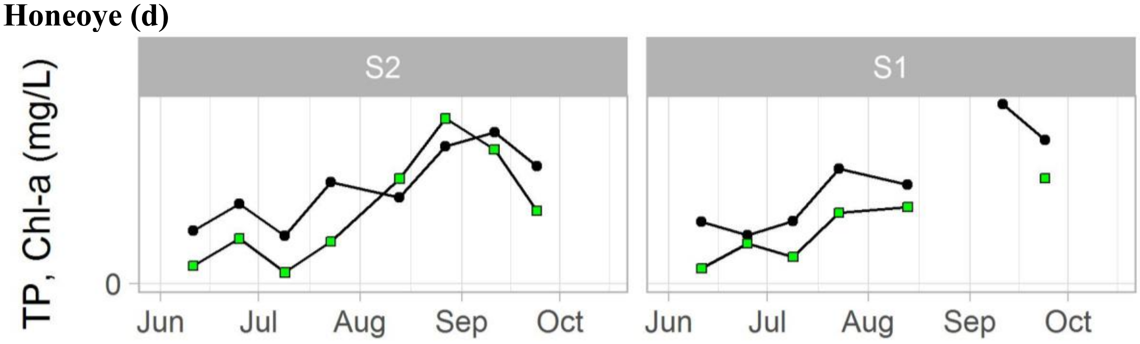
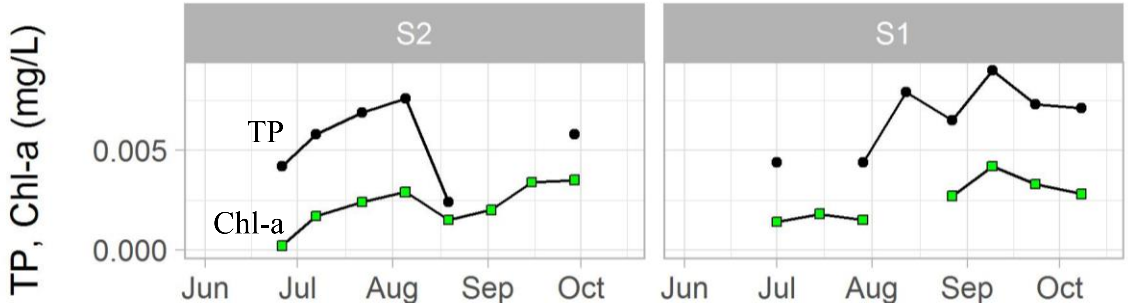
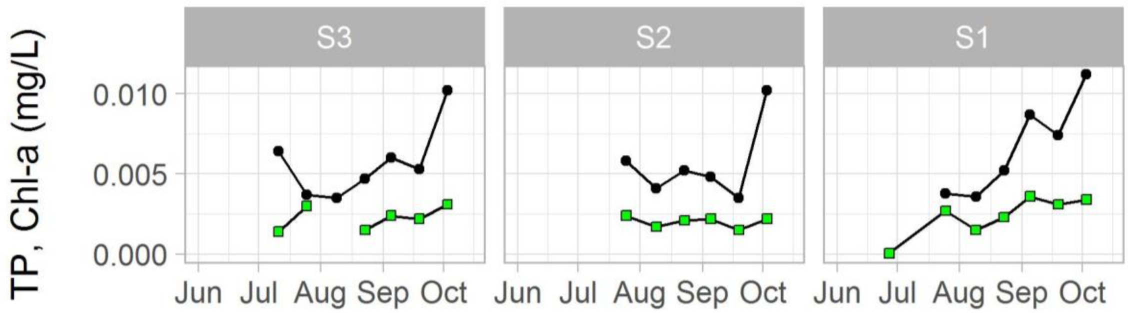



**Figure 19.** 2018-time series of TP (mg/L; in black) and Chl-a (mg/L; in green) the Finger Lakes by station: (a) Conesus, (b) Hemlock, (c) Canadice, (d) Honeoye. Panels arranged from south to north (left to right).

**Canandaigua (e)**




**Keuka (f)**




**Seneca (g)**

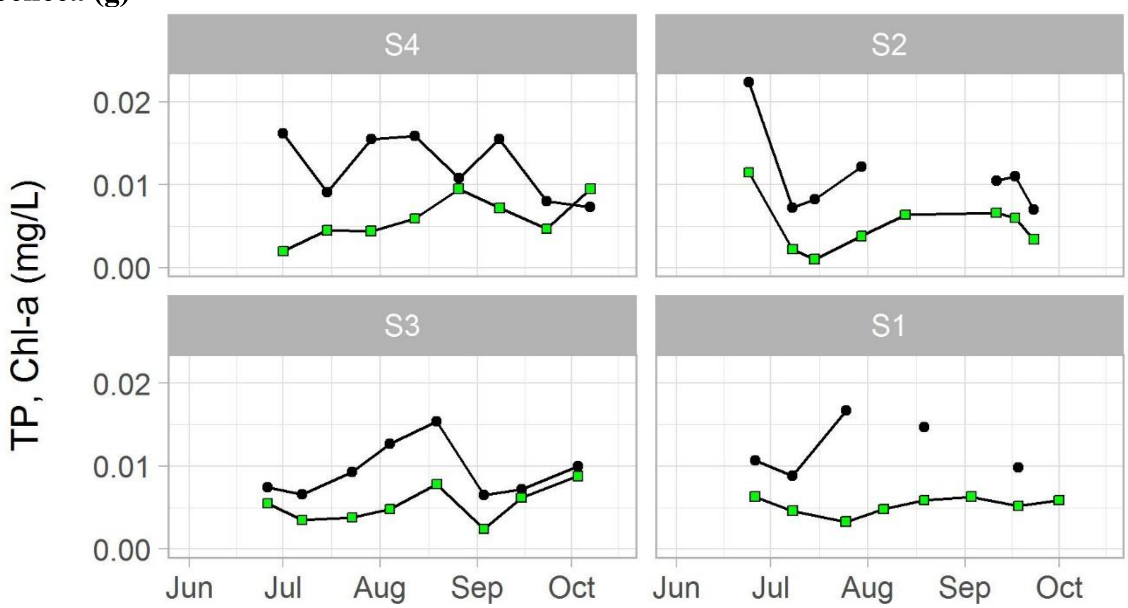
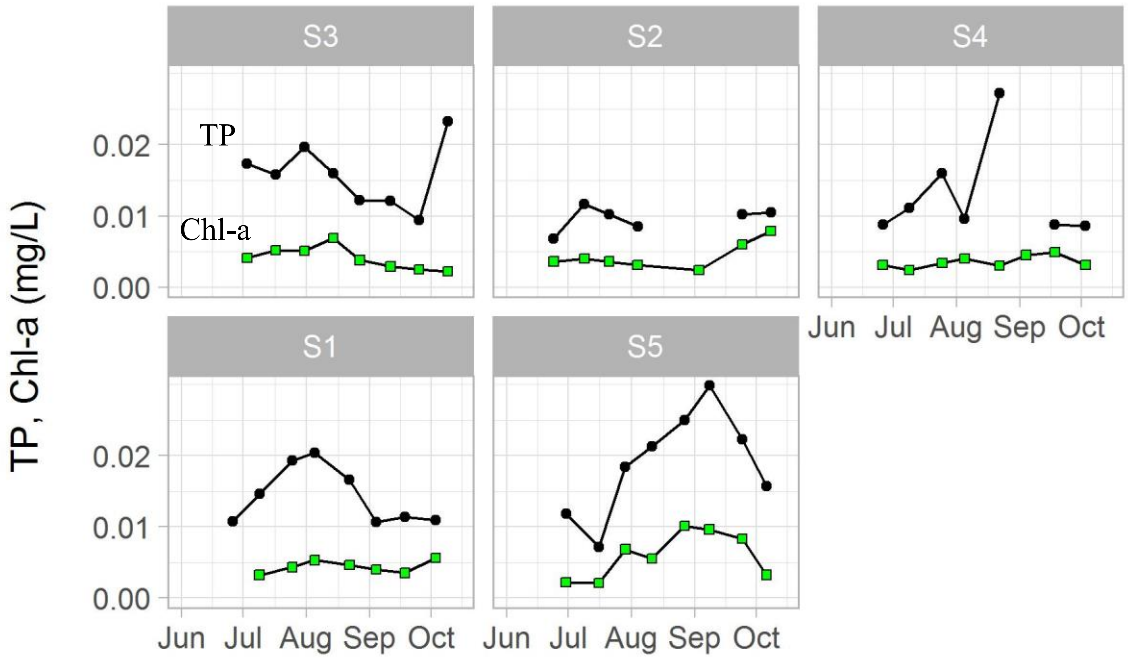
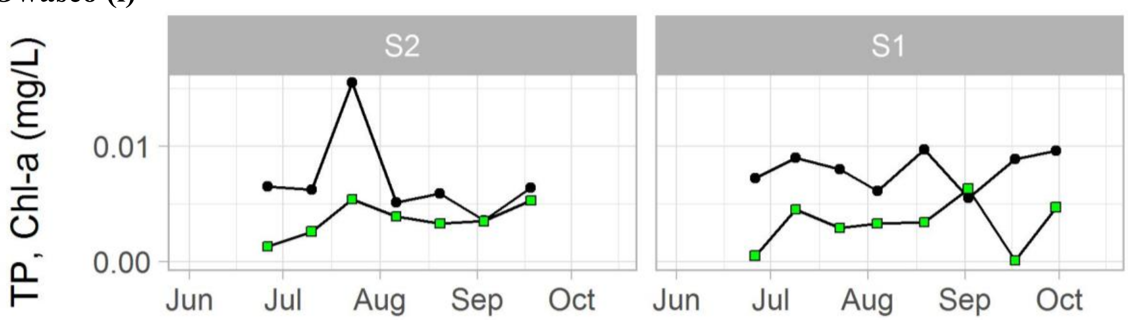



**Figure 19 continued.** 2018-time series of TP (mg/L; in black) and Chl-a (mg/L; in green) in the Finger Lakes by station: (e) Canandaigua, (f) Keuka, (g) Seneca. Panels arranged from south to north (left to right).

**Cayuga (h)**




**Owasco (i)**




**Skaneateles (j)**

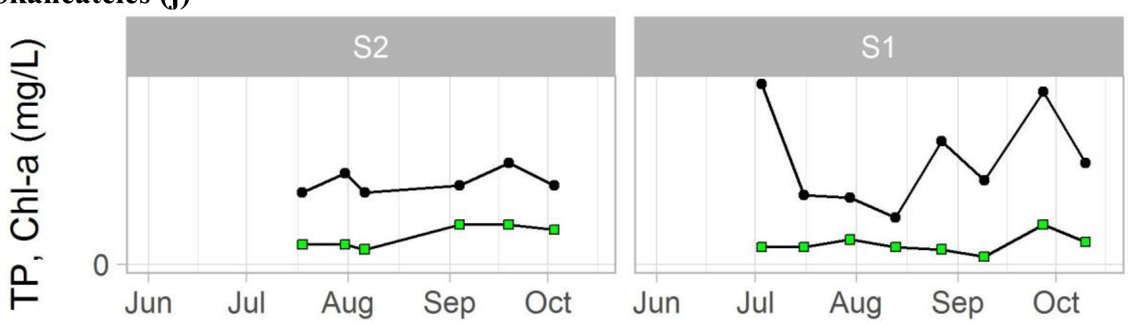



**Figure 19 continued.** 2018-time series of TP (mg/L; in blue) and Chl-a (mg/L; in green) in the Finger Lakes by station: (h) Cayuga, (i) Owasco, (j) Skaneateles. Panels arranged from south to north (left to right). TP – black circles, Chl-a – green circles.

**Otisco (k)**

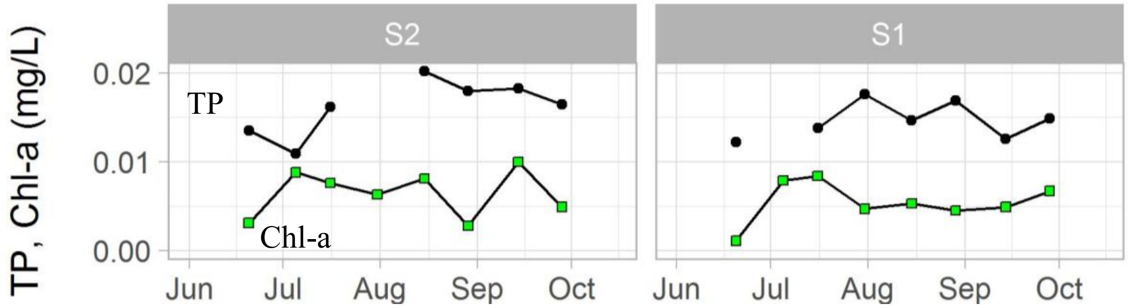



**Figure 19 continued.** 2018-time series of TP (mg/L; in black) and Chl-a (mg/L; in green) in the Finger Lakes by station: (k) Otisco. Panels arranged from south to north (left to right).

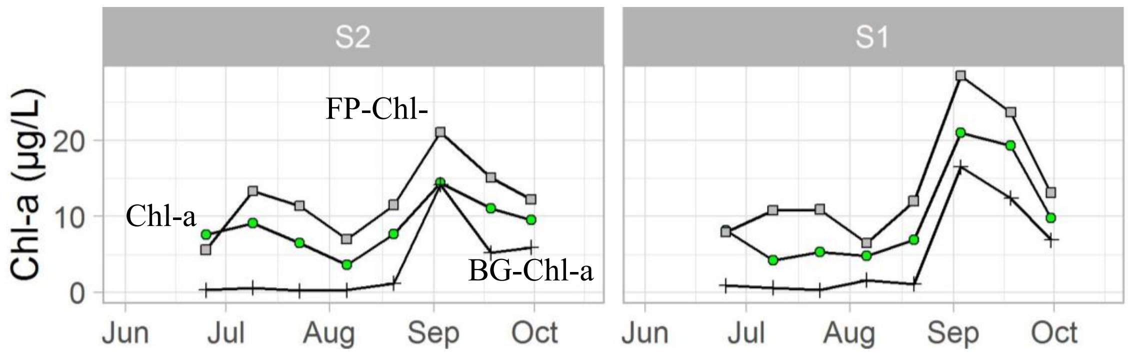
## Seasonal Patterns in Chl-a and Blue-green Algae (BGA)

Seasonal patterns in Chl-a and Blue-green Chl-a (BG-Chl-a) were variable within and between the Finger Lakes in 2018. In general, patterns in BGA were a small component of total Chl-a, but there were exceptions. The two measures of total Chl-a and Fluoroprobe Chl-a (FP-Chl-a) were comparable but there is a slight offset between the two measures, with FP-Chl-a usually systematically higher than lab extracted Chl-a. The summary below is a brief characterization of lake algae patterns for each of the Finger lakes in 2018. For more detail, see Figure 20. The discussion of open-water and shore bloom samples and microcystin toxin is presented in Section 6.

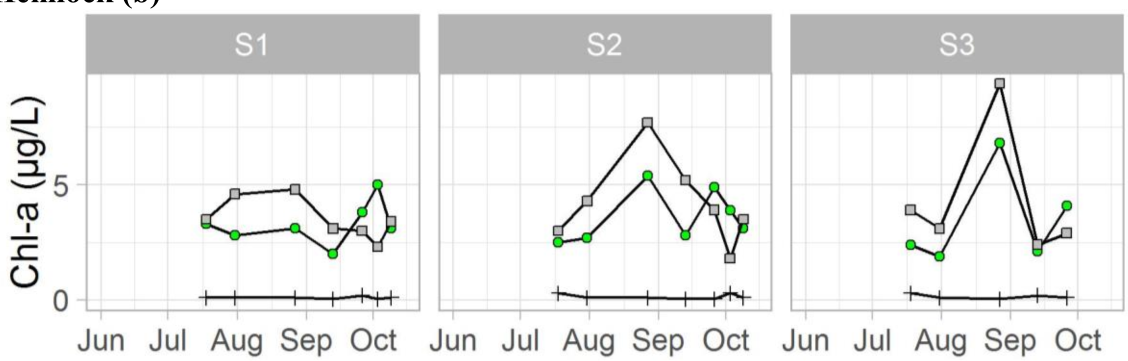
| Lake | Summary |
| --- | --- |
| Conesus Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was low in the early summer and increased throughout the season<br>• At S2 (southern), BG-Chl-a ranged from <1 to 16.5 µg/L (%BG-Chl-a ranged from 5-67%)<br>• At S1 (northern), BG-Chl-a ranged from <1 to 14.2 µg/L (%BG-Chl-a ranged from 3-58%) |
| Hemlock Lake | • The proportion of FP-Chl-a that was BG-Chl-a was very low throughout the season<br>• BG-Chl-a ranged from <0.05 to 0.6 µg/L<br>• For all but three observations, % BG-Chl-a was less than 10% of FP-Chl-a |
| Canadice Lake | • BG-Chl-a was very low throughout the season, ranging from 0.2 in early summer to 3 µg/L in the late summer<br>• % BG-Chl-a ranged from 13-33% |
| Honeoye Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was low in the early summer and increased throughout the season<br>• At S2 (southern), BG-Chl-a ranged from 2 to 41.5 µg/L (%BG-Chl-a ranged from 25-83%)<br>• At S1 (northern), BG-Chl-a ranged from 2 to 55 µg/L (%BG-Chl-a ranged from 31-85%) |
| Canandaigua Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was low in the early summer and increased throughout the season<br>• At S2 (southern), BG-Chl-a ranged from 0.05 to 2.3 µg/L (%BG-Chl-a ranged from |

| Lake | Summary |
| --- | --- |
| | 1-33%)<br>• At S1 (northern), BG-Chl- ranged from 0.05 to 2.8 µg/L (%BG-Chl-a ranged from 7-47%) |
| Keuka Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was low in the early summer and increased throughout the season<br>• BG-Chl-a was low in 2018 and ranged from 0.01 to 2.4 µg/L<br>• %BG-Chl-a ranged from 5-56% |
| Seneca Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was low in 2018<br>• BG-Chl-a ranged from 0.05 to 1.5 µg/L<br>• %BG-Chl-a ranged from 0-30% |
| Cayuga Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was variable in Cayuga Lake in 2018<br>• BG-Chl-a and % BG-Chl-a was highest in the northern sites<br>• At S3-S4 (southern-mid lake), BG-Chl-a ranged from 0.05 to 1.4 µg/L (%BG-Chl-a ranged from 0-20%)<br>• At S1 (northern), BG-Chl-a ranged from 0.5 to 2 µg/L (%BG-Chl-a ranged from 6-31%)<br>• At S5 (northern), BG-Chl-a ranged from 0.9 to 7.9 µg/L (%BG-Chl-a ranged from 39-64%) |
| Owasco Lake | • Both the concentration and the proportion of FP-Chl-a that was BG-Chl-a was low in 2018<br>• BG-Chl-a ranged from 0.05 to 0.4 µg/L<br>• %BG-Chl-a ranged from 1-10% |
| Skaneateles Lake | • The concentration of BG-Chl-a was low in 2018<br>• BG-Chl-a ranged from 0.1 to 1.3 µg/L<br>• %BG-Chl-a ranged from 7-50% |
| Otisco Lake | • The concentration and the proportion of FP-Chl-a that was BG-Chl-a was variable in 2018<br>• BG-Chl-a was low in 2018 and ranged from 0.3 to 3.8 µg/L<br>• %BG-Chl-a ranged from 3-41% |

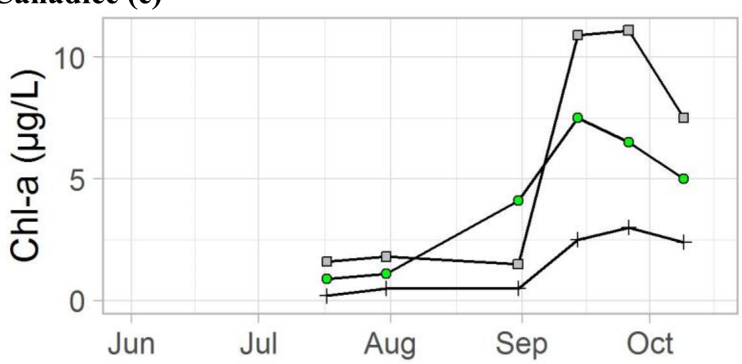
**Conesus (a)**




**Hemlock (b)**




**Canadice (c)**




**Honeoye (d)**

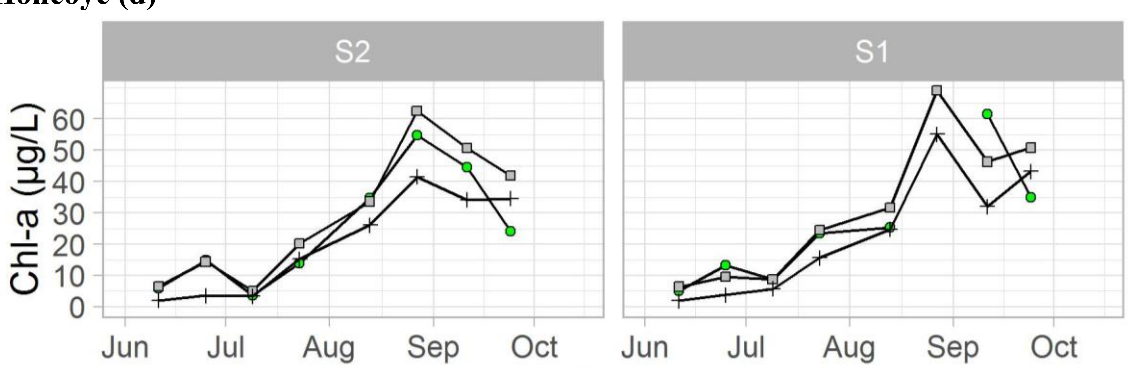
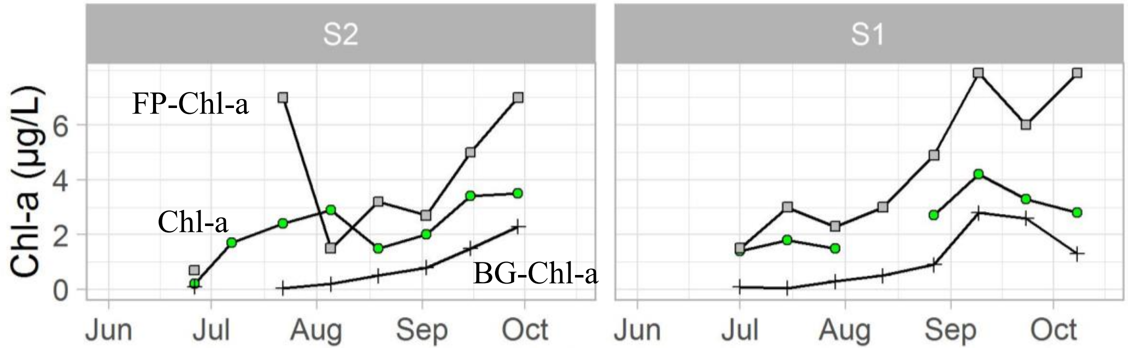
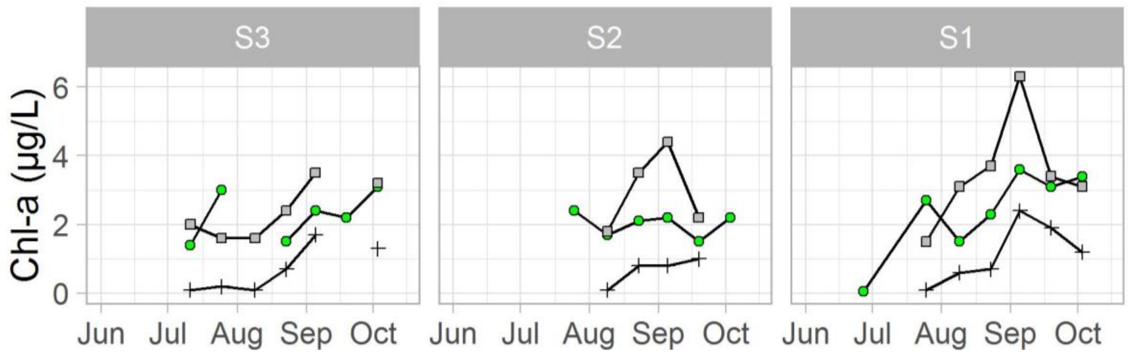



**Figure 20.** 2018-time series of Chlorophyll (µg/L) in the Finger Lakes by station: (a) Conesus, (b) Hemlock, (c) Canadice, (d) Honeoye. Panels arranged from south to north (left to right). Chl-a – green circles, FP Chl-a – gray squares, FP BG Chl-a – crosses. Panels arranged from south to north (left to right).

**Canandaigua (e)**




**Keuka (f)**




**Seneca (g)**

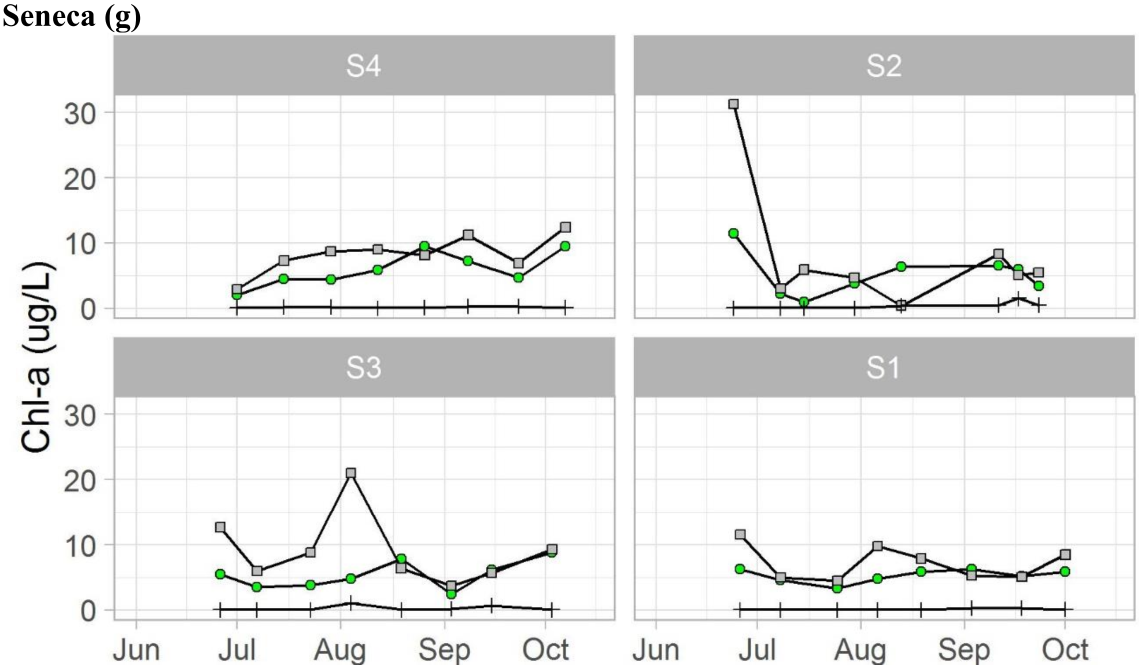
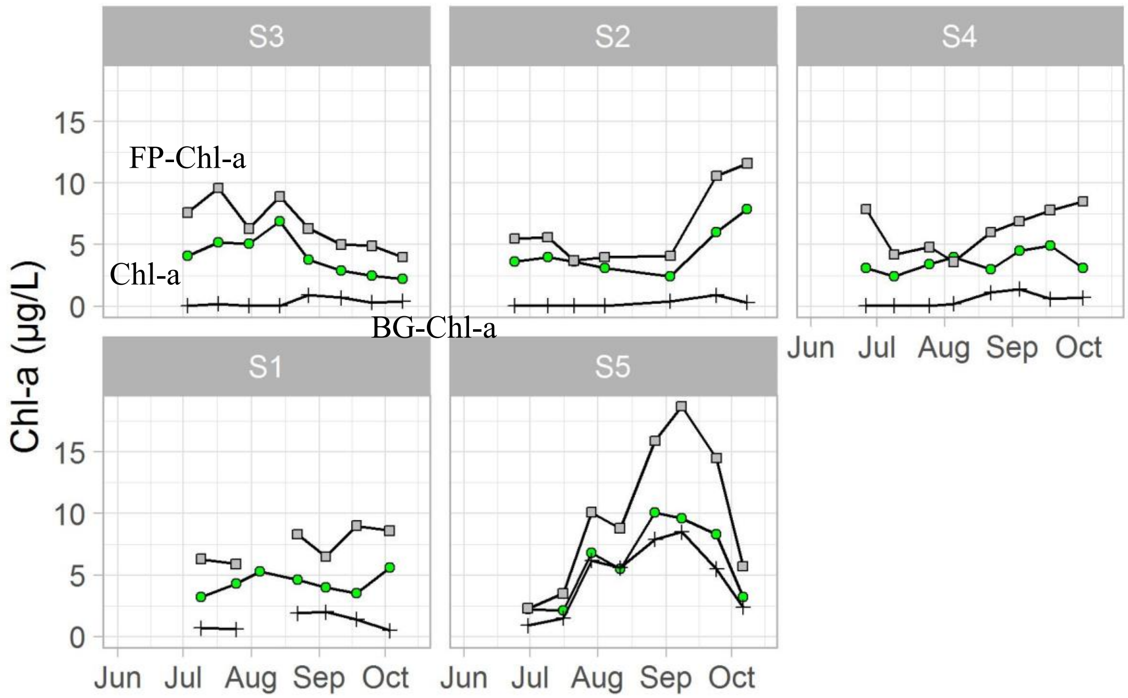
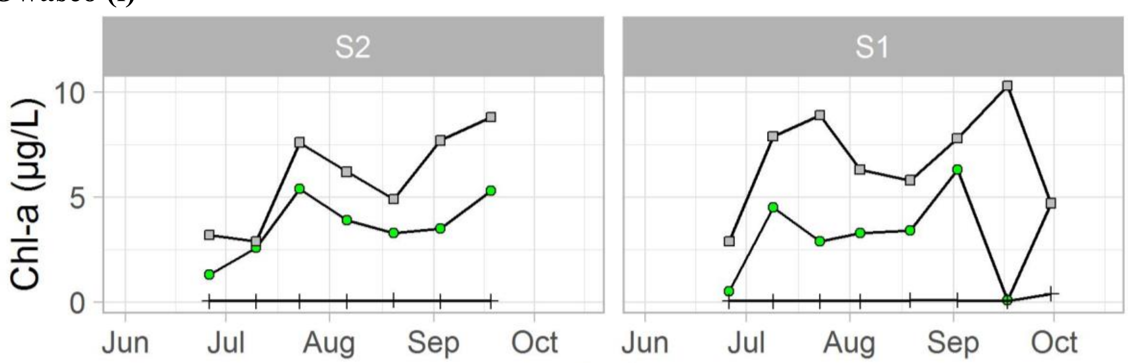



**Figure 20.** 2018-time series of Chlorophyll (µg/L) in the Finger Lakes by station: (e) Canandaigua, (f) Keuka, (g) Seneca. Panels arranged from south to north (left to right). Chl-a – green circles, FP Chl-a – gray squares, FP BG Chl-a – crosses.

**Cayuga (h)**




**Owasco (i)**




**Skaneateles (j)**

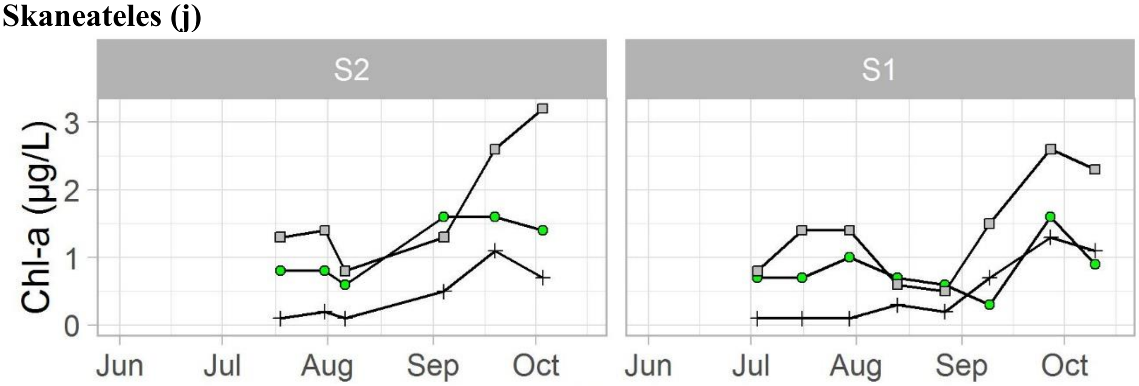



**Figure 20.** 2018-time series of Chlorophyll (µg/L) in the Finger Lakes by station: (h) Cayuga, (i) Owasco, (j) Skaneateles. Panels arranged from south to north (left to right). Chl-a – green circles, FP Chl-a – gray squares, FP BG Chl-a – crosses.

**Otisco (k)**

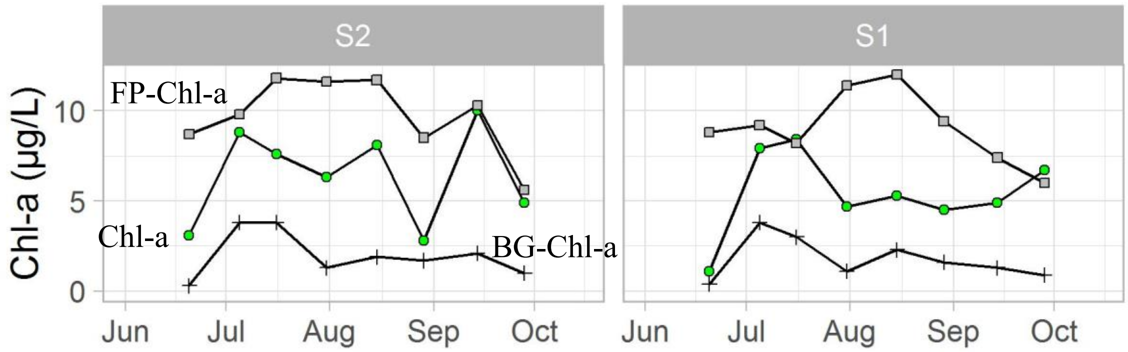



**Figure 20.** 2018-time series of Chlorophyll (µg/L) in the Finger Lakes by station: (k) Otisco. Panels arranged from south to north (left to right). Chl-a – green circles, FP Chl-a – gray squares, FP BG Chl-a – crosses.

## Other Water Quality Parameters

### Dissolved Forms of Nitrogen; TDN, $NO_X$, $NH_3$

As with TDP, dissolved nitrogen (TDN) can be comprised of both available and unavailable types. Other forms of nitrogen previously discussed also vary during the summer in response to biological uptake, conversion between various forms, and movement into and out of the lake. These forms were routinely monitored through CSLAP on the Finger Lakes in all surface samples, and in some of the lakes in deep water samples.

Summer average TDN concentrations in the Finger Lakes varied between 0.214 (Canadice) and 0.997 mg/L (Cayuga). Average TDN was 0.477 mg/L. As with the other water quality indicators, $NO_X$ observations were also highly variable in 2018 NYS CSLAP lakes. $NO_X$ ranged from 0.005 mg/L to ~0.716 mg/L with an interquartile range of 0.007 to 0.021 mg/L. The median statewide $NO_X$ concentration was 0.010 mg/L (mean = 0.041 mg/L; Figure 21a). NOx concentrations in the eleven Finger Lakes varied between 0.005 and 0.783 mg/L (Figure 21b). All the Finger Lakes to the west of Seneca Lake had average NOx concentrations less than 0.1 mg/L. All of the eastern Finger Lakes had NOx concentrations more than five-times the NYS mean concentration (0.041 mg/L), consistent with patterns in TN (Figure 22).

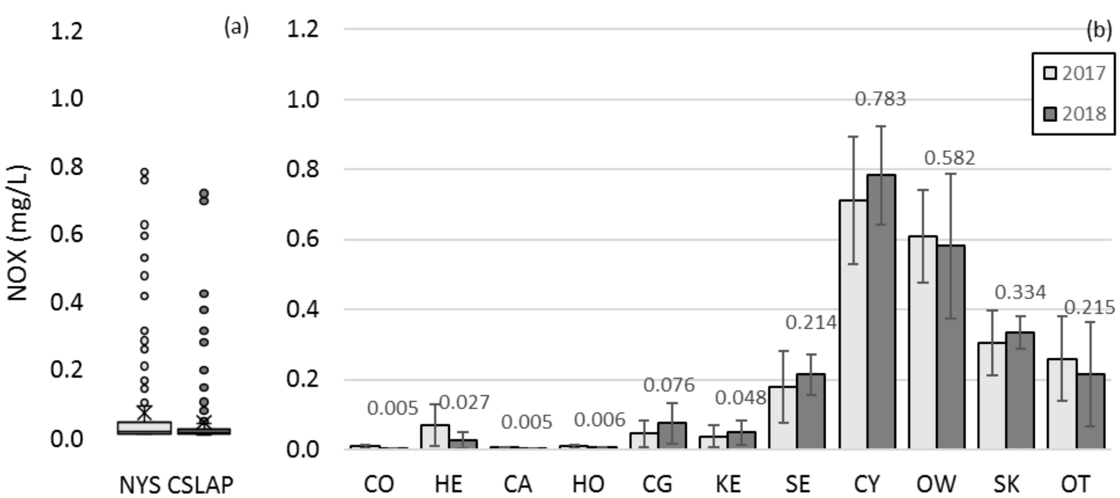



**Figure 21.** Summer average, open water, surface $NO_X$ concentrations (mg/L) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

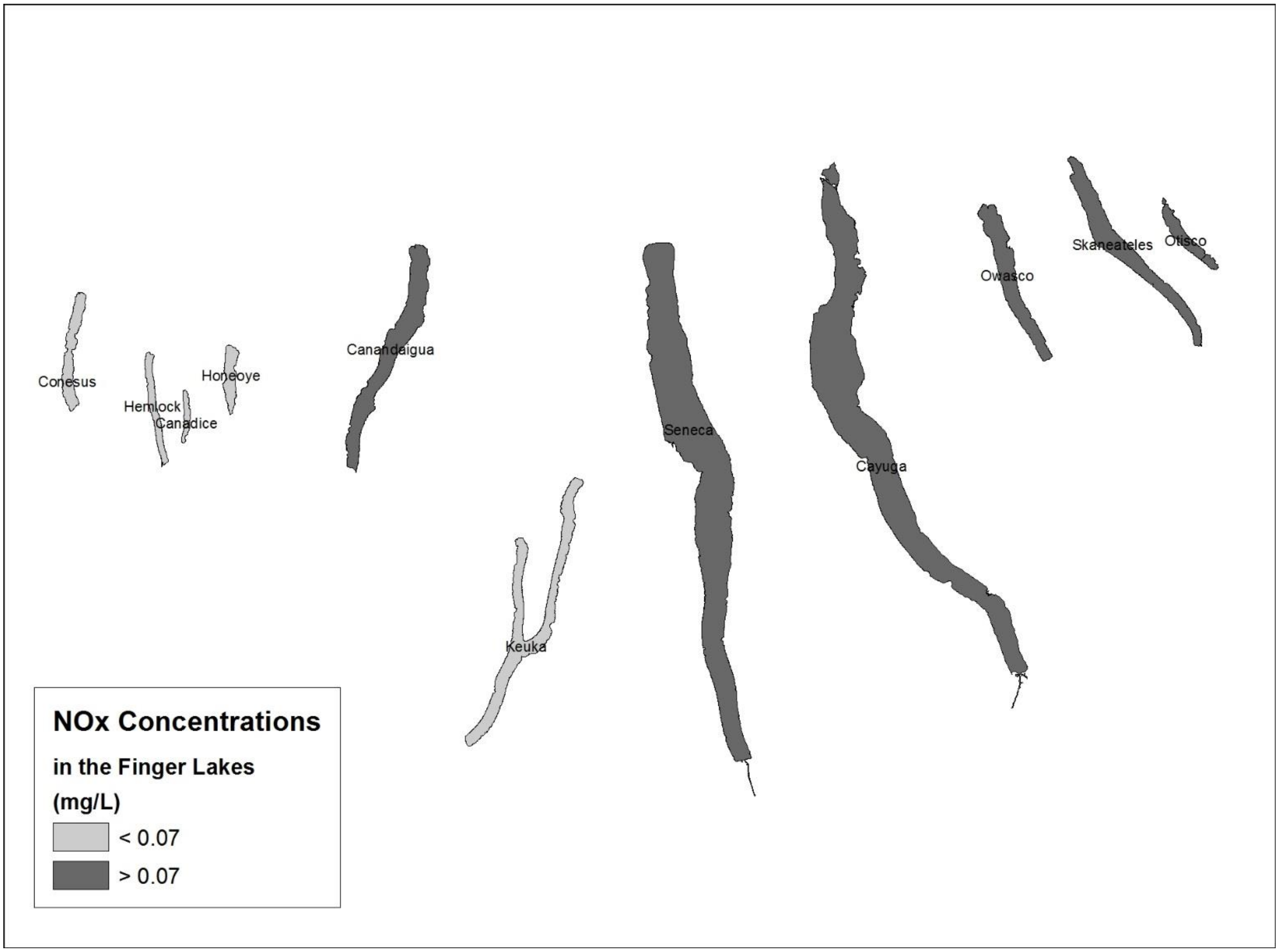



**Figure 22.** Oxidized Nitrogen (NOx) concentrations (mg/L) in the Finger Lakes in 2018.

The reduced (i.e. oxygen deficient) form of nitrogen, $NH_3$ (ammonia), was analyzed in NYS CSLAP lakes in 2018. In NYS, the range in ammonia was 0.007 to 0.474 mg/L (Figure 23a). The mean statewide concentration was 0.047 mg/L (median = 0.033 mg/L).

Hemlock, Canadice, Canandaigua, Keuka and Skaneateles had the lowest average $NH_3$ concentrations, all below 0.020 mg/L in 2018 (Figure 23b). Honeoye Lake had the highest average concentration at 0.040 mg/L. Unlike for $NO_X$ and TN, there were no apparent geographic patterns in $NH_3$ in 2018. The reason for the decline in $NH_3$ in 2018 compared with 2018 is unknow although it is important to note that all summer average surface $NH_3$ values in the Finger Lakes are below the method limit of quantification (LOQ; 0.0567 mg/L) and most are near the method detection limit (LOD; 0.015 mg/L).

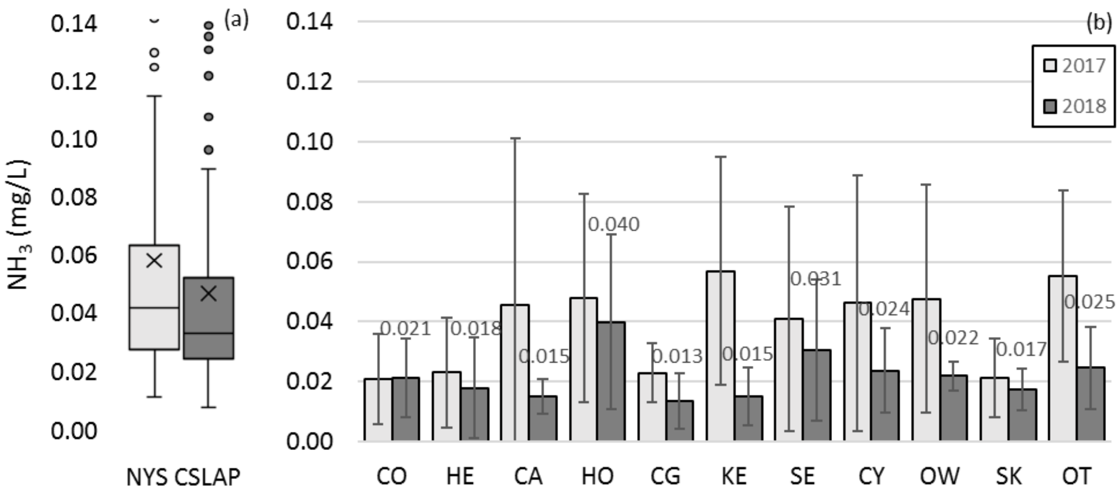



**Figure 23.** Summer average, open water, surface $NH_3$ concentrations (mg/L) in 2017-2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

The relative proportion of $NH_3$ and $NO_X$ varied geographically in the Finger Lakes (Figure 24), consistent with the similar $NH_3$ concentration in all lakes and the much higher concentrations in $NO_X$ observed in the east.

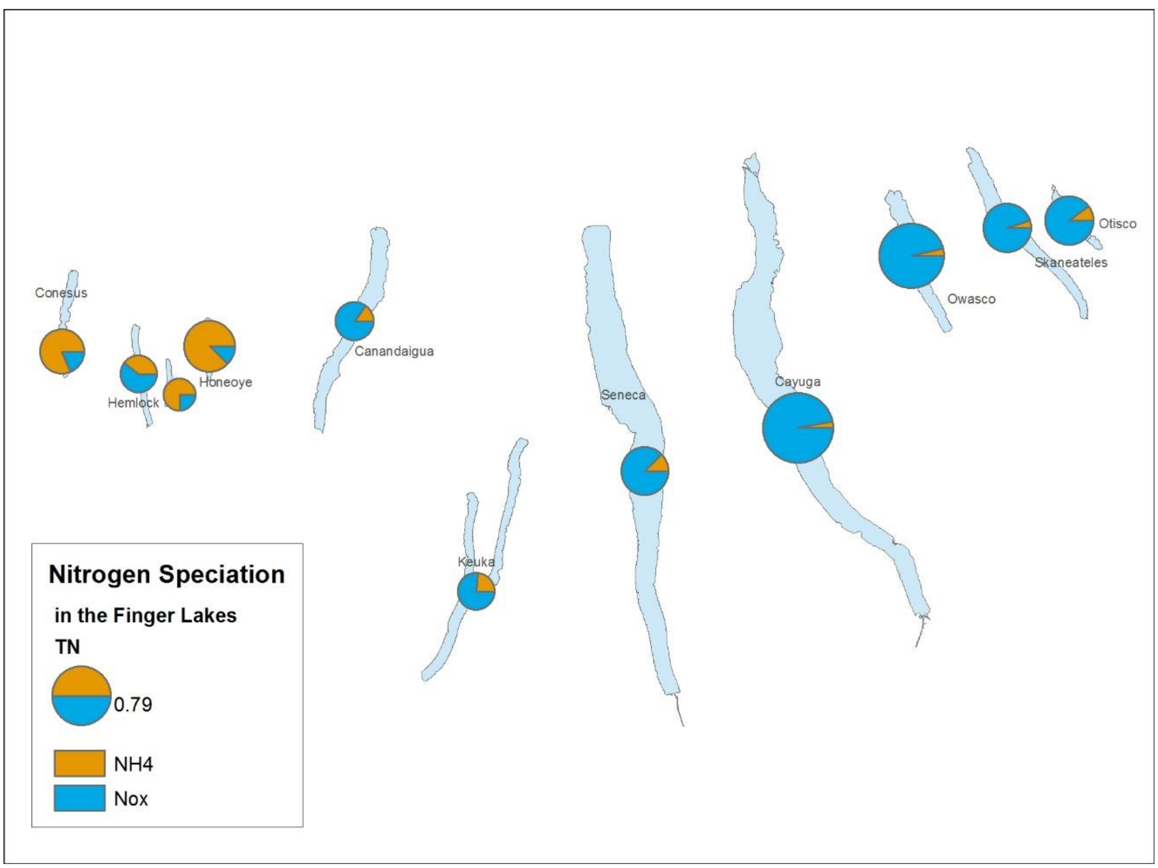



**Figure 24.** Proportions with charts of average summer oxidized ($NO_X$) to reduced ($NH_3$) nitrogen species in the surface waters of the Finger Lakes in 2018. Pie chart size is proportional to the total concentration of N species in each lake.

## Geographical Distribution of Nitrogen

Lakes west of Seneca Lake (Keuka – Conesus) had substantially lower concentrations for both TN and $NO_X$ (all available observations) compared with the eastern lakes (Seneca – Otisco). Figure 25a and b are box-whisker plots of all TN and $NO_X$ observations partitioned into the two geographic groups of lakes: WEST and EAST. The TN observations from the western lakes (N = 288) were right-skewed with an average concentration of 0.412 mg/L (median = 0.38 mg/L). The interquartile range for these lakes was 0.292 to 0.477 mg/L. The eastern lakes had much higher TN concentrations, averaging 0.760 mg/L (median = 0.647 mg/L), more than 1.5-times the average concentration of the western lakes. The interquartile range of the eastern lakes was 0.534 to 0.990 mg/L. Note that the 75$^{th}$ percentile of the TN observations in western lakes was less than the 25$^{th}$ percentile of the eastern lakes. A Kruskal-Wallis was performed on these groups and the difference in TN between the lakes was statistically significant ($p <<< 0.01$).

The Kruskal-Wallis is a statistical test that determines if the differences between two groups of data are statistically significant (more than just random chance). The p-value represents the likelihood of making an incorrect conclusion with a p-value of 0.01 indicating a 1% chance of making an incorrect conclusion.

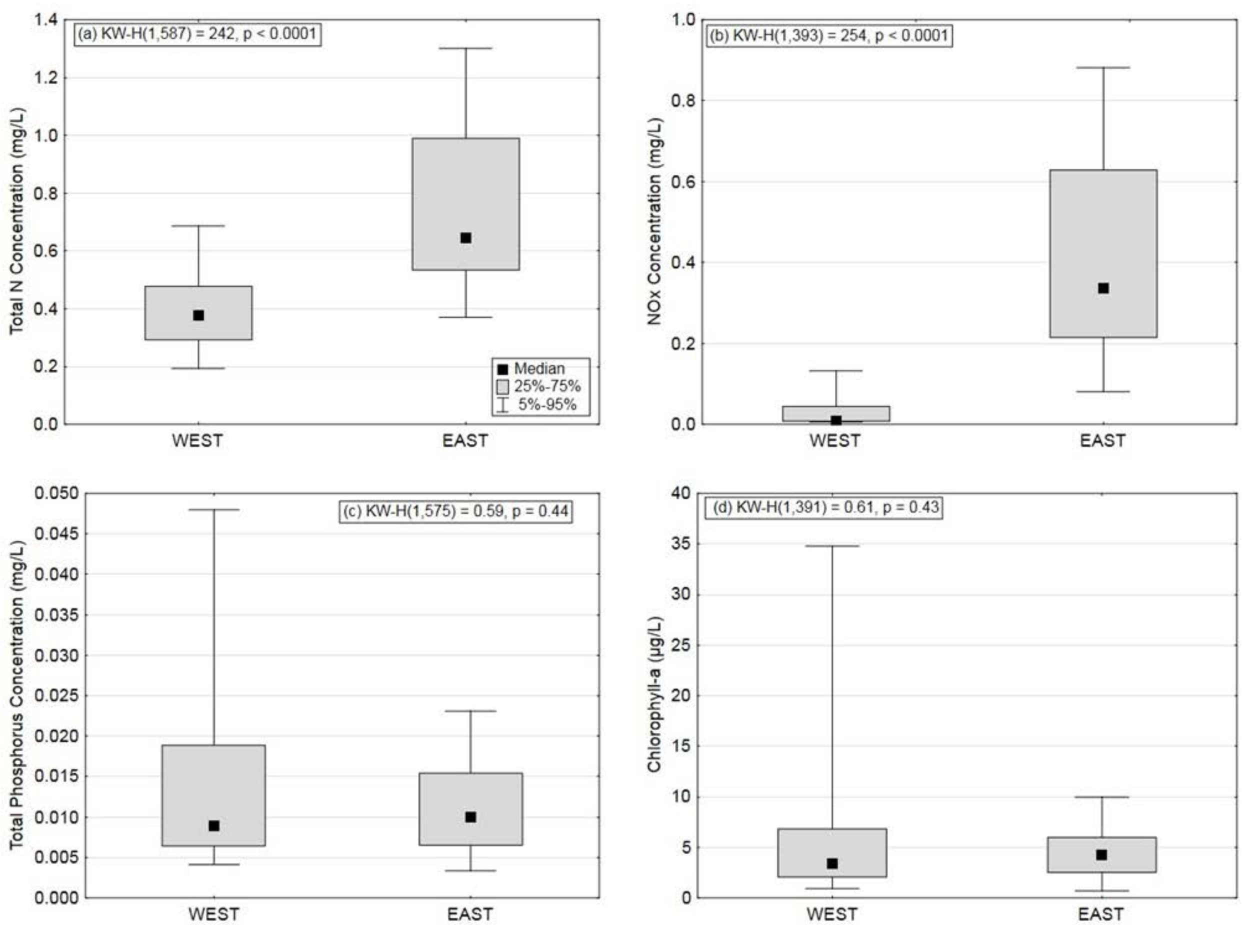



**Figure 25.** Distribution plots of surface, open water: (a) TN (mg/L), (b) $NO_X$ (mg/L), (c) TP (mg/L), and (d) Chl-a (ug/L) observations for western and eastern Finger Lakes for 2017 and 2018.

The statistical differences between the western and eastern lakes were strong for $NO_X$ as well (Figure 31b). All $NO_X$ observations (N = 196) in the western lakes were less than 0.2 mg/L averaging 0.033 mg/L (median = 0.007 mg/L), while the observations from the eastern lakes ranged from 0.007 to 1.10 mg/L. The eastern lakes averaged 0.41 mg/L of $NO_X$ (median = 0.338 mg/L), more than 10-times the average concentration of the western lakes. The 90th percentile of $NO_X$ in the western lakes was less than the 25th percentile of the eastern lakes. A Kruskal-Wallis was performed on these groups and the difference in TN between the lakes was statistically significant ($p <<< 0.01$). The same statistical treatment was applied to summer average TP and Chl-a observations portioned into the west and east groups, but geographic differences were not found for these parameters (see Figures 25c and 25d).

While correlation can be insightful, it should not be confused with causation. **Correlation** implies there is a statistical relationship between two variables. **Causation** implies that one variable determines the response of another.

The geographical pattern in TN in the Finger Lakes was preliminarily investigated to assess potential watershed factors that correlated with the distribution of TN in these lakes. Each lake's watershed boundary was determined in ArcGIS and the watershed area was overlaid with the National Land Cover Data (NLCD 2011) to determine the area (and overall percentage) of various land cover in each of the 11 watersheds. The number of septic systems in each Finger Lake watershed were determined in ArcGIS (http://www.dec.ny.gov/docs/water_pdf/dowvision.pdf). Wastewater treatment plant effluent inputs as sources of TN were not considered for this analysis but likely contributes to TN levels in some watersheds.

Summer average TN concentration was inversely related to percent of the watershed as forested in the Finger Lakes in 2017-2018 (Figure 26a); that is as percent forested land decreased, lake TN concentrations increased. Percent land as pasture and cultivated crops (i.e., row crops such as corn and soybeans) was positively correlated with TN concentrations in the Finger Lakes (Figure 26b,c) explaining 44% and 91% of the variability in TN, respectively. The septic system analysis (Figure 26d) showed a positive correlation with TN concentration as well.

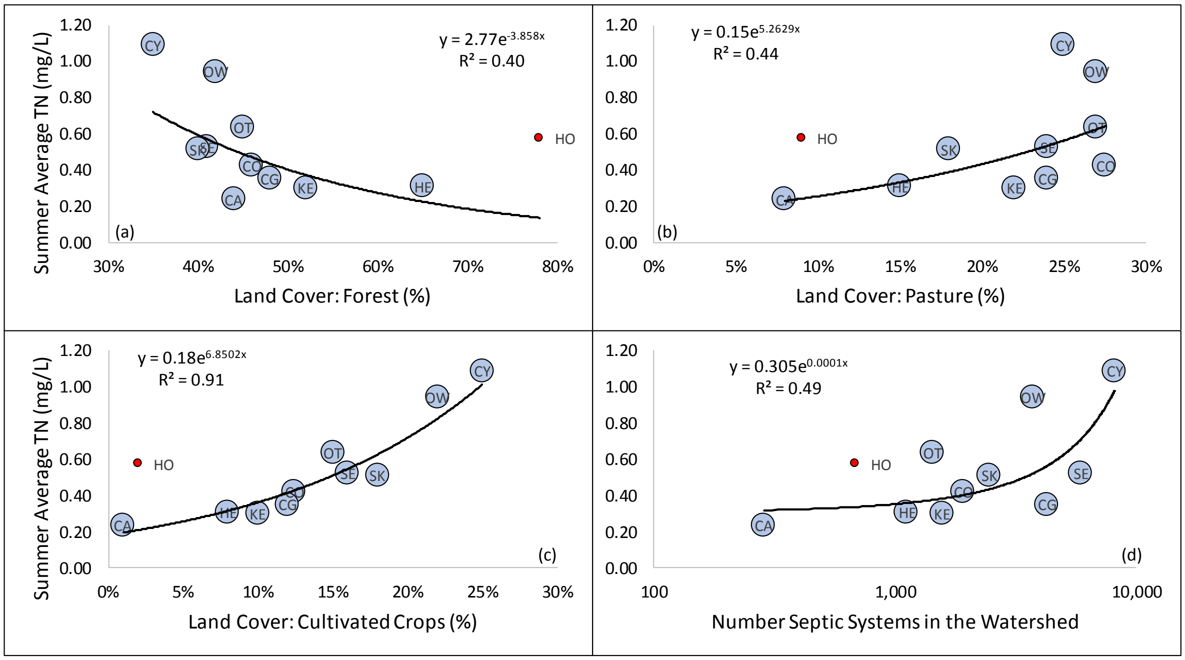



**Figure 26.** Relationship between 2017-2018 average TN (mg/L) and NCLD (2011) land use patterns in the Finger Lakes for: (a) percent forest, (b) percent pasture, (c) percent cultivated crops, and (d) number of septic systems in the watershed. Note: the red symbol represents Honeoye lake and was excluded from the analysis. The Statistical best-fit relationship is shown (solid line).

Neither $NO_X$ nor $NH_3$ were good predictors of Chl-a in 2018 NYS lakes (Figures 27 and 28). The relationships between $NO_X$-Chl-a and $NH_3$-Chl-a for the Finger Lakes were also weak but consistent with the respective relationships for all NYS lakes.

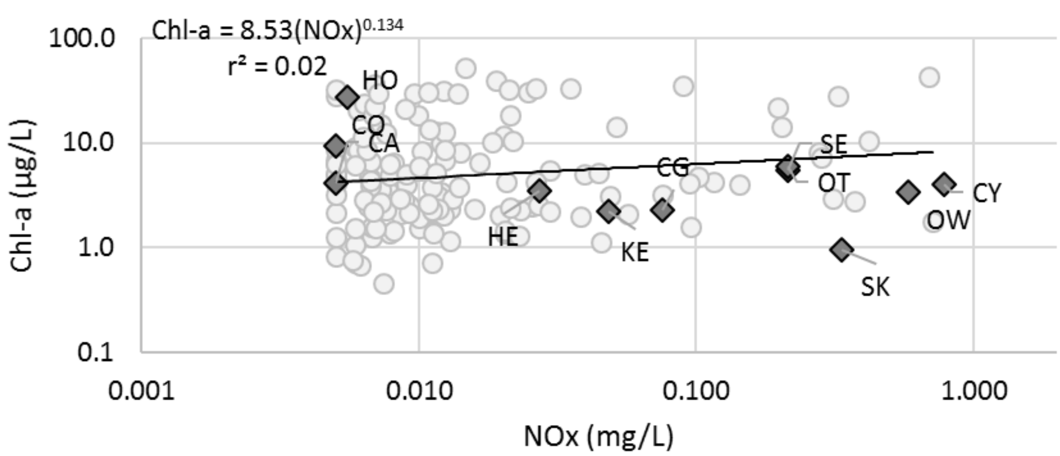



**Figure 27.** Relationship between summer average $NO_X$ concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2018 NYS CSLAP dataset (gray circles) with the Finger Lakes as diamonds. NYS statistical best-fit relationship is presented. Note the scale is log-log.

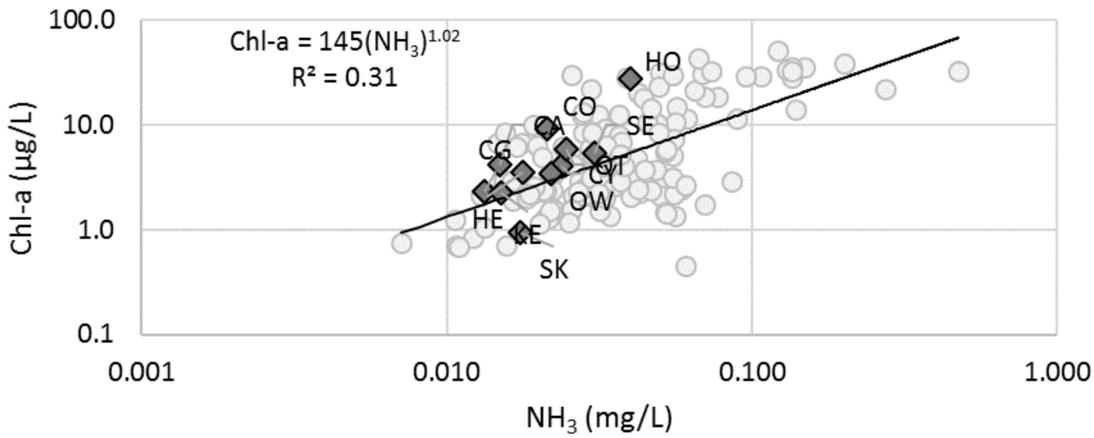



**Figure 28.** Relationship between summer average $NH_3$ concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2018 NYS CSLAP dataset (gray circles) with the Finger Lakes as diamonds. NYS statistical best-fit relationship is presented. Note the scale is log-log.

## Calcium

Calcium is a trace metal closely associated with limestone geology and hardwater lakes. It can be considered a surrogate for alkalinity or buffering capacity—lakes with high calcium levels are generally less susceptible to swings in pH associated with acid rain or other acidic inputs to lakes. Calcium is also a micronutrient required by freshwater mussels to grow their shells and may be one of the most significant limiting factors to colonization by invasive mussels. Calcium is usually stable in most lake systems, so it is analyzed in only two samples per year through CSLAP. Calcium levels may vary spatially within a lake, due to inputs from concrete, limestone leaching, or tributary inputs. Open water calcium levels may be significantly lower than those measured near developed shorelines, thus underestimating the potential for "microhabitats" for dreissenid mussels.

In 2018, CSLAP lakes analyzed for calcium ($Ca^{2+}$, N=144) ranged from 1.5 to 58 mg/L (Figure 29a). The quartile range was 5.9 to 24 mg/L with a median statewide concentration of 12.5 mg/L (mean = 15.8 mg/L). Calcium concentrations in the eleven Finger Lakes were all higher than the statewide median in 2018 (Figure 29b). In fact, most had average concentrations above the NYS 75$^{th}$ percentile for $Ca^{2+}$ (24 mg/L). Honeoye Lake had the second lowest calcium concentration, averaging 18.6 mg/L in 2018. All Finger Lakes had calcium concentrations high enough to support colonization and growth of invasive dreissenid mussels with estimates of critical growth thresholds ranging from as low as 10 mg/L (Bootsma and Lia 2013) to 20 mg/L (Hincks and Mackie 1997). Zebra mussels have been confirmed in each of the Finger Lakes except Canadice Lake (the Finger Lake with the lowest calcium levels), and quagga mussels have been found in Canandaigua, Cayuga, Keuka, Owasco, Seneca, and Skaneateles Lakes.

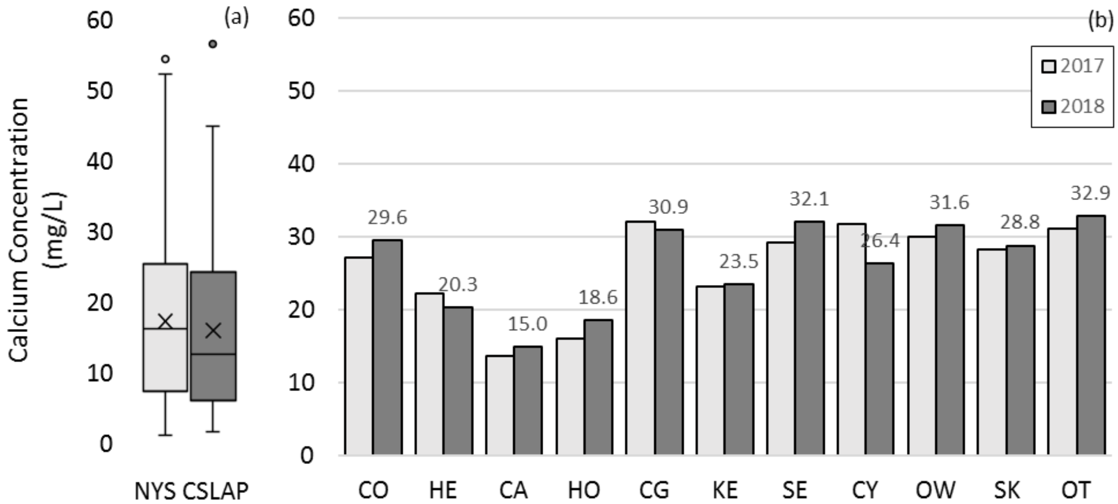



**Figure 29.** Summer average, open water, surface $Ca^{2+}$ concentrations (mg/L) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

The surface water calcium concentrations were substantially lower in 2017 and 2018 compared with the NYSDEC Synoptic Survey in the late 1990s (Callinan 2001; Figure 30). Calcium concentrations decreased by more than 20% in all lakes, except Conesus and Canadice Lakes. The exact mechanism for this is unclear but maybe due to uptake and sequestration into the shells of invasive zebra and quagga mussels.

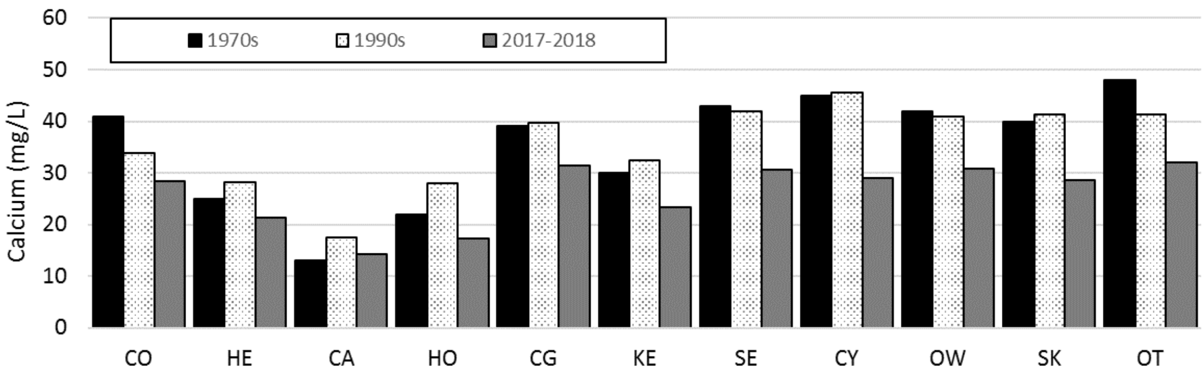



**Figure 30.** Current (2017-2018 average) and historical (late-1990's) surface water calcium (mg/L) concentrations.

## Chloride

Chloride concentrations vary in freshwater lakes due to natural conditions (e.g., geology and soils) but is also a constituent of road deicing agents (road salt), and can enter lakes from stormwater runoff, intrusion from salt water, wastewater and industrial discharges. The NYS drinking water standard for chloride is 250 mg/L, a value rarely seen in NYS lakes. No standards exist for protection of aquatic life, although this is an active area of research in the northeastern United States.

Chloride ($Cl^-$) concentrations varied substantially between CSLAP lakes in 2018. $Cl^-$ concentrations (N=160) ranged from 5 to 249 mg/L (Figure 31a). The interquartile range was 13.4 to 38.2 mg/L with a median statewide concentration of 24 mg/L (mean = 34 mg/L). Summer average $Cl^-$ concentrations were also highly variable between the Finger Lakes in 2018 (Figure 31b). Owasco Lake had the lowest chloride concentration (20.6 mg/L), followed by Skaneateles Lake (21.4 mg/L). Seneca Lake had the highest concentration of $Cl^-$ in the Finger Lakes (126 mg/L), substantially more than the next highest (Conesus Lake; 51.5 mg/L).

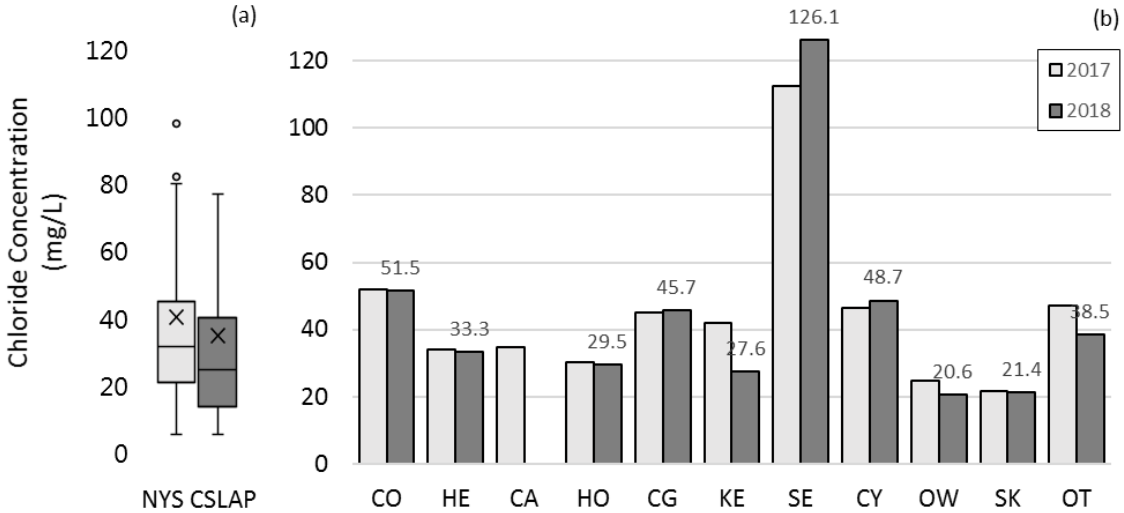



**Figure 31.** Summer average, open water, surface $Cl^-$ concentrations (mg/L) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

$Cl^-$ concentrations have increased in nine of the eleven Finger Lakes since the 1970's and increased in ten of the eleven lakes since the late-1990's (Callinan 2001). Honeoye and Canandaigua chloride concentrations have doubled since the late 1990's and six other lakes have increased by more than 50% (Conesus, Hemlock, Canadice, Keuka, Skaneateles, and Otisco). Seneca Lake $Cl^-$ concentrations have decreased ~33% since the 1970's and 8% since the late-1990s due to reductions in industrial discharge and natural flushing and dilution (Figure 32). Cayuga Lake $Cl^-$ has increased by 15% since Callinan's study (2001) but has decreased ~ 40% since compared with the values reported in Bloomfield (1978).

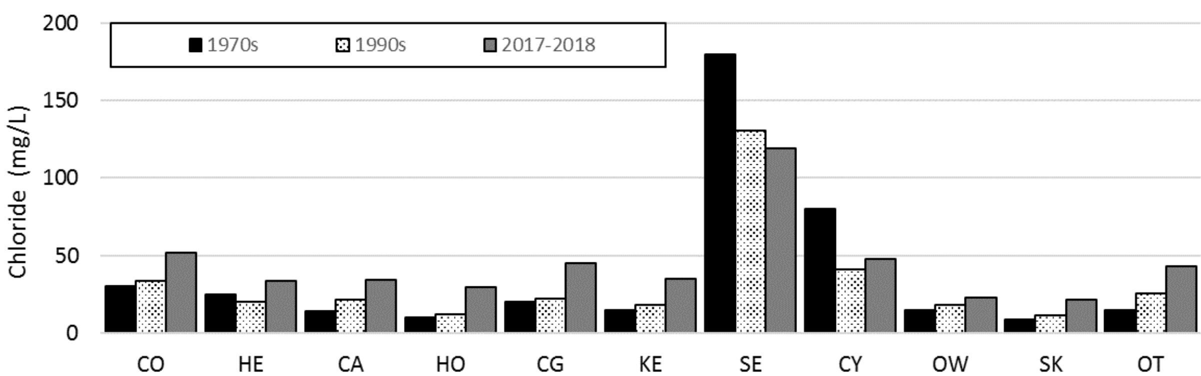



**Figure 32.** Current (2017-2018 average) and historical (1970s [Bloomfield 1978] and late-1990's, [Callinan 2001]) surface water chloride (mg/L) concentrations.

## pH, Specific Conductivity, and Color

pH characterizes the acidity of water on a simple scale. It is the negative logarithm of the hydrogen ion concentration, and is measured on a 14-point scale, from 0 (very acidic) to 14 (very basic) with 7 being neutral (equal concentrations of hydrogen and hydroxide ions). This means that a pH of 5 is 10-times more acidic than a pH of 6. It should be noted that the pH of uncontaminated rainwater is 5.6, due to the dissolution of carbon dioxide, a slightly acidic gaseous compound, although most lakes exhibit higher pH due to the buffering of runoff water (the primary source of water inputs) from limestone and soil particles.

The survival of most aquatic organisms is strongly dependent on pH. Many aquatic organisms do not properly function in water with pH below 6.5 or above 8.5, corresponding to NYS water quality standards. However, aquatic organisms in some lakes have adapted to naturally depressed pH- between 6 and 6.5- associated with dissolved organic matter ("brownness"), and periodic high pH readings may be managed by other aquatic organisms. Aquatic life impacts from low pH are well understood. However, high pH from strongly alkaline inputs or algae blooms (drawing $CO_2$ out of the water through respiration) can also stress aquatic life. This sensitivity of aquatic organisms to pH also reflects the sensitivity of some chemical compounds to pH—the sensitivity of fish to low pH water is a function of aluminum compounds, which can clog gills once certain forms of aluminum predominate at lower pH values. Other compounds, such as ammonia, are more highly toxic at elevated pH. pH is an important water quality indicator as it determines the level of acidity or alkalinity of a water body and influences all important chemical transformations in a lake ecosystem. In most freshwater lakes, pH ranges from 6 to 9 (Wetzel 2001). Historical NYSDEC data, particularly collected as part of the Adirondack Lake Survey Corporation (ALSC) study of more than 1600 lakes in the mid- 1980s, demonstrated that the lowest pH- often well below a pH of 5, can be found in small, high elevation lakes, particularly in the Adirondacks. pH in many of these lakes has slowly increased in response to the federal Clean Air Act amendments from the 1990s which reduced the levels of NOx and SOx (oxidized sulfur compounds) in acidic rainfall.

The eleven Finger Lakes are classified as neutral to slightly alkaline lakes (Table 9), consistent with the hardwater, high calcium levels as discussed earlier. Summer average pH values ranged from 7.49 (Canadice) to 7.93 (Keuka). While no observations were less than 6.5 in 2018, three lakes had individual pH values exceed 8.5.

**Table 9.** Summary of pH (standard units) conditions in the Finger Lakes in 2018.

| Lake | Summer Average pH | Minimum pH | Maximum pH |
|---|---|---|---|
| **Conesus** | 7.40 | 6.75 | 8.34 |
| **Hemlock** | 7.41 | 7.05 | 8.52 |
| **Canadice** | 7.29 | 6.97 | 7.70 |
| **Honeoye** | 7.18 | 6.43 | 8.86 |
| **Canandaigua** | 7.47 | 7.07 | 8.42 |
| **Keuka** | 7.56 | 6.76 | 8.48 |
| **Seneca** | 7.60 | 7.18 | 8.61 |
| **Cayuga** | 7.50 | 7.00 | 8.27 |
| **Owasco** | 7.32 | 6.64 | 8.23 |
| **Skaneateles** | 7.28 | 6.85 | 7.99 |
| **Otisco** | 7.62 | 7.09 | 8.48 |

## Specific Conductance

Specific conductivity (SC; conductivity corrected to 25°C) measures the amount of current that can be carried through water (and "conduct" electricity). The current is carried by ions such as sodium, potassium, and calcium, so the conductivity is a rough measure of the concentrations of these ions. It is also closely related to water hardness and alkalinity (buffering capacity) and is usually a characteristic of the geology of the basin surrounding the lake. However, while conductivity itself is not a strong indicator of water quality, changes in conductivity can: (1) indicate changes in pollutant inputs to lakes, (2) change biological habitat, (3) change the way nutrients remain in the water. Patterns in SC were similar to those discussed for $Ca^{2+}$.

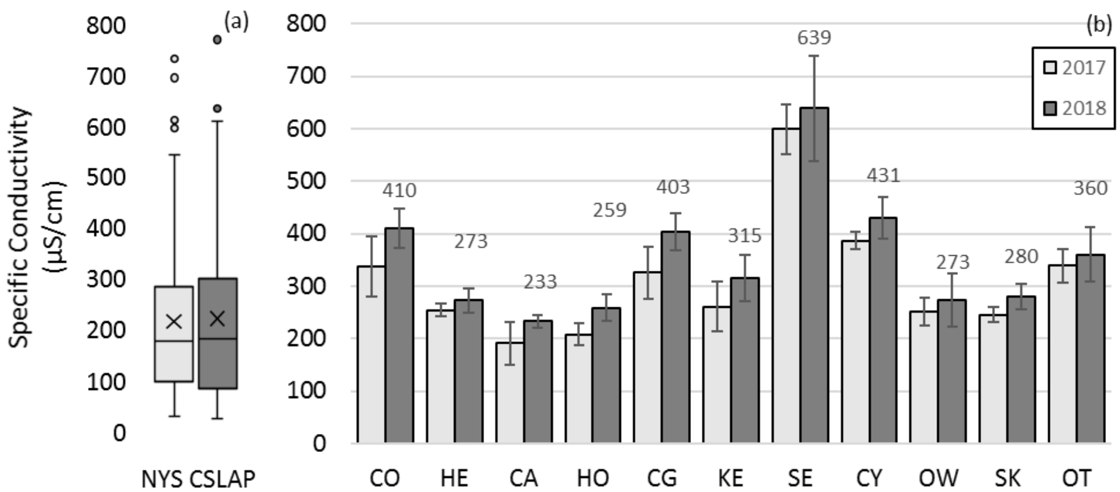



**Figure 33.** Summer average, open water, surface SC concentrations (µS/cm) in 2017 and 2018: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

## Color

Water color is a surrogate for dissolved organic carbon and is manifested in a brownness in the water associated with weak organic (tannic and fulvic) acids. These weak acids are derived from organic soils, or heavily vegetated wetlands or littoral areas in the lake and can result in slightly depressed pH. However, these are most apparent when elevated brownness limits the transparency of the water. When lakes have high levels of dissolved organic matter, they are often referred to as dystrophic, indicating that this condition influences the evaluation of trophic state (since phosphorus readings, chlorophyll-a values, and water clarity are not as balanced as in other clear water- or even greenish- lakes).

Strong water color is not strongly linked to public water quality perception, since dissolved color is often "natural" in many lakes. However, changes in color can indicate changes in runoff patterns to lakes and may be considered a problem. High color can be negatively correlated to conductivity, since dissolved organic matter is often comprised of neutrally charged particles that do not carry current. The ALSC dataset demonstrated that tea-colored lakes are most common in the western Adirondacks, but they can be found in other regions.

NYS lakes are extremely variable with regards to color, ranging from 2 to 88 CU (Figure 34a). The interquartile range was 6 to 16 CU with a median statewide value of 10 CU (mean = 14 CU). The Finger Lakes have very low color compared to NYS lakes generally and lakes in the Adirondack region specifically (Figure 34b). Summer average color values were between 2 (Skaneateles) and 11 (Honeoye) CU, all less than the NYS average in 2018.

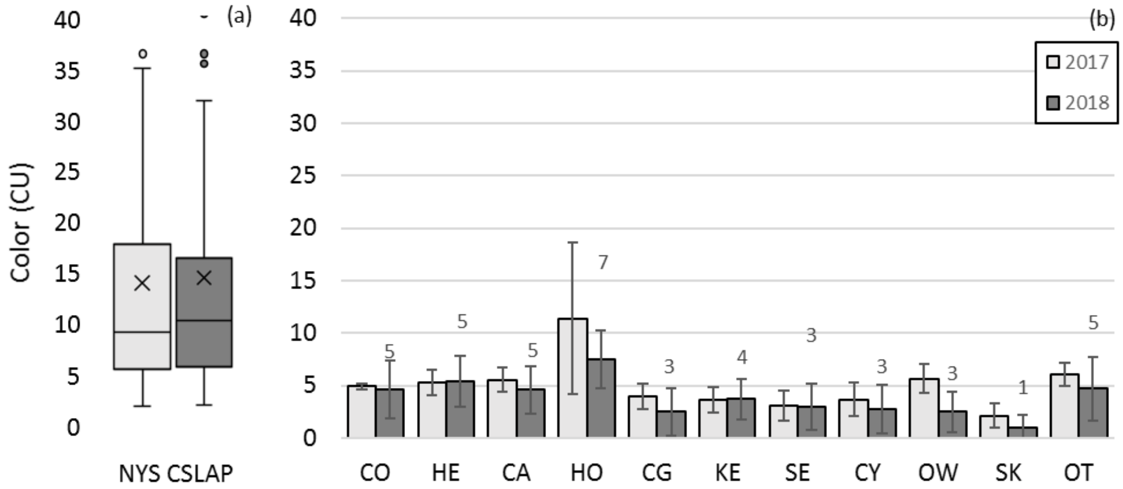



**Figure 34.** Summer average, open water, surface Color (CU) in 2017 and 2018 (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

In NYS lakes, color was moderately inversely related to clarity (as color increased, clarity decreased; Figure 35) with the relationship $R^2$ equal to 0.41. The color-SD relationship for the Finger Lakes was consistent with the pattern observed in NYS lakes. However, color was not a strong driver of clarity in the Finger Lakes in 2018, with color only explaining a small amount of the variability in Secchi depth for these lakes (relationship not shown). This is not unexpected given the relatively low color of the Finger Lakes.

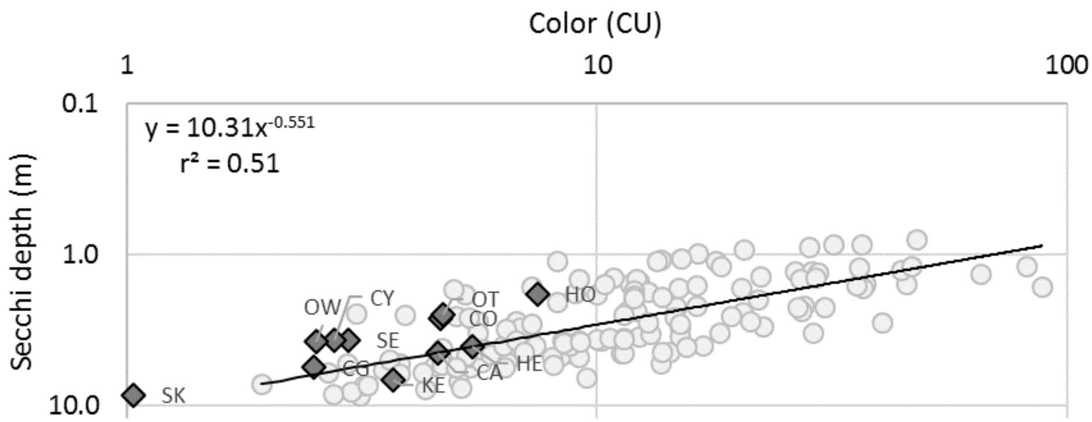



**Figure 35.** Relationship between summer average Color (CU) and Secchi disk depth (m) for the 2018 NYS CSLAP dataset (gray circles) with the Finger Lakes as diamonds. NYS statistical best-fit relationship is presented (solid line). Note the scale is log-log.

## Quality Control Performance

In 2017 and 2018, NYSDEC collected duplicate field information and water chemistry samples on “ride alongs” with CSLAP volunteers in the Finger Lakes. Duplicate field measurements and chemistry sampling were done to assess the reproducibility, precision, and comparability of CSLAP data (collected by volunteers) on these important freshwater resources. In 2018, the NYSDEC-CSLAP field auditing program was expanded to approximately 30 additional CSLAP lakes in Central New York. The QC samples were essentially field duplicates of the surface (1.5m below surface) samples that were collected at the same time, with the same equipment, and processed in the same manner as the volunteer samples. Therefore, this sampling evaluated each component of the sampling related to sampler performance- sample collection, transfer of samples from collection to storage devices, sample processing (sample transfer to individual aliquot bottles and filtration), and sample transport to the laboratories. The NYSDEC staff also used the opportunity to answer other limnological questions posed by CSLAP volunteers and to learn more about each of the lakes. One site was chosen at each lake to conduct these quality control visits. After processing, the QC samples were relinquished to the analytical laboratory for analysis.

Two preliminary evaluation techniques were used to compare the professional and volunteer data sets: (1) paired scatterplots (NYSDEC Sampler v. Volunteer samples) and (2) the differences between paired measurements (NYSDEC Sampler-Volunteer) were analyzed as metrics of data performance and usability. The paired scatterplot comparisons are presented in this report.

Comparisons of paired field measurements for temperature (air and water) and Secchi disk (SD) clarity were generally good (Figure 36). There were some discrepancies in paired air temperature readings by the volunteer and NYSDEC, mostly likely resulting from mis-reads of the thermometers by the volunteers.

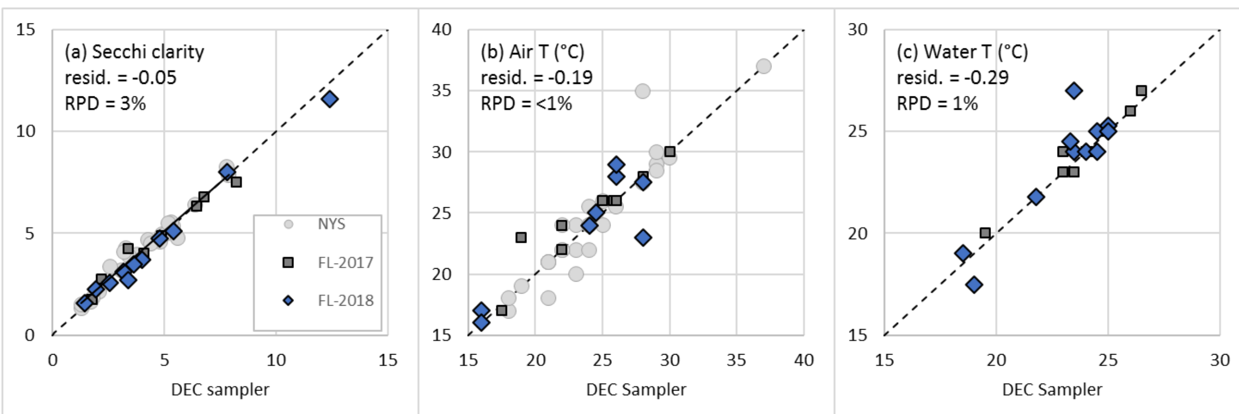



**Figure 36.** Comparison of NYSDEC staff samples with volunteer samples in the Finger Lakes in 2017and 2018. The dashed line represents the 1:1 line of equality. Resid. = average difference between NYSDEC Sampler-Volunteer measurement. RPD = relative percent difference.

Chemistry field duplicates collected by NYSDEC auditors for the total phosphorus (TP) and chlorophyll-a (Chl-a) performed well against volunteer samples with only several discrepancies large enough to result is a mischaracterization of trophic state (Figure 37).

Many differences in TP measurements were within the contract laboratory's Level of Detection (± 1 LOD) and most were within Level of Quantification (± 1 LOQ). This metric of performance provides a quantitative approach for identifying significant differences between duplicates; i.e., if the difference is smaller than the test LOD (or LOQ), we can have high confidence that the discrepancy is due to random analytical variability and not necessarily sampler error. Differences in Chl-a were skewed towards slightly higher NYSDEC Sampler values compared to volunteer samples. This pattern was observed in the Fluoroprobe Chl-a values as well and may be attributed to incomplete mixing of the sampling container prior to filtering. TN, NOx, Color performed well as the majority of differences for these metrics were well within respective ± 1 LOQ.

The performance of pH, and Specific Conductivity performance was variable. Large differences were observed in certain cases for these metrics and for Specific Conductivity were distinctly skewed. Possible sources of error are (1) Contamination of sample water due to skin contact and/or (2) vigorous shaking of mixing container introducing air to sample and thus affecting sample chemistry. This QC information is critical as the NYSDEC evaluates CSLAP data quality and will use this information to make important programmatic and training modifications.

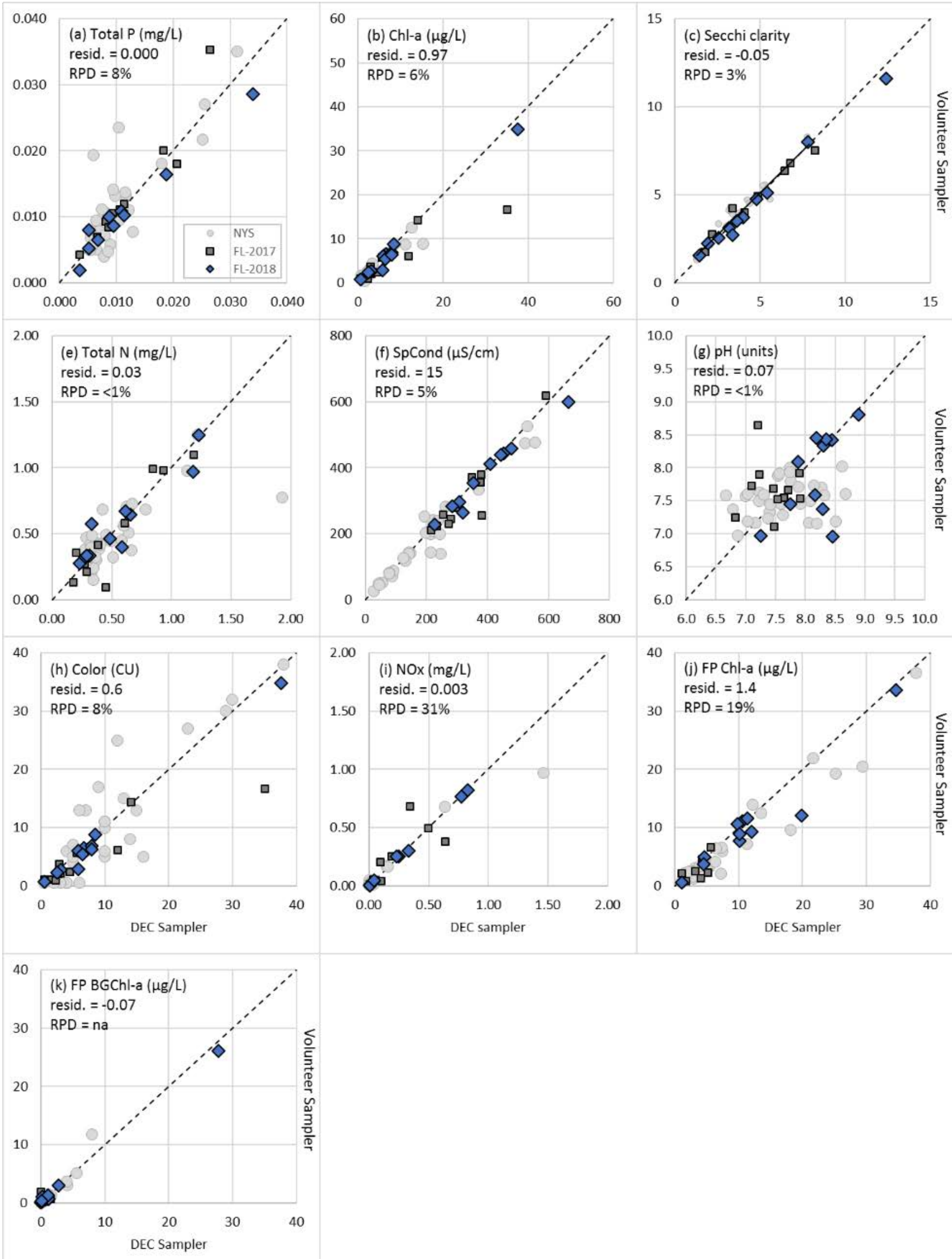



**Figure 37.** Comparison of NYSDEC staff samples with volunteer samples in the Finger Lakes in 2017 and 2018. The dashed line represents the 1:1 line of equality. Resid. = average difference between NYSDEC Sampler-Volunteer measurement. RPD = relative percent difference.

# Section 5: Evaluation of Trophic State

## Context

Trophic state refers to the level of biomass production, specifically primary (biological) productivity for a given water body. Primary productivity, defined as the mass of algae produced within a water body, is usually estimated by measurements of Chl-a, the main photosynthetic pigment in algal cells. Trophic state is a common metric to assess the health of a waterbody and has explicitly defined criteria in NYS (Table 10 for: (1) Chl-a—a common surrogate of algal biomass, (2) TP—the primary nutrient that limits algae growth, and (3) SD—a measure of water clarity which is commonly influenced by primary production.

The term trophic refers to nutrition, and originates from the Greek word trophikos, or food. In an ecological setting, it refers to the relationships among different organisms in the food chain. In a lake setting, the food chain, or more properly the food web, is based on phytoplankton, or algae. The amount of algae produced in a lake dictates the production of other organisms; hence, algae are referred to as the primary producers. Lakes with large amounts of algae (and other plants and animals), excessive nutrients and reduced water clarity are called *eutrophic*, literally "well-nourished", and lakes with little biological production, few nutrients and very clear water are called *oligotrophic*, or "scant(ly) nourished." Lakes with intermediate nourishment are called *mesotrophic*. Eutrophication is the process in which lakes become overly nourished, whether naturally or induced by human activities (cultural eutrophication).

These definitions are not synonymous with water quality conditions or an indication of supporting lake use—many eutrophic lakes are highly productive sports fisheries, and many oligotrophic lakes do not support aquatic life, often due to high lake acidity imparted by acid rain. However, higher trophic states result in not only reduced water clarity and higher algae levels, but also declines in drinking water quality, reduced oxygen in the lower waters, greater susceptibility to nuisance and harmful algal blooms, and dominance by invasive aquatic plants. In many waterbodies, the trophic status dictates both the support of designated uses and serves as a surrogate for water quality conditions. For the Finger Lakes, supporting drinking water use for thousands of residents and swimming opportunities for countless visitors, lake management objectives will largely point to attaining or maintaining a lower trophic status.

**Table 10.** NYS Trophic State Criteria

| Trophic State | Meaning | TP (mg/L) | Chl-a (µg/L) | SD (m) |
|---|---|---|---|---|
| **Oligotrophic** | Poorly nourished, low algal production | < 0.010 | < 2 | > 5 |
| **Mesotrophic** | | 0.010 – 0.020 | 2 – 8 | 2 – 5 |
| **Eutrophic** | Well nourished, high levels of algal production | > 0.020 | > 8 | < 2 |

Dr. Robert Carlson from Kent State University (Carlson 1977) established empirical relationships between TP, Chl-a, SD and used the resulting equations to define the Trophic State Index (TSI) for a set of mid-western US lakes in the mid-1970s. This allows each of these indicators to be used to define the trophic state of any lake, and to compare these indicators in a way that might provide some additional insights about the algal dynamics in lakes.

- Eq.1: $TSI(Chla) = 9.81 - LN(Chla) + 30.6; where\ Chla = chlorophylla\ concentration\ in\ \mu g/L$
- Eq.2: $TSI(TP) = 14.42 * LN(TP) + 4.15; where\ TP = TP\ concentration\ in\ \mu g/L$
- Eq.3: $TSI(SD) = 60 - 14.41 * LN(SD); where\ SD = Secchi\ clarity\ depth\ in\ meters$

Carlson developed these trophic state indices on a logarithmic scale from 0 (extremely unproductive) to 100 (extremely productive) so that every increase of 10 TSI units indicates a doubling of algal biomass. TSI values in a range between 40 and 50 correspond to mesotrophic conditions for each of these trophic indicators, with values higher than 50 corresponding to eutrophic conditions, and TSI values lower than 40 attributed to oligotrophic conditions. These original TSI values have been adjusted for NYS to align with the boundaries of mesotrophy (NYSDEC 2017; Table 11). All subsequent discussions of trophic state will use the NYS criteria.

**Table 11.** Carlson and NYS Trophic State Criteria

| Trophic State | Oligotrophic | | Mesotrophic | | Eutrophic | |
|---|---|---|---|---|---|---|
| | Carlson (1977) | NYS | Carlson (1977) | NYS | Carlson (1977) | NYS |
| **Total Phosphorus** | <40 | **<37** | 40-50 | **37-47** | >50 | **>47** |
| **Chlorophyll-a** | <40 | **<37** | 40-50 | **37-51** | >50 | **>51** |
| **Secchi Disc Clarity** | <40 | **<37** | 40-50 | **37-50** | >50 | **>50** |

The Finger Lakes varied significantly in 2017 and 2018, ranging from oligotrophic in Skaneateles and Keuka Lakes to eutrophic conditions in Honeoye Lake. The remainder of the Finger Lakes are currently classified as mesotrophic, although Otisco, Cayuga, and Conesus were in the range of upper mesotrophy, corresponding to a TSI greater than 45. Differences between TSI(Chl-a), TSI(TP) and TSI(SD) were generally small within each lake (Table 11). Figure 38 shows the distribution of trophic state in the Finger Lakes using the 2017-2018 average TSI(Chl-a).

Carlson TSI values derived from trophic indicator measurements from the 1970s (Bloomfield 1978), the late 1990s (Callinan 2001), the mid-2000s (Callinan 2013), and 2017-2018 CSLAP results are presented in Table 12. Earlier researchers noted substantial interannual variability for individual lakes within each specified period. For example, Callinan noted that even for oligotrophic Skaneateles Lake (TSI(Chl-a) of 37 during the late 1990s), individual summer TSI(Chl-a) values ranged from 32-40 during that timeframe due to year-to-year differences in algal growth, grazing by zooplankton, and timing of sample collection. In some lakes, Chl-a can also vary in response to active management of algae and water clarity with the use of algaecides.

Modest differences were observed between the three TSI scores within lakes. As an example, in Canadice Lake, all three TSI scores were between 35-41 (Table 12). However, some slight TSI differences were observed across the Finger Lakes. For all lakes, TSI(Chl-a) was greater than TSI(SD) and TSI(TP). As an example, Honeoye Lake TSI(SD) was 52, TSI(TP) was 55 but TSI(Chl-a) was 62. Differences between a lake's TSI scores can be insightful in determining relative degrees of nutrient and/or light limitation (Carlson 1977, Wetzel 2001).

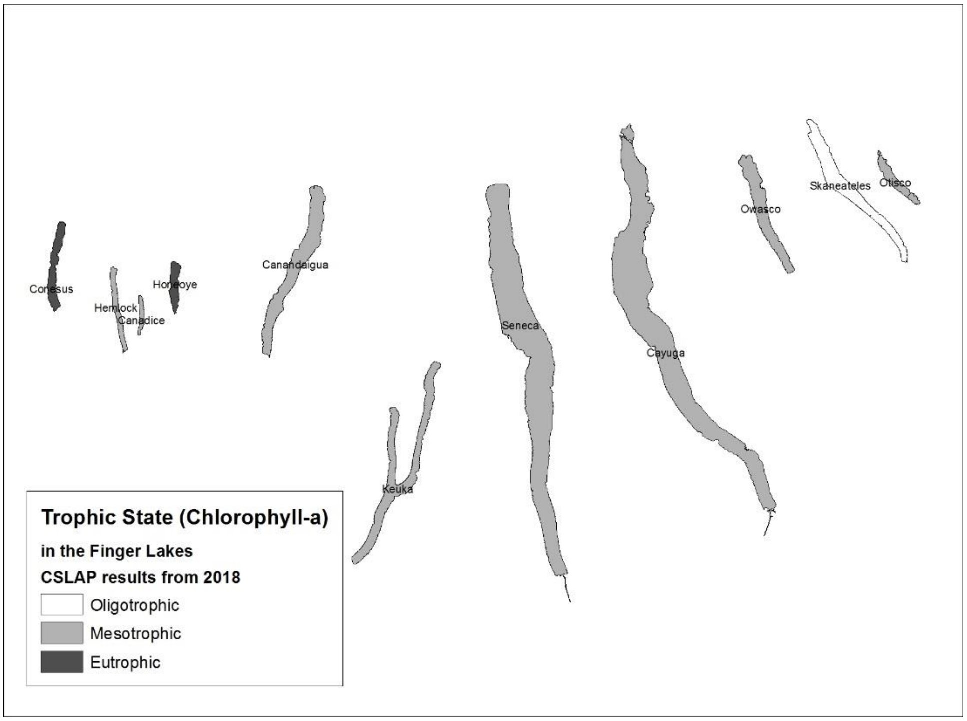



**Figure 38.** Geographic distribution of Chl-a trophic state assessments in the Finger Lakes in 2018.

**Table 12.** Carlson TSI for the Eleven Finger Lakes from the 1970, late 1990s, and 2017-2018 average.

| Lake | TSI(SD) | | | | TSI(TP) | | | | TSI(Chl-a) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1970s | late 1990s | mid-2000s | 2017-18 | 1970s | late 1990s | mid-2000s | 2017-18 | 1970s | late 1990s | mid-2000s | 2017-18 |
| **Otisco** | 36 | 49 | 42 | **46** | 37 | 41 | 44 | **46** | 36 | 47 | 49 | **49** |
| **Skaneateles** | 35 | 31 | 30 | **31** | 30 | 24 | 25 | **26** | 37 | 27 | 27 | **31** |
| **Owasco** | 44 | 45 | 38 | **42** | 42 | 40 | 41 | **38** | 47 | 44 | 48 | **45** |
| **Cayuga** | 42 | 40 | 40 | **43** | 46 | 37 | 44 | **43** | 45 | 43 | 47 | **47** |
| **Seneca** | 45 | 33 | 33 | **42** | 44 | 37 | 36 | **41** | 52 | 39 | 41 | **46** |
| **Keuka** | 38 | 34 | 34 | **33** | 42 | 34 | 29 | **32** | 46 | 41 | 40 | **40** |
| **Canandaigua** | 39 | 30 | 32 | **36** | 39 | 30 | 34 | **32** | 37 | 31 | 39 | **38** |
| **Honeoye** | 44 | 50 | 56 | **52** | 42 | 50 | 52 | **55** | 62 | 51 | 62 | **62** |
| **Canadice** | 36 | 35 | 40 | **37** | 38 | 35 | 39 | **35** | 37 | 40 | 40 | **41** |
| **Hemlock** | 43 | 37 | 39 | **40** | 37 | 37 | 38 | **36** | 48 | 41 | 47 | **42** |
| **Conesus** | 37 | 42 | 44 | **45** | 48 | 49 | 52 | **47** | 27 | 51 | 50 | **50** |

Figure 39 is an adaptation of Figure 13-16 in Wetzel (2001), depicting the relationship between the three TSI scores. All lakes had TSI(Chl-a) greater than TSI(TP), suggesting that these lakes are phosphorus limited, consistent with results for TP, TN, N:P, and Chl-a presented previously (Section 4). 2017-2018 lake scores for TSI(Chl-a) minus TSI(SD) were positive in all lakes which indicates that transparency in these lakes is greater than predicted by the TSI(Chl-a) score alone. This pattern is caused by light attenuation (reduction) being dominated by large particles, cyanobacterial colonies, or the removal of small inorganic particles from the water column from zooplankton grazing (Wetzel 2001) or perhaps dreissenid mussel filter feeding.

The Finger Lakes were all in the upper-right quadrant of Figure 39, indicating a similarity in the eleven Finger Lakes. Conversely, the 2017-2018 NYS CSLAP data set were scattered throughout the matrix which shows that a diverse number of factors determine productivity and clarity in NYS.

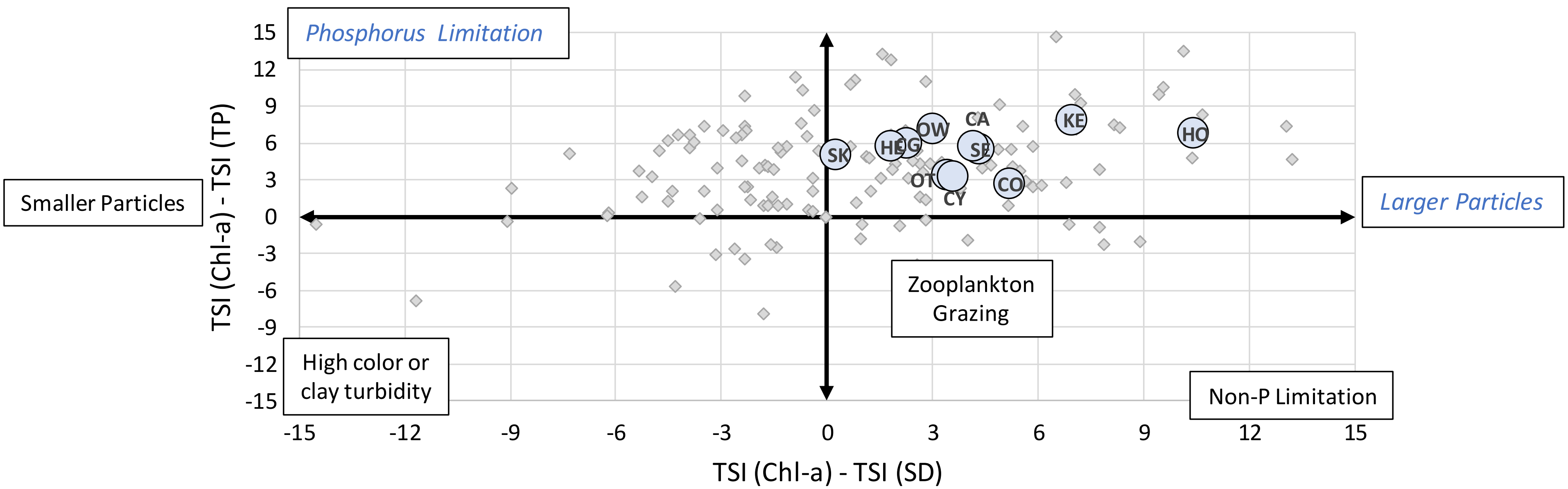



**Figure 39.** Matrix plot between [TSI(Chl-a) minus TSI(SD)] versus [TSI(Chl-a) minus TSI(TP)] for all NYS lakes (gray diamonds) and the Finger Lakes (circles) for 2017-2018 average. Possible mechanisms causing lake orientation on the matrix is provided.

# Section 6: Harmful Algal Blooms

## Background

Algal blooms have been observed and reported on NYS lakes for at least several centuries. Blooms comprised of cyanobacteria have been around for at least that time period, though most likely longer. Cyanobacteria are among the oldest organisms on earth, dating back several billion years. In recent years, however, these blooms have attracted significant interest around the world and in New York due to very high-profile blooms in the Great Lakes, all Finger Lakes, and hundreds of smaller lakes and ponds throughout NYS. Blooms have also been identified in other waterbodies in the Finger Lakes region, including some flowing waters.

NYSDEC and NYSDOH began the process of developing a procedure to formally document cyanobacteria blooms through a Centers for Disease Control (CDC) grant in 2008. NYSDEC established a Harmful Algal Bloom (HAB) Program which includes surveillance and many monitoring partnerships, particularly through CSLAP and SUNY College of Environmental Science and Forestry (SUNY ESF) beginning in the early 2010s. This is comprised of a robust CSLAP open water monitoring program, and collections of suspected shoreline bloom samples observed by or reported by volunteers on all CSLAP lakes. Additionally, NYSDEC worked collaboratively to develop shoreline surveillance and monitoring networks on Honeoye Lake in 2013, Owasco Lake in 2014, Seneca Lake in 2015, and Otisco Lake in 2017. Additional shoreline networks were established on Skaneateles, Cayuga, and Canandaigua Lakes in 2018.

**What is a HAB?**

Harmful algae blooms are dense concentrations of cyanobacteria (blue green algae) that can produce liver, nerve and dermal toxins, or other harmful substances. Exposure to blooms can result in health impacts through skin exposure, ingestion or inhalation.

In 2018, the Upstate Freshwater Institute was the HABs Program primary lab for fluoroprobe Chl-a, visual identification of algae, and microcystin analyses for the Finger Lakes. The results are interpreted by NYSDEC HABs Program staff in Albany. The NYSDEC HABs Program has additional partnerships for analysis of HABs samples, including Stony Brook University, the Finger Lakes Institute, and SUNY ESF.

## What is a Bloom?

Bloom reports can take the form of visual observations, collected samples with associated analytical results, digital pictures, beach operational decisions, and other data or information. Reports come into the NYSDEC, generally in mid- to late-week in late summer. These timeframes reflect when largest number of lakes are surveyed, public observations and lake use increase, and when cyanobacteria blooms are most likely to occur. Most bloom reports fit the following two categories:

- **Visual –** cyanobacteria blooms usually look like spilled paint, pea soup, or green streaks on the water surface, or large concentrations of green dots on or within the water column. They can also exhibit heavy green discoloration throughout the water column. In many cases, bloom reports don't fit cleanly in one of these categories but will share many visual characteristics. Beach operators may make closure decisions based on visual observations of blooms.

- **Sampling results** – when a bloom is suspected, samples are often collected and submitted to one of the laboratories cited above. Upon receipt at the laboratory, samples are run through a fluoroprobe (bbe Moldaenke) and analyzed for total and fractional Chl-a, including measurements of cyanobacteria (blue green algae or BG Chl-a) content. The chlorophyll pigment is not extracted from the cells, so this measurement is not as accurate as the extracted chlorophyll measurement (Table 1). However, fluoroprobe measurements can be generated quickly, require little analyst time or cost (once the equipment is purchased), and unlike extracted samples, can distinguish between potentially harmful blooms (comprised of cyanobacteria) and blooms of other algae. Samples with total Chl-a levels above 10 µg/L are inspected (qualitatively) microscopically for the dominant algal taxa with cyanobacteria generally reported to genus and only samples with total Chl-a levels above 10 µg/L are run for microcystin analysis.

Bloom reports are characterized by the NYSDEC HABs Program using the following categories, recognizing that the status of each report can change based on additional information:

## Visual bloom assessments

Visual characterization of a HAB is central to the NYSDEC's overall HAB monitoring strategy. Research has shown that well trained volunteers are highly accurate at correctly differentiating a HAB from other non-harmful algae. This allows for a rapid determination by NYSDEC and prevents unnecessary sampling

- **Not a Bloom** represents a low likelihood that a cyanobacteria bloom is present. The following criteria must be met: (1) in the absence of a sample, visual evidence is not consistent with a cyanobacteria bloom; samples show (2) BG Chl-a < 25 µg/L; (3) a microscopic scan without dominance by cyanobacteria and bloom-like densities; or (4) only in absence of the previous criteria being met: microcystin ≤ 4 µg/L.

- **Suspicious Bloom** fulfills either of the following criteria: (1) characterized by NYSDEC HABs Program or NYSDOH staff from surveillance reports or digital photographs from visual evidence of a bloom is likely to be cyanobacteria. In absence of digital photographs, a descriptive field report from professional staff or trained volunteer may indicate suspicious conditions; (2) staff from NYSDOH, NYSDEC or NYSOPRHP close a regulated swimming beach due to the visual observation of a bloom.

- **Confirmed Bloom** fulfills at least one of the following criteria: (1) BG Chl-a levels ≥ 25 µg/L (as measured with a fluoroprobe); (2) microscopic confirmation that majority of sample is cyanobacteria and present in bloom-like densities; or (3) only in absence of the previous criteria being met: microcystin ≥ 4 µg/L but less than high toxin thresholds and accompanied by ancillary visual evidence of the presence or recent history of a bloom. These BG Chl-a thresholds were developed from the NYSDEC interpretation of the World Health Organization (WHO) thresholds between moderate and high probability of acute health effects, as described in detail in the NYSDEC program guide (http://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf).

- **Confirmed with High Toxins Bloom** are Confirmed Blooms with laboratory analytical results meeting one of the following criteria: (1) total microcystin ≥ 20 µg/L from shoreline bloom samples; (2) total microcystin ≥ 10 µg/L from open water bloom samples; or (3) known risk of exposure to anatoxin or another cyanotoxins, based on evaluation of these cyanotoxin testing results and consultation between NYSDEC HABs Program or NYSDOH staff.

## NYSDEC NYHABS

In 2019, the NYSDEC is establishing an interagency collaborative effort with new staff and the NYSDOH. This program is being called "NYHABS", the New York Harmful Algal Bloom System. NYHABs provides an interactive map of HAB reports, updated daily for all of New York State. Submission of HABs reports are done with a Survey123 (ESRI ArcGIS Online) fillable form that works on any platform (desktop, mobile, tablets). The reporting individual can fill the form out anywhere, but ideally in the field where exact location can be captured and photos attached to bloom report. Reports include status, extent, 'reported by' information, and exact location of HABs, avoiding the association of a bloom to an entire waterbody. Reports will remain current on the map for two weeks. After two weeks, all HABs will be visible as "Archived".

The core mission of the HABs program has not changed. The NYSDEC still functions as the hub for interagency and public collaboration, monitoring, and determination of bloom status. Also, the NYSDEC's core avoidance messaging (Know it, Avoid it, Report it) remains unchanged but, NYHABS has modernized the way information is received by and is disseminated from NYSDEC. The major changes are summarized below:

1. No more email notifications; NYSDOH will inform local health departments about local HABs occurrences

2. All HAB reports go into a central data system (NYHABS) which is updated daily

3. Users can view and export information as needed from a user friendly ESRI ArcGIS Online platform

4. Focus on visual reports and less on extensive shore bloom sampling

Anyone accessing NYHABs for information can filter by lake or county and export reports and view photos. Please see on.ny.gov/nyhabs for more information.

It should be assumed that harmful algal blooms may occur on any waterbody, particularly those identified as mesotrophic or eutrophic. Any lake resident, visitor, or recreational user should follow the advice provided by the NYSDEC and the NYSDOH:

- Avoid contact with any surface scums or heavily discolored water,
- If exposed to the bloom, rinse with clean water, and seek medical assistance if experiencing nausea, vomiting, rashes, or difficulty breathing,
- Report all health symptoms and exposure information to the local health department, and
- Report bloom information to the NYSDEC at HABsInfo@dec.ny.gov

## Statewide Distribution of HABs

The distribution of HABs is provided in Figure 40 showing the 2012-18 cumulative summary of Suspicious, Confirmed and Confirmed with High Toxin Blooms locations throughout NYS. This map shows the "peak" occurrence in each waterbody- Confirmed with High Toxin Blooms supersede Confirmed Blooms, which supersede Suspicious Blooms. It should be noted that some waterbodies bloom in some years, but not others.

New York State HABs 2012-18

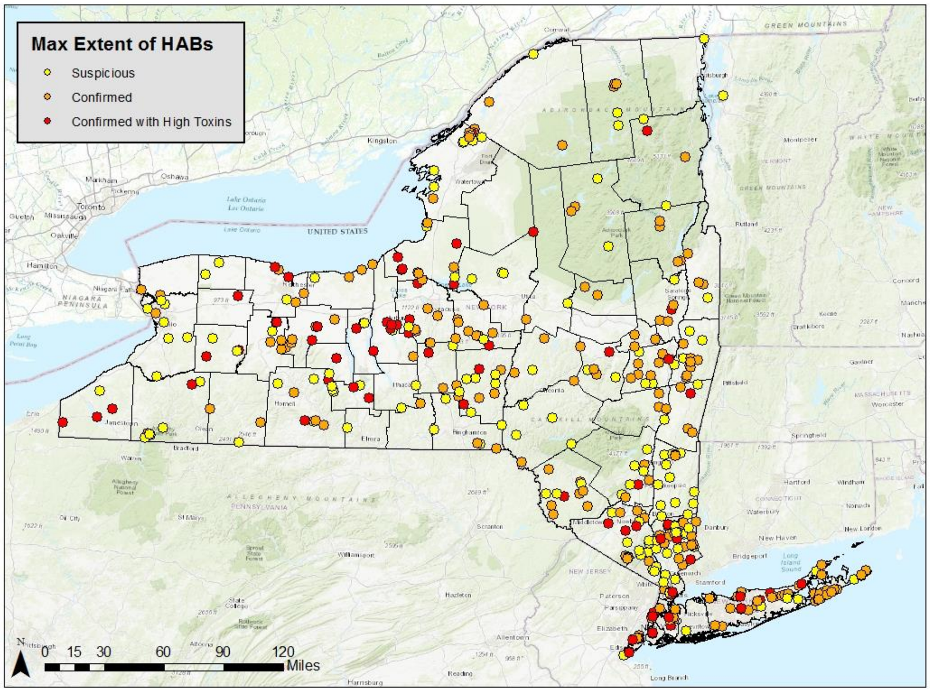



**Figure 40.** HABs Distribution 2012-2018

Table 13 shows the number of NYS waterbodies that have had documented Suspicious, Confirmed and Confirmed with High Toxin Blooms in each year since 2012. A part of the increase in blooms can be attributed to increasing numbers of surveillance and monitoring partnerships and greater public attention to the issue, although the actual occurrence of HABs may have increased, particularly in the Finger Lakes and other large waterbodies. The 2012-18 cumulative row on the bottom of the table reflects the total number of waterbodies in each category; many individual lakes were cited each year but are only counted once in the cumulative totals.

**Table 13.** HABs Reports in NYS Lakes

| Year | Suspicious | Confirmed | High Toxins | Total |
|---|---|---|---|---|
| **2012** | 20 | 29 | 9 | 58 |
| **2013** | 17 | 37 | 22 | 76 |
| **2014** | 19 | 51 | 23 | 93 |
| **2015** | 40 | 62 | 35 | 137 |
| **2016** | 41 | 95 | 38 | 174 |
| **2017** | 45 | 84 | 36 | 165 |
| **2018** | **57** | **83** | **40** | **180** |
| **2012-18** | 122 | 171 | 101 | 394 |

## Finger Lakes Distribution of HABs

The table inset to the right, shows the Suspicious, Confirmed, and Confirmed with High Toxins Blooms in the Finger Lakes. Information about open water and shoreline bloom reports from CSLAP can be found in the Individual Lake Chapters (Section 9). This table should not be considered a definitive assessment of blooms in these lakes; this only represents the extent to which credible bloom reports were provided to NYSDEC and its partners and does not reflect the true extent, duration, or intensity of blooms on these waterbodies. The extent of blooms in each lake is documented in the Individual Lake Chapters, particularly those with active surveillance networks.

| Lake | '12 | '13 | '14 | '15 | '16 | '17 | '18 |
|---|---|---|---|---|---|---|---|
| **Otisco** | | | | S | | C | C |
| **Skaneateles** | | | | | | HT | HT |
| **Owasco** | | HT | HT | HT | HT | HT | HT |
| **Cayuga** | | | C | | C | HT | HT |
| **Seneca** | | | | HT | HT | HT | HT |
| **Keuka** | | | | | | HT | HT |
| **Canandaigua** | | | | HT | C | HT | HT |
| **Honeoye** | S | HT | HT | HT | C | C | C |
| **Canadice** | | | | | | C | |
| **Hemlock** | | | | | | C | C |
| **Conesus** | | | S | | C | C | C |

Bloom reports in some lakes (or in some years) are primarily a function of vigilant surveillance- blooms are observed and reported when surveyors look for blooms, particularly when this surveillance includes large portions of the shoreline. For the Finger Lakes and some waterbodies elsewhere in NYS in general, blooms may have been present in each year since 2012 but were not reported or observed due to the lack of complete surveillance (and some lakes were not sampled each year). This may particularly be the case in very large lakes, where blooms can often escape detection unless the lakes are closely surveyed.

## Potential Factors Influencing HABs in the Finger Lakes

As demonstrated in Figure 40, HABs occur in many waterbodies throughout New York. In 2018, HABs were observed on 10 Finger Lakes. While it is known that excessive nutrient levels, particularly phosphorus, can trigger the formation of algal blooms generally, and HABs specifically, an increasing number of blooms have been documented on mesotrophic (moderate nutrient lakes) to oligotrophic lakes (low nutrient lakes). The frequency, duration, and intensity of blooms are influenced by many factors. Research over the last few decades has documented several factors that trigger HABs, although it is likely that the reasons for blooms on any lake could be unique to that lake (NYSDEC 2017). Furthermore, there may be additional, unidentified factors that influence HABs that are not discussed in this report. Some factors, as illustrated in the scientific literature (below), that appear to affect bloom formation include: meteorology (warm, calm periods), elevated algae levels, elevated nutrient levels, food web changes (zebra and quagga mussels), and lake geometry and orientation. Localized nutrient sources, nitrogen to phosphorus ratios, nutrient fractions (dissolved or suspended), and seasonal nutrient inputs may be the proximate cause of some blooms in some lakes (Andersen et al. 2002).

Other factors, including flow and stratification characteristics, buoyancy concentration in deep photic (algae-growing) zones, wind concentration due to fetch length, food web interactions, and temperature or flash runoff increases from climate change may play an important role in bloom formation and toxin production. The data- water quality, biological condition, morphometry, and physical characteristics- from these lakes and from lakes with little to no evidence of blooms continues to be closely evaluated by the NYSDEC to gain a greater understanding of the causes of blooms. Future research and detailed evaluations are occurring as part of the 2018 Governor's HABs initiative and will continue with extensive reviews of the Finger Lakes and NYS HABs dataset.

**Climate:** The temperate climate in NYS allows for the growth and development of HABs. Warm summer temperatures, high light intensity and calm wind conditions in the late summer offer an ideal environment for cyanobacterial growth. The effects of climate change will likely have a exacerbate HABs in NYS lakes. More intense, frequent rain events which deliver nutrients to lakes followed by periods of warm, stagnant conditions with high light intensity will allow for cyanobacteria to thrive in the future (Pearl and Otten 2013, Pearl et al. 2016, Chapra et al. 2017). Additional elements of climate change that may increase bloom frequency and duration, including longer growing seasons, earlier ice-out and later ice-in periods, changes in thermal stratification patterns, and selectivity for cyanobacteria relative to other phytoplankton.

**Elevated Algal Levels and Lake Productivity:** The frequency of shoreline blooms increases as open water algal levels (extracted Chl-a) increase, due to the greater likelihood that there is sufficient algal material in the water to concentrate into bloom quantities along the shoreline. In NYS more than half of all lakes with open water Chl-a levels above 10-15 µg/L report shoreline blooms. It should be recognized, however, that blooms can occur throughout a waterbody, along the shoreline only, or as patchy growth at any location in a lake, although densest concentrations tend to accumulate on the shoreline. This is a concern since this corresponds to the area where people recreate or the location of domestic (individual) water intakes.

**Elevated Nutrient Levels:** The relationship between nutrients and HABs has been well documented for decades (Heisler et al. 2008). In NYS, the frequency of open water and shoreline cyanobacteria blooms increases as open water total phosphorus (TP) readings increase. Open water blooms are uncommon when open water phosphorus levels are less than 0.030 mg/L but increase when TP rises from 0.030-0.050 mg/L (and above 0.100 mg/L). Shoreline cyanobacteria blooms, however, occur in nearly 30% of the lakes even at TP levels < 0.020 mg/L, and increase until TP levels reach approximately 0.060 mg/L. At elevated phosphorus levels, cyanobacteria blooms occur in nearly three-quarters of all lakes. However, as noted above, even in low nutrient lakes, large bloom "patches" can be found near the center of the lake, due to surface accumulation of large quantities of HABs associated with the buoyancy of some cyanobacteria.

**Lake Geometry and Orientation:** The physical configuration of some lakes renders them susceptible to blooms. Several lakes exhibiting cyanobacteria blooms despite relatively low nutrient levels appear to be polymictic. Phosphorus levels may build up near the lake bottom. During frequent summer mixing events, these nutrients can migrate to the lake surface and trigger algae growth. In addition, some cyanobacteria can extract nutrients from deeper water or bottom sediments in these lakes with intermediate depths, and then migrate to the surface.

Fetch length is the distance over water across which wind can blow unabated. Bloom frequency increases as the Maximum Fetch Length/Shoreline Length ratio increases for lakes with relatively low open water phosphorus readings, if the maximum fetch is frequently oriented with wind direction, but the relationship is not as well defined for higher TP levels. This suggests that the physical configuration of the lake may play a role in triggering shoreline blooms in waterbodies with relatively low nutrient levels. The Maximum Fetch Length to Shoreline Length (FL:SL) ratios range from 0.33 (Keuka) to 0.44 (Skaneateles

**Lake Depth Categories**

**Shallow -** Lakes that are less than about 6 meters deep, defined thermal layers are not established. Typically, the entire water column can be well-mixed

**Polymictic -** Lakes that are about 6-15 meters deep, in which thermal layers are often weakly established. Lake mixing periods can occur during high wind events, alternating with periods of thermal stratification and nutrient release from bottom sediments

**Deep -** Lakes that are deeper than 15 meters form strong thermal stratification layers that remain intact throughout the growing season. Deepwater nutrients generally don't migrate to the water surface until fall turnover. However, even deep lakes may have shallower sections that exhibit some of the "shallow" or "polymictic" characteristics described above.

and Cayuga). FL:SL ratios in the Finger Lakes would fall in the upper half of the more than 425 NYS lakes surveyed for HABs in the last six years, and the maximum fetch for these lakes would fall in the highest 10$^{th}$ percentile for NYS lakes. The Finger Lakes all have elongated N-S orientations with large shoreline distances which can allow surface accumulations of wind-blown HABs from a very large open area of the lake to be concentrated (Chorus and Bertram 1999). Shoreline blooms are far more common than open water blooms in lakes. These blooms- either originating near the shoreline or concentrated by wind or water movement along the lake shore- may be reported by lake residents or visitors.

**Zebra/Quagga Mussels:** Dreissenid mussels (zebra and quagga mussels) can significantly alter the biological condition of lakes. While dreissenids will filter phytoplankton out of the water column, thereby increasing water clarity, they selectively remove green algae, diatoms, and other algae, leaving cyanobacteria at relatively higher concentrations in the lake. This results in less competition for nutrients, further exacerbating cyanobacteria growth. The frequency of shoreline and open water blooms in lakes with dreissenid mussels is consistently higher than in lakes without dreissenid mussels. There has been substantial research of the complex influence of dreissenid mussels on algal bloom development in the Great Lakes (Hecky et al. 2004) and lakes in Michigan. Sarnelle et al. (2012) demonstrated that low phosphorus (TP ~ 0.01 mg/L – the lower bounds of mesotrophy in NYS trophic determination), low productivity lakes are at a greater risk for HABs in the presence of zebra mussels compared to low phosphorus lakes without these invasive bivalves. HABs data collected over the last six years indicate that low nutrient lakes with dreissenid mussels are 3-5 times more likely to experience HABs than those without these mussels (NYSDEC 2018).

## Algal Indicators and Toxins

All of the shoreline and open water HABs samples submitted are analyzed for different algal toxins. These include several congeners of microcystin (a liver toxin that is the most common cyanotoxin in New York waterbodies), anatoxin-a (a neurotoxin), cylindrospermopsin (a liver toxin), and BMAA (β-Methylamino-L-alanine, a neurotoxin that may be associated with several neurological disorders). To date, neither cylindrospermopsin nor BMAA have been detected in any NYS samples.

USEPA has developed total microcystin guidance values for treated drinking water. In 2015, USEPA issued a 10-day drinking water health advisory of 0.3 µg/L for children (less than six years old), and 1.6 µg/L for older children (>6 years of age) and adults. This advisory was intended to apply to treated drinking water, not "raw" lake water, and the lower 0.3 µg/L advisory level has been adopted by NYSDOH as a health advisory for local health departments.

Exposure to any cyanobacteria HABs can cause health effects in people and animals when water with blooms is touched, swallowed, or when airborne droplets are inhaled. This is true regardless of toxin levels; some blue-green algae produce toxins, while others do not. Exposure to blooms and toxins can cause symptoms such as diarrhea, nausea or vomiting, skin, eye or throat irritation, allergic reactions, or breathing difficulties. For more information go to www.health.ny.gov/harmfulalgae. However, although the presence of cyanobacteria blooms is considered a risk even if cyanotoxins levels are undetectable, toxin levels will continue to be closely evaluated through CSLAP and other HAB surveillance and monitoring programs in the Finger Lakes and in NYS.

NYSDEC research has shown that the frequency of Confirmed with High Toxin Blooms increases with increasing open water TP and TN (NYSDEC 2017). The frequency of these blooms increase as TP levels exceed 0.035 mg/L (= 35 µg/L) and also increases as TN levels rise. Recent research indicates a potential relationship between nitrogen enrichment and toxin levels - these datasets will continue to be evaluated to determine if these relationships are present in NYS lakes (Davis et al. 2008).

## Algal Indicators and Toxins in the Finger Lakes in 2018

The majority of open-water samples in the Finger Lakes collected in 2018 had very low concentrations of BG Chl-a (Figure 41). Only seven samples (from Honeoye Lake) exceeded the NYSDEC's Confirmed Bloom threshold. Among all samples, 84% had BG Chl-a concentrations less than 2.5 µg/L and approximately 90% of all samples were less than 5 µg/L.

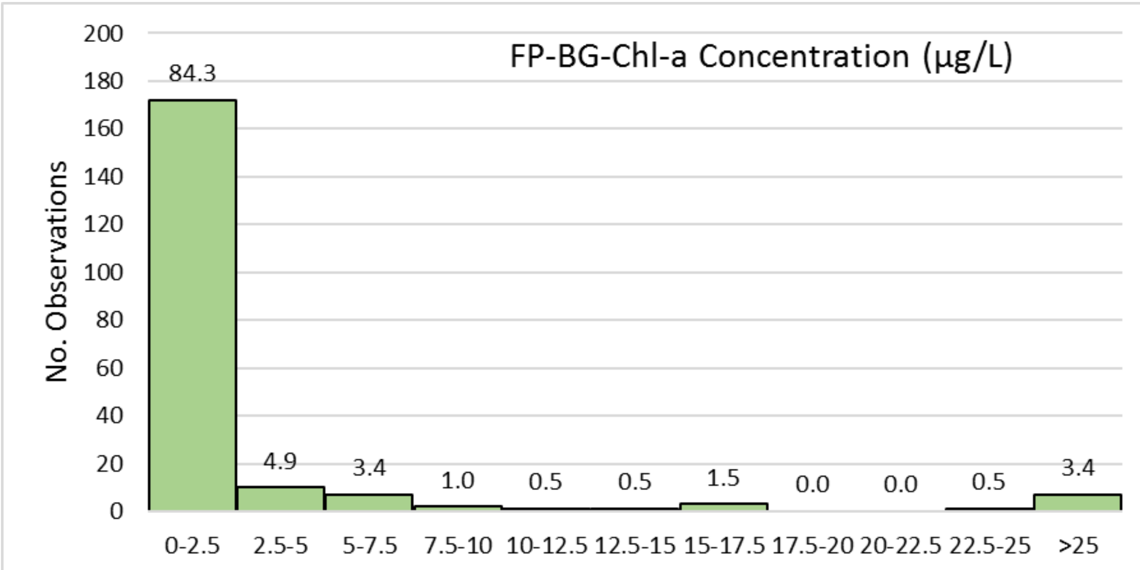



**Figure 41.** BG Chl-a concentration (µg/L) in the open- water samples from the Finger Lakes in 2018. Data labels are percent occurrence.

Concentrations of microcystin were low in the open water (Figure 42); concentrations in 80.5% of samples analyzed were below the method detection limit (< 0.3 µg/L). Eight samples (from Honeoye Lake – S1 and Cayuga Lake – S5) were above the limit of detection, but the concentrations were well below the NYSDEC Confirmed with High Toxins Bloom threshold for an open water sample (10 µg/L).

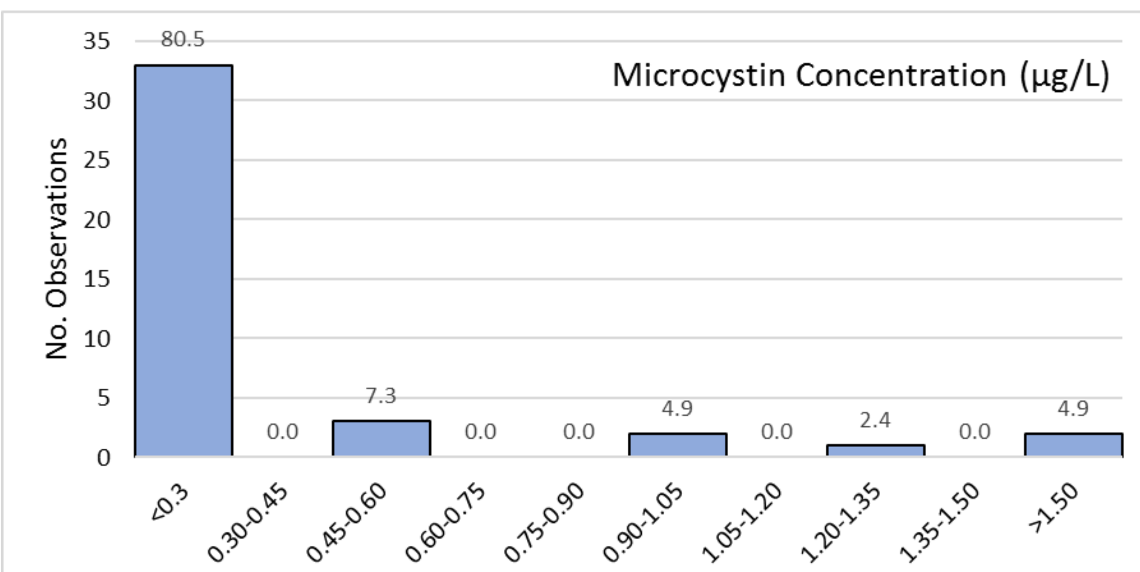



**Figure 42.** Open-water microcystin concentration (µg/L) in the Finger Lakes in 2018.

## Enhanced Shoreline Surveillance in the Finger Lakes

With guidance and training from the NYSDEC, seven of the Finger Lakes, have developed local enhanced shoreline surveillance programs (Table 14) that extend HAB monitoring to cover significant/expansive portions of the Finger Lakes shorelines. Each lake has a local leader that works to develop the shoreline program, provides logistical support and additional training to many volunteers, and liaises with the NYSDEC. The individual volunteers are trained by NYSDEC and agree to survey specific zones on their lakes weekly at about the same time and submit a report whether a bloom is present or not and provide a qualitative assessment of bloom appearance and extent (e.g., pea soup that is small/localized). If a HAB is present, the volunteers take pictures and collect a sample. They deliver forms, photos, and/or mail samples on an as needed basis.

**Table 14.** Finger Lakes with Enhanced Shoreline Surveillance Networks

| Lake Name | # of CSLAP Sites | Number of Shoreline Zones | Local Website |
|---|---|---|---|
| Canandaigua Lake | 2 | 16 | http://www.canandaigualakeassoc.org/science-education/blue-green-algae-2/ |
| Cayuga Lake | 5 | 80 | http://www.communityscience.org/cayuga-lake-2018-harmful-algal-blooms-results/ |
| Honeoye Lake | 2 | 10 | |
| Otisco Lake | 2 | 20 | |
| Owasco Lake | 2 | 40 | https://owla.org/habs/ |
| Seneca Lake | 4 | 100 | https://senecalake.org/Blooms |
| Skaneateles Lake | 2 | 30 | https://skaneateleslake.org/bloom-updates/ |

The enhanced shoreline surveillance programs provide a valuable service to their communities and to the NYSDEC. They educate and deliver targeted messaging about HABs on their lakes, including specific location of blooms. In 2018, these groups submitted more than 2,100 surveillance reports that covered hundreds of miles of shoreline in the Finger Lakes region (Table 15). The visual reporting mechanism was highly accurate as well. Combined, the Enhanced Surveillance volunteers correctly identified a HAB with 87% accuracy. NYSDEC research has shown that the accuracy of the shoreline volunteers has improved each successive year in the program.

**Table 15.** Surveillance Results in 2018

| Lake Name | Surveillance Reports | Open water samples* | Shore bloom samples | No Bloom | Suspicious | Confirmed | Conf. High Toxins | Accuracy (%) |
|---|---|---|---|---|---|---|---|---|
| Canandaigua Lake | 295 | 17 | 27 | 2 | 2 | 1 | 24 | 93 |
| Cayuga Lake | 483 | 41 | 32 | 2 | 14 | 11 | 19 | 94 |
| Honeoye Lake | 137 | 39 | 43 | 13 | 1 | 34 | 0 | 67 |
| Otisco Lake | 126 | 17 | 2 | 8 | 1 | 1 | 0 | 50 |
| Owasco Lake | 269 | 16 | 16 | 7 | 2 | 2 | 8 | 77 |

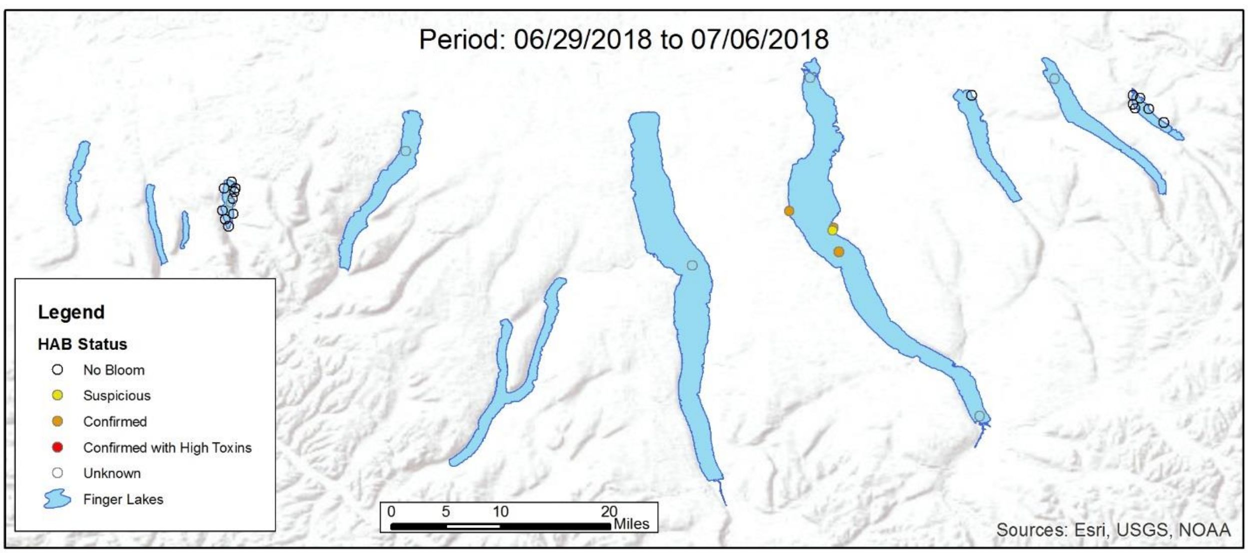
| Lake Name | Surveillance Reports | Open water samples* | Shore bloom samples | No Bloom | Suspicious | Confirmed | Conf. High Toxins | Accuracy (%) |
|---|---|---|---|---|---|---|---|---|
| Seneca Lake | 702 | 35 | 41 | 1 | 1 | 5 | 35 | 98 |
| Skaneateles Lake | 136 | 15 | 16 | 6 | 0 | 4 | 6 | 63 |
| **Total** | **2,173** | **246** | **196** | **39** | **21** | **58** | **92** | **87** |

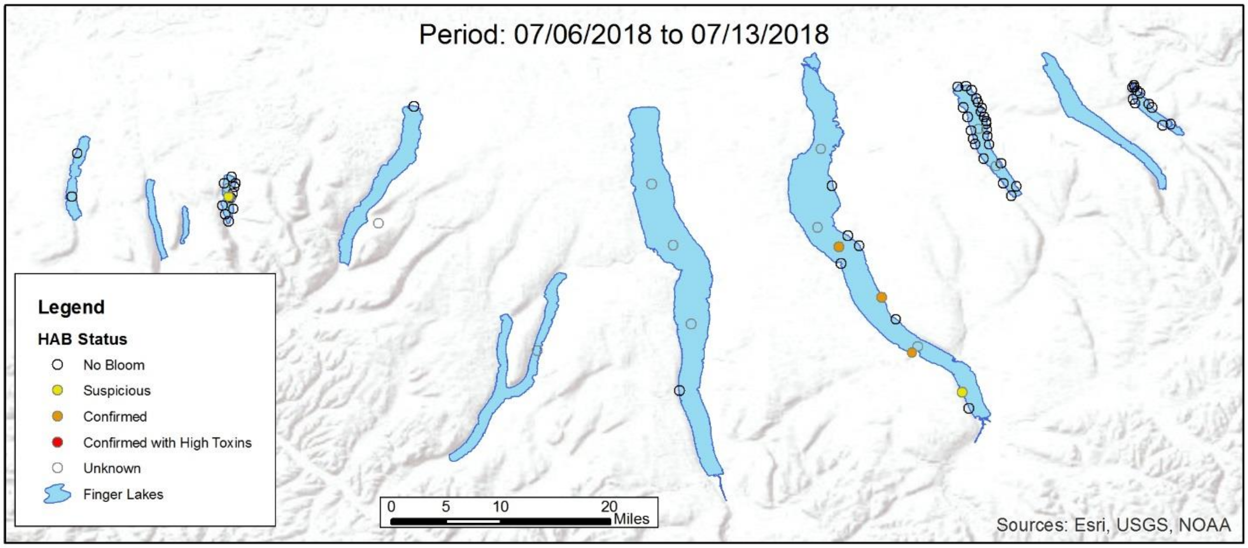
* through CSLAP

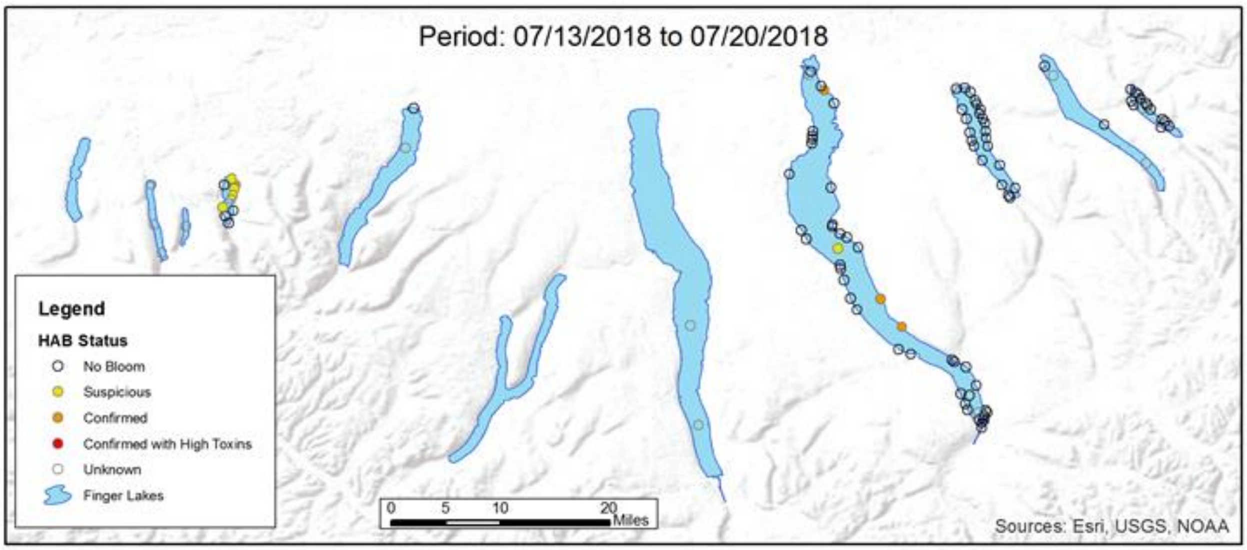
The shore bloom concentrations of BG Chl-a and microcystin were higher compared to open water concentrations but spatially and temporarily variable within and among lakes. Values of BG Chl-a often exceeded the NYSDEC Confirmed Bloom threshold (Section 9). This is expected as nearshore samples are collected: (1) only if a bloom is present and (2) these samples reflect the skim sampling methodology designed to capture the "worst-case scenario" of a bloom and concentrate the bloom material for analysis. Concentrations of microcystin were variable in nearshore samples as well, with many samples exceeding the Confirmed with High Toxins Bloom threshold (Section 9). Wide ranges in results were expected because of the differences in the types of established HABs monitoring programs among the lakes and the inherent range in results related to sampling of the densest scum material. Therefore, shore bloom results will be discussed qualitatively.

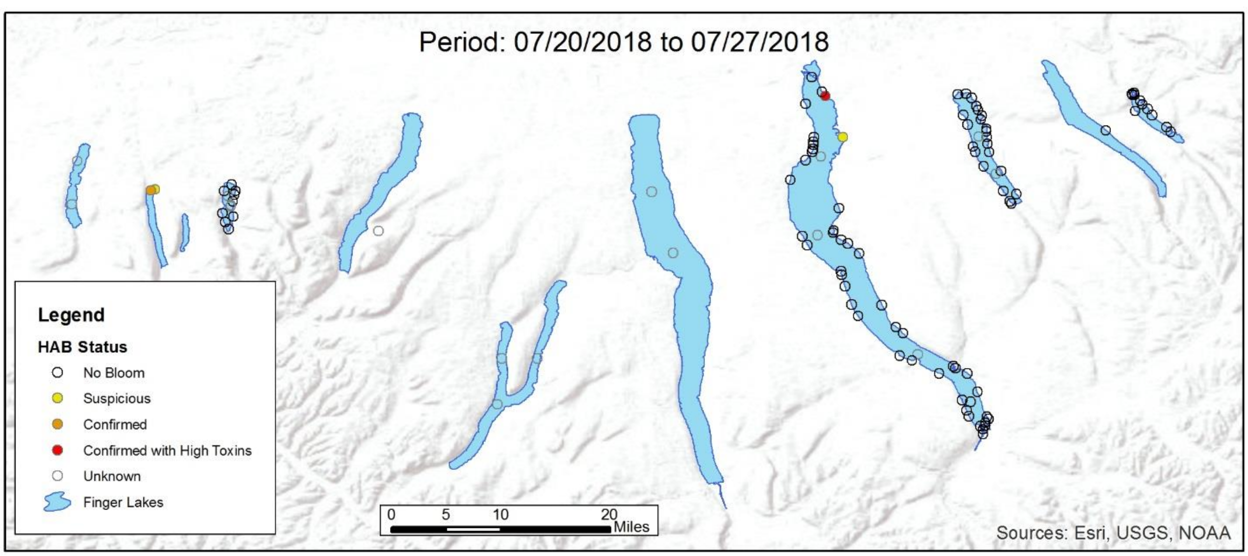
## Individual surveillance maps

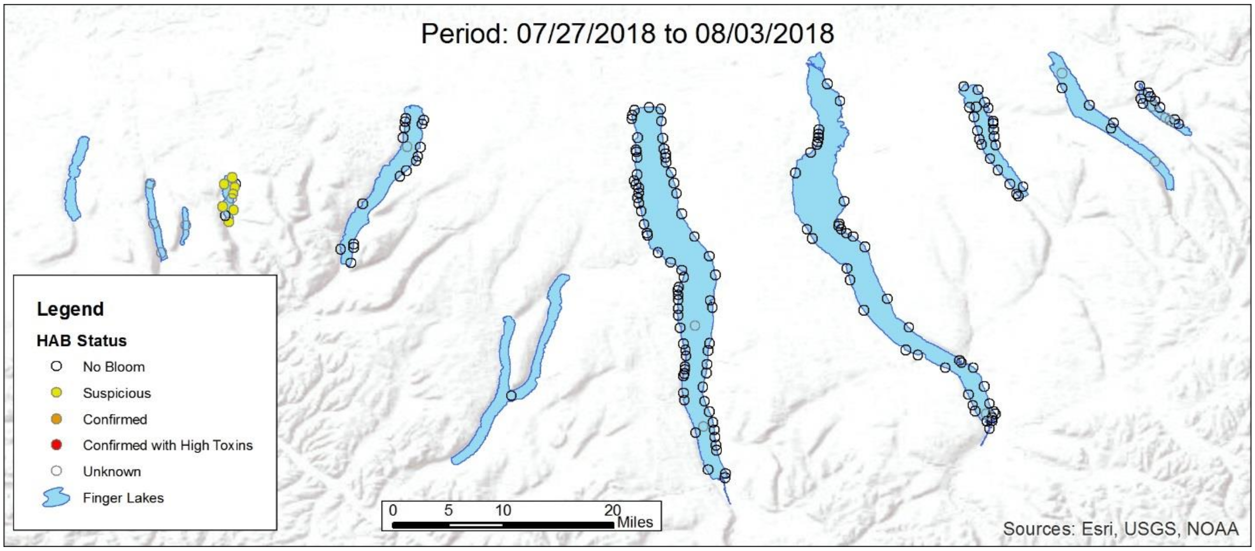
The establishment of seven enhanced shoreline surveillance programs allows for a detailed look at the distribution and timing of blooms on a regional scale. Figure 43 shows the location of bloom reports from the shoreline zones in the Finger Lakes weekly from late June through September in 2018.

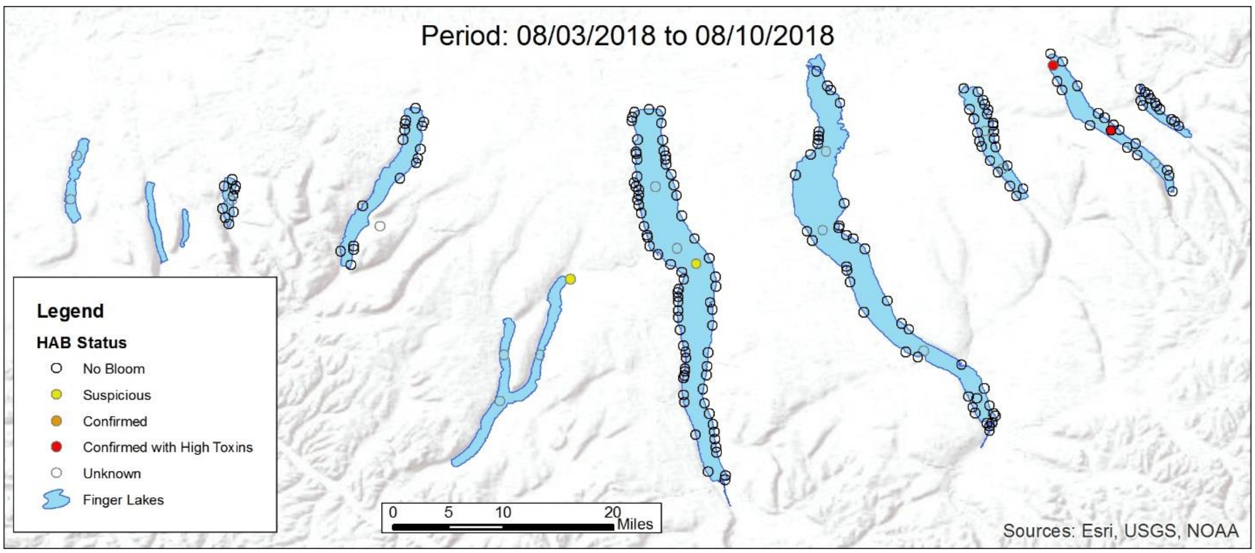


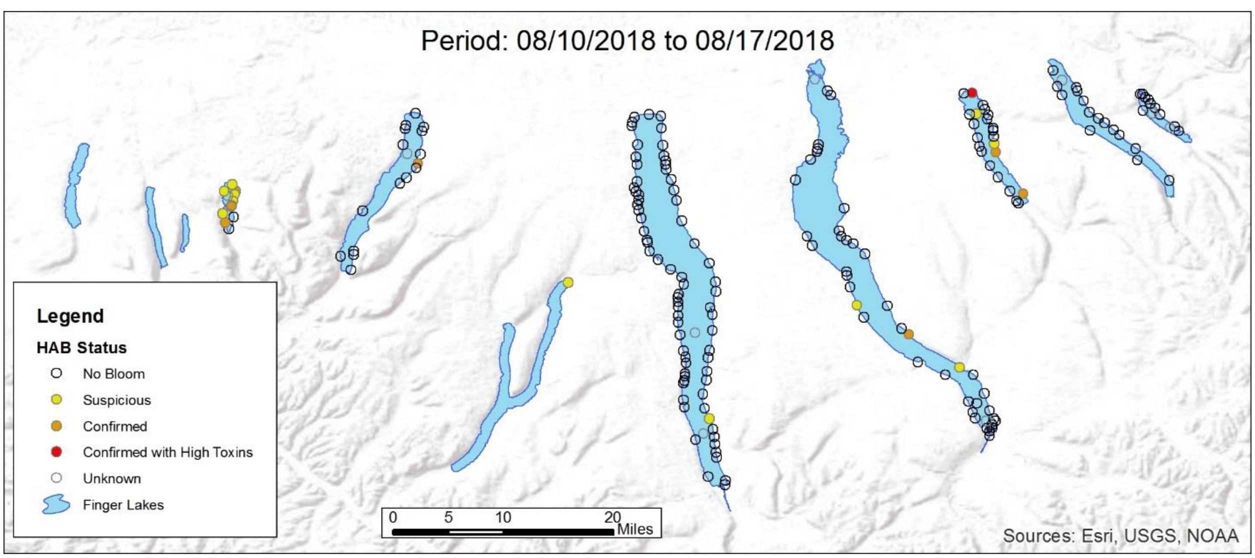

Period: 07/06/2018 to 07/13/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

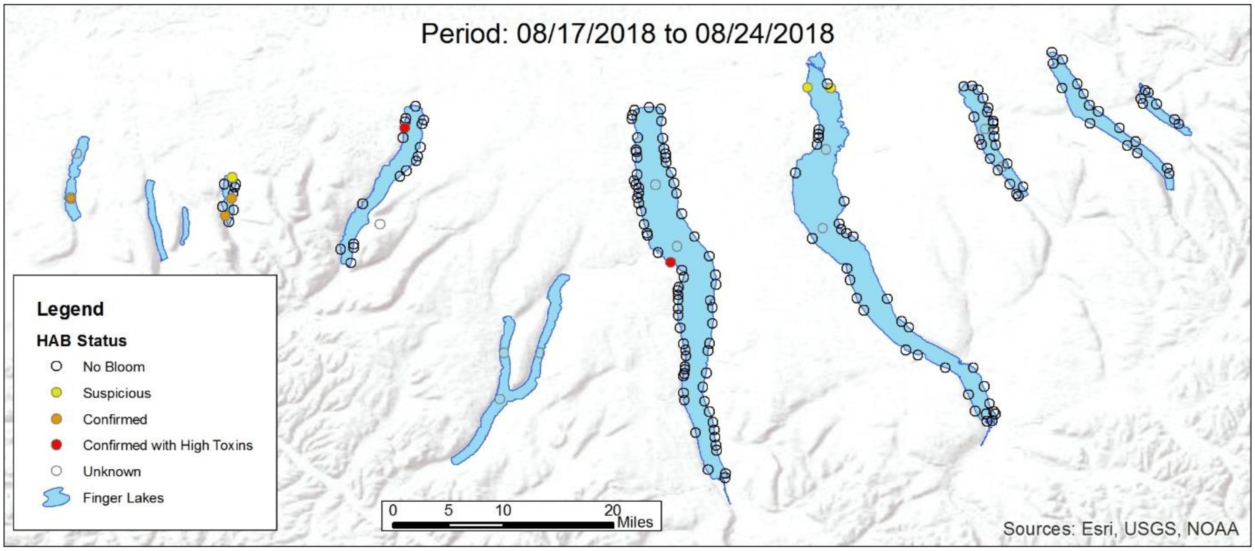

Period: 07/13/2018 to 07/20/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

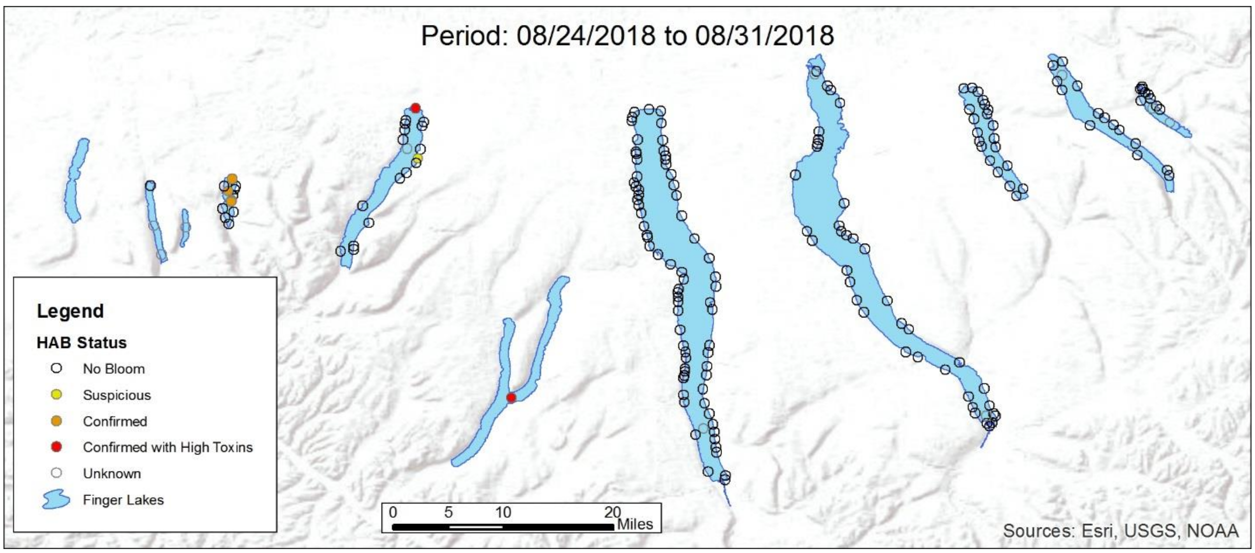

Period: 07/20/2018 to 07/27/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

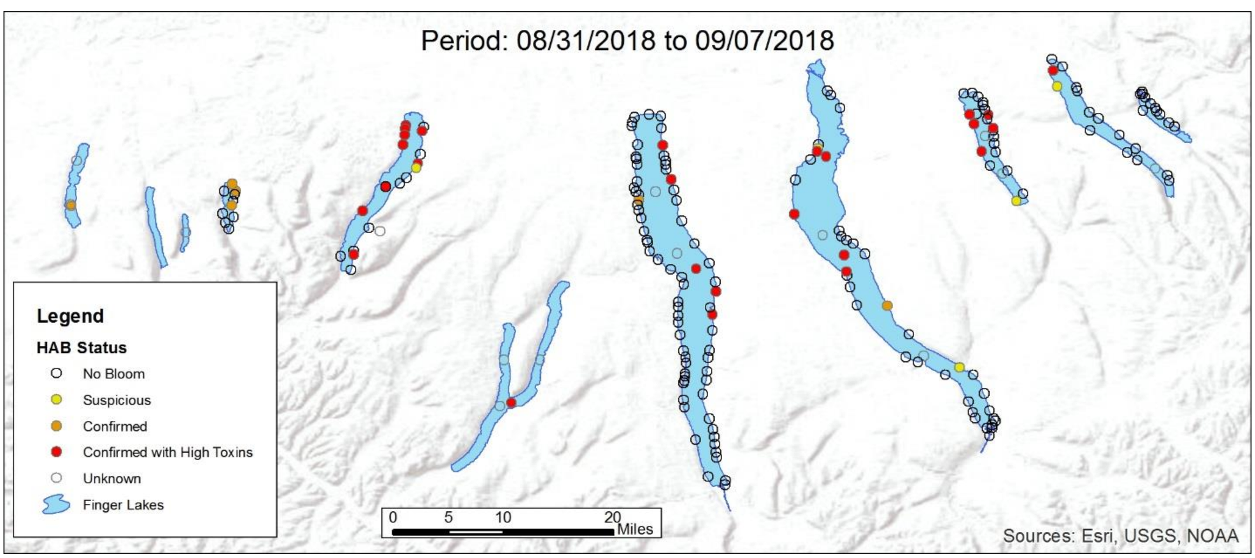

Period: 07/27/2018 to 08/03/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

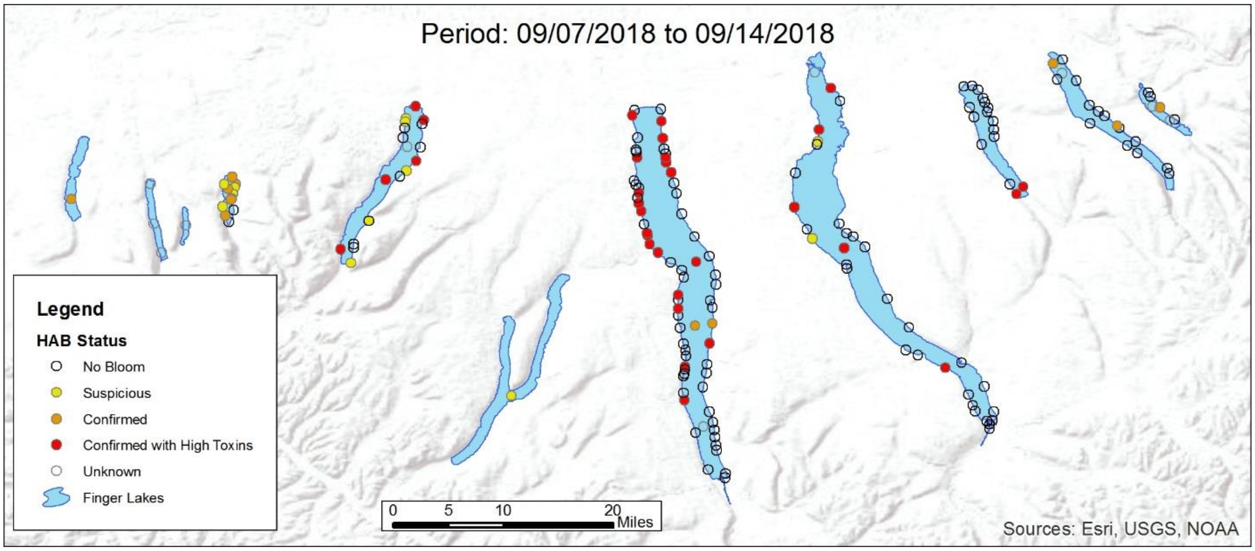

Period: 08/03/2018 to 08/10/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

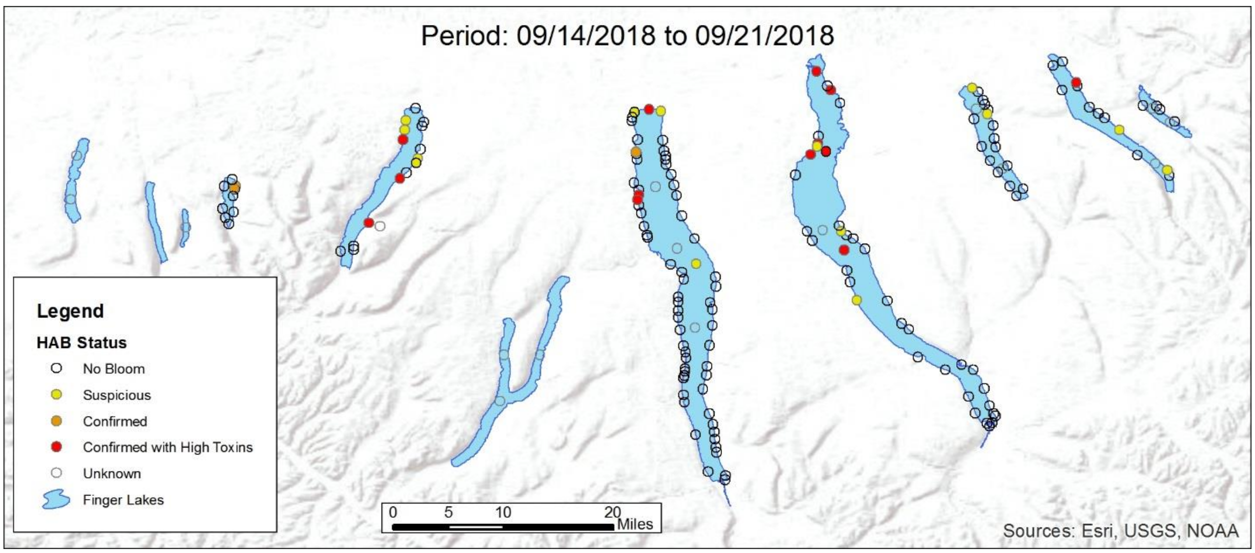

Period: 08/10/2018 to 08/17/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

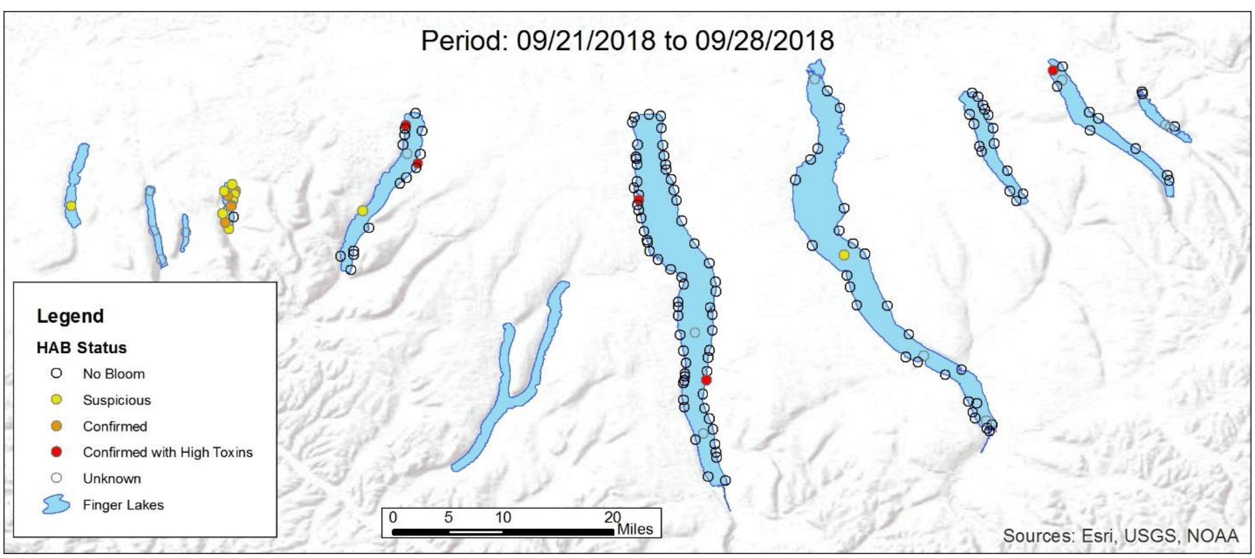

Period: 08/17/2018 to 08/24/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA


Period: 08/24/2018 to 08/31/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA


Period: 08/31/2018 to 09/07/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA


Period: 09/07/2018 to 09/14/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA


Period: 09/14/2018 to 09/21/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA


Period: 09/21/2018 to 09/28/2018
Legend
HAB Status
No Bloom
Suspicious
Confirmed
Confirmed with High Toxins
Unknown
Finger Lakes
0 5 10 20 Miles
Sources: Esri, USGS, NOAA

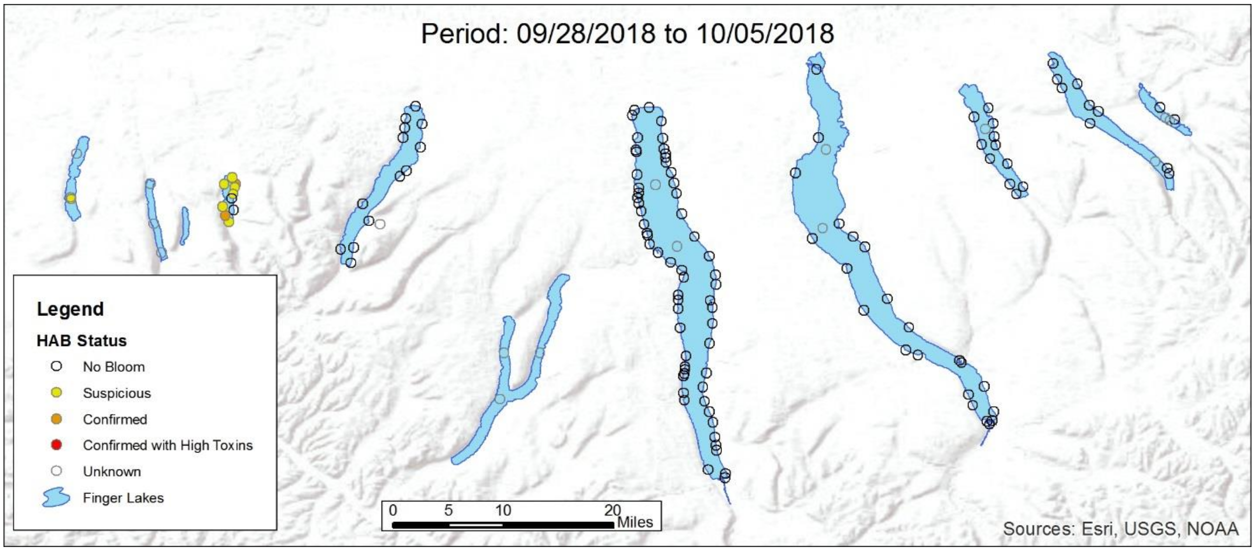



**Figure 43.** Shoreline bloom location and status in the Finger Lakes in 2018.

With the exception of Honeoye Lake, blooms were short in duration, scattered, and geographically isolated in the Finger Lakes through mid-August. By the week of August 31, blooms were widespread throughout the region with eight of the eleven lakes reporting a bloom at that time (varying extents and locations). During that time, dozens of visual reports were submitted and many HABs samples were collected for analysis. The BG-Chl-a and microcystin concentrations and resulting bloom status varied within and among lakes during that time. For lake-specific results, please see Section 9. Some blooms continued until mid-late September and most had dissipated by the end of September.

## Summary

In summary, the Finger Lakes have good water quality but represent environments adequate for the development of HABs (Table 16). All 11 lakes have: (1) favorable climate, (2) N-S orientation, (3) long fetch lengths, (4) long retention times, and (5) the presence of invasive dreissenid mussels (except Canadice). With the documented blooms on Skaneateles, Keuka, and other low nutrient lakes (Sarnelle et al. 2012, Vanderploeg et al. 2002, Raikow et al. 2004, Knoll et al. 2008) it is apparent that oligotrophic systems provide enough resources to allow the development of HABs.

Complex physical, environmental, and biological factors interact to influence the proliferation, extent, and duration of HABs both within lakes and among systems. Local-scale meteorology, nutrient ratios, concentrations of dissolved organic matter, micro-nutrient availability, mussel prevalence, and zooplankton grazing pressure are among the factors that influence bloom development and duration. These and other factors will continue to be researched in the Finger Lakes to identify proximate bloom triggers, determine the factors driving bloom growth and collapse, and develop additional management plans for mitigating HABs.

**Table 16.** Factors that influence the occurrence of harmful algal blooms (HABs)

| | Factor | | | | | | |
|---|---|---|---|---|---|---|---|
| **Lake** | **Climate** | **Productivity (Chl-a)** | **Nutrients (TP)** | **Orientation** | **Fetch Length** | **Water Residence** | **Dreissenid mussels** |
| **Conesus** | X | ✓✓ | ✓✓✓ | X | ✓✓ | ✓ | X |
| **Hemlock** | X | ✓✓ | ✓✓ | X | ✓✓ | ✓✓ | X |
| **Canadice** | X | ✓ | ✓ | X | ✓ | ✓✓ | |
| **Honeoye** | X | ✓✓✓ | ✓✓✓ | X | ✓ | ✓ | X |
| **Canandaigua** | X | ✓✓ | ✓ | X | ✓✓ | ✓✓ | X |
| **Keuka** | X | ✓✓ | ✓ | X | ✓✓ | ✓✓ | X |
| **Seneca** | X | ✓✓ | ✓✓ | X | ✓✓✓ | ✓✓✓ | X |
| **Cayuga** | X | ✓✓ | ✓✓ | X | ✓✓✓ | ✓✓ | X |
| **Owasco** | X | ✓✓ | ✓✓ | X | ✓✓ | ✓✓ | X |
| **Skaneateles** | X | ✓ | ✓ | X | ✓✓ | ✓✓✓ | X |
| **Otisco** | X | ✓✓ | ✓✓✓ | X | ✓ | ✓ | X |
| **Description** | temperature, light, precipitation and runoff, wind | ✓ oligo<br>✓✓ meso<br>✓✓✓ eu | ✓ < 0.01mg/L<br>✓✓ 0.01 - 0.02 mg/L<br>✓✓✓ > 0.02 mg/L | all ~ N-S orientation | ✓ < 10 km<br>✓✓ 10 – 25 km<br>✓✓✓ > 25 km | ✓ < 2 y<br>✓✓ 2-10y<br>✓✓✓ > 10y | present in waterbody |

✓ indicates a factor's positive influence on HABs

X presently a factor common to all eleven Finger Lakes

## Section 7: Future Work

This report provides information regarding current limnological conditions within the Finger Lakes and documents observed changes over the past four decades relative to 2017-2018. Important questions remain unanswered and additional research is necessary to better understand and define potential trends identified in this report.

Through the expanded CSLAP initiative, made possible through funding from the Environmental Protection Fund, volunteer scientists monitored twenty-eight locations on all eleven Finger Lakes during the summer (June – September) of 2018. The continued sampling of these sites will support a robust dataset and more comprehensive assessment of the Finger Lakes upon which to make critical management decisions.

Continued CSLAP sampling in 2019, HABs monitoring networks, the continuing statewide HABs analyses overseen by NYSDEC as part of the Governor's HABs Initiative, and the continuing partnerships among agencies, lake associations, and lakefront residents will enhance our understanding of Finger Lakes water quality.

In future reports, analysis will include more lake-specific information and possibly utilize additional, external data. Third party data will be evaluated to insure compliance with NYSDEC's quality assurance protocols. NYSDEC's winter sampling program in the Finger Lakes will also be incorporated into future reports to give a year-round view of nutrient concentrations and ecological processes in these lakes.

The CSLAP volunteers put forth a significant effort to provide this data. Quality control results provide assurance that the data collected through CSLAP is of sufficient quality to aid NYSDEC in making accurate assessments and important management decisions to protect the water quality of these important natural resources.

# Section 8: References

Anderson, D. M., Glibert, P. M., & Burkholder, J. M. (2002). Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries, 25(4), 704-726.

Birge, E. A., & Juday, C. (1914). A limnological study of the Finger Lakes of New York (No. 791). US Government Printing Office.

Bloomfield, J. A. (1978). Lakes of New York State. Volume 1. Ecology of the finger lakes. Academic.

Bootsma, H. A., & Liao, Q. (2013). Nutrient cycling by dreissenid mussels: controlling factors and ecosystem response. Quagga and zebra mussels: biology, impacts, and control, 2nd edn. Taylor & Francis, London, 555-574.

Callinan, C. W. (2001). Water quality study of the Finger Lakes. New York State Department of Environmental Conservation, Division of Water. https://www.dec.ny.gov/lands/25576.html

Callinan, C. W., Hassett, J. P., Hyde, J. B., Entringer, R. A., & Klake, R. K. (2013). Proposed nutrient criteria for water supply lakes and reservoirs. Journal-American Water Works Association, 105(4), E157-E172.

Carlson, R. E. (1977). A trophic state index for lakes1. Limnol and Oceanogr, 22(2), 361-369.

Chapra, S. C., Boehlert, B., Fant, C., Bierman Jr, V. J., Henderson, J., Mills, D., ... & Strzepek, K. M. (2017). Climate change impacts on harmful algal blooms in US freshwaters: a screening-level assessment. Environmental Science & Technology, 51(16), 8933-8943.

Chia, M.A., Jankowiak, J.G., Kramer, B.J., Goleski, J.A., Huang, I., Zimba, P.V., Bittencourt-Oliveira, M.C & Gobler, C.J. (2018) Succession and toxicity of Microcystis and Anabaena (Dolichospermum) blooms are controlled by nutrient-dependent allelopathic interactions. Harmful Algae (74) 67-77

Chorus, I. and J. Bartram, (eds.). Toxic Cyanobacteria in Water. World Health Organization, London. 416p

Davis, T. W., Berry, D. L., Boyer, G. L., & Gobler, C. J. (2009). The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of Microcystis during cyanobacteria blooms. Harmful algae, 8(5), 715-725.

Halfman, J.D., S. Bradt, D. Doeblin, K. Homet, J. Andrews, M. Gad, P. Spacher & I. Dumitriu. (2017). The Water Quality Monitoring Report for Owasco Lake, NY. Department of Geoscience, Hobart and William Smith Colleges, Geneva, NY. 26 p.

Hecky, R. E., Smith, R. E., Barton, D. R., Guildford, S. J., Taylor, W. D., Charlton, M. N., & Howell, T. (2004). The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences, 61(7), 1285-1293.

Heisler, J., Glibert, P. M., Burkholder, J. M., Anderson, D. M., Cochlan, W., Dennison, W. C., ... & Lewitus, A. (2008). Eutrophication and harmful algal blooms: a scientific consensus. Harmful algae, 8(1), 3-13.

Hincks, S.S. and G.L. Mackie. 1997. Effects of pH, calcium, alkalinity, hardness, and chlorophyll on the survival, growth, and reproductive success of zebra mussel (Dreissena polymorpha) in Ontario lakes. Can. J. Fish. Aquat. Sci. 54: 2049-2057.

Kishbaugh, S.A. 1994. Applications and Limitations of Qualitative Lake Monitoring Data. Lake and Reservoir Management. 9(1): 17-23.

NYSDEC (2017). 2017 Finger Lakes Region Lakes Report. Albany, NY. 122p. http://nysfola.mylaketown.com/uploads/tinymce/nysfola/FingerLakes_2016R.pdf

NSYDEC (2018). Harmful Algal Bloom Action Plan Skaneateles Lake. Albany, NY. 91p.

NYSDEC (2018). Harmful Algal Bloom Action Plan Owasco Lake. Albany, NY. 119p.

Oglesby, R. T., & Schaffner, W. R. (1978). Phosphorus loadings to lakes and some of their responses. Part 2. Regression models of summer phytoplankton standing crops, winter total P, and transparency of New York lakes with known phosphorus loadings 1. Limnol and Oceanogr, 23(1), 135-145.

Paerl, H. W., Gardner, W. S., Havens, K. E., Joyner, A. R., McCarthy, M. J., Newell, S. E., ... & Scott, J. T. (2016). Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae, 54, 213-222.

Paerl, H. W., & Otten, T. G. (2013). Harmful cyanobacterial blooms: causes, consequences, and controls. Microbial ecology, 65(4), 995-1010.

Sarnelle, O., White, J. D., Horst, G. P., & Hamilton, S. K. (2012). Phosphorus addition reverses the positive effect of zebra mussels (Dreissena polymorpha) on the toxic cyanobacterium, Microcystis aeruginosa. Water research, 46(11), 3471-3478.

Schaffer, W. R., & Oglesby, R. T. (1978). Phosphorus loadings to lakes and some of their responses, part 1. Limnol Oceanogr, 23, 120-134.

Schindler, D. W. (1977). Evolution of phosphorus limitation in lakes. Science, 195(4275), 260-262.

Smith, V.H. (1982) The nitrogen and phosphorous dependence of algal biomass in lakes: An empirical and theoretical analysis. *Limnol. Oceanogr*., 27(6), 1101-1112.

Suikkanen, S, Fistarol, G.O. & Granéli, E. (2004) Allelopathic effects of the Baltic cyanobacteria *Nodularia spumdigena, Aphanizomenon flos-aquae* and *Anabaena lemmermannii* on algal monocultures. Journal of Experimental Marine Biology and Ecology, 308(1), 85-101

Thomann, R. V., Mueller, J. A., & a Mueller, J. (1987). Principles of surface water quality modeling and control (Vol. 12, p. 644). New York: Harper & Row.

Vollenweider, R. A. (1970). Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Paris: OECD.

Wetzel, R. G. (2001). Limnology: lake and river ecosystems. Academic Press. New York, NY. 1006 p.

## Websites and Online Resources

iMapInvasives; http://www.nyimapinvasives.org

NYSDEC and NYFOLA instructional videos; (http://www.dec.ny.gov/chemical/81849.html)

NYSDEC and NYFOLA sampling protocol quizzes; (http://www.dec.ny.gov/ docs/water_pdf/cslapquiz2.pdf

NYSDEC and NYFOLA written sampling protocols; (http://www.nysfola.org/cslap)

NYSDEC Consolidated Assessment and Listing Methodology (CALM); https://www.dec.ny.gov/chemical/36730.htm)

NYSDEC CALM; http://www.dec.ny.gov/docs/water_pdf/asmtmeth09.pdf

NYSDEC Citizen Statewide Lake Assessment Program; https://www.dec.ny.gov/chemical/81576.html

NYSDEC CSLAP on-line data entry; https://www.cslapdata.org/index.php

NYSDEC CSLAP Quality Assurance documents; http://www.dec.ny.gov /chemical/81849.html

NYSDEC HABs Action Plans for 12 priority lakes; https://on.ny.gov/HABsAction

NYSDEC HABs Program Guide; http://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf

NYSDEC HABs Program; https://www.dec.ny.gov/chemical/77118.html

NYSDEC HABs FAQs; https://www.dec.ny.gov/chemical/91570.html

NYSDEC HABs Notifications Page; https://www.dec.ny.gov/chemical/83310.html

NYSDEC NYHABs;
https://nysdec.maps.arcgis.com/apps/webappviewer/index.html?id=ae91142c812a4ab997ba739ed9723e6e

NYSDEC LCI Program; https://www.dec.ny.gov/chemical/31411.html

NYSDEC Lake Monitoring Standard Operating Procedures; http://www.dec.ny.gov /docs/water_pdf/sop20314.pdf

NYSDEC VISION APPROACH to implement the Clean Water Act 303(d) Program and Clean Water Planning
http://www.dec.ny.gov/docs/water_pdf/dowvision.pdf
NYSDEC Waterbody Inventory Priority Water Lists (WI/PWLs) Lower Genesee River;
http://www.dec.ny.gov/chemical/36744.html.

NYSDEC WI/PWLs Oswego River/Finger Lakes Basin (West); http://www.dec.ny.gov/chemical/36737.html

NYSDOH HABs information; www.health.ny.gov/harmfulalgae

## Section 9: Individual Lake Chapters