Lake Champlain Long-Term Water Quality and Biological Monitoring Program

Summary of Program Activities During 2023

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Prepared by:

Vermont Department of Environmental Conservation
Watershed Management Division
1 National Life Drive, Davis 3
Montpelier, VT 05620-3522

New York State Department of Environmental Conservation
Region 5
P.O. Box 296
Ray Brook, NY 12977-0296

Lake Champlain Research Institute

SUNY Plattsburgh-Hudson 136D

101 Broad Street

Plattsburgh, NY 12901

Submitted to:
Lake Champlain Basin Program
P.O. Box 204
54 West Shore Rd.
Grand Isle, VT 05458

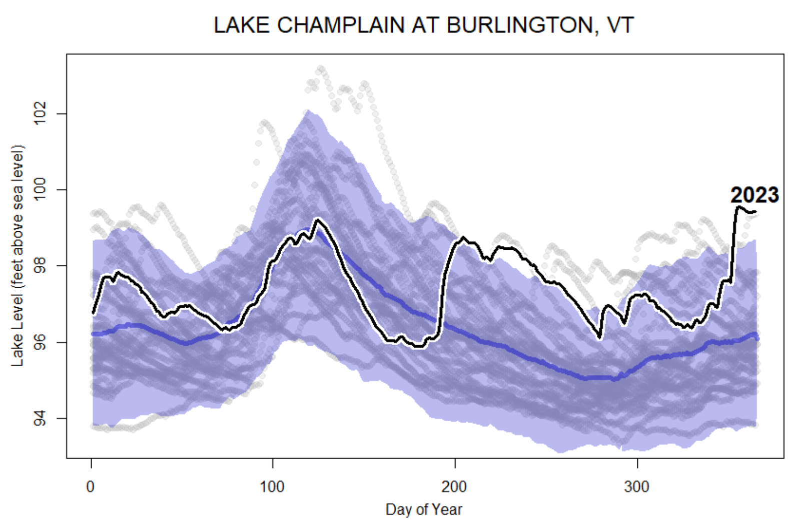
Purpose of Report

The workplan for the Lake Champlain Long-Term Water Quality and Biological Monitoring Program approved by the Lake Champlain Basin Program specifies the following annual reporting requirements:

An annual report will consist of a summary of the history and purpose of the (program), description of the sampling network, summary of field sampling and analytical methods, parameter listings, and data tables. The purposes of this annual report will be achieved by maintaining an up-to-date Program Description document, graphical presentations of the data, and an interactive database, including statistical summaries, on the project website...... In addition, the quarterly report produced in April each year will provide a summary of program accomplishments for the calendar year just ended, including the number of samples obtained and analyzed at each site by parameter.

The Program Description document, interactive access to the project data, and graphical and statistical summaries of the data are available on the [program webpage, and in appendices to this report]. The purpose of this report is to provide a summary of sampling activities and other accomplishments during 2023.

Highlights of the 2023 Season



(blue line represents long-term mean discharge for each date, starting in 1990. Shaded area represents 95% confidence interval around the mean. Black line is this year)

The sampling season in 2023 was characterized by a relatively small spring freshet, but unusually wet conditions in the Champlain basin during summer, with a major flood event in July. Tributary flows and lake-levels approached historic maximums in mid-August. Wet conditions also prevailed in the late autumn and early winter, with the year closing with record high lake levels on Dec 31, higher than at the peak of the spring freshet, following a second major flood event in December. Two tributaries, the Little Chazy River and the Winooski River, had the highest cumulative discharge observed during the monitoring period, and a number of tributaries had the second-highest cumulative discharge (Figure 2). The monitoring data reveal a range of trends, which can be explored on the program webpage and the figures in Appendix A-D. Several notable trends will be highlighted here.

The July floods delivered massive loads of terrestrial materials, including phosphorus, to the lake, but elevated total phosphorus (TP) was not immediately obvious in the monitoring data (likely because a large fraction of this load was sediment bound, and settled out relatively quickly upon reaching the lake). Several sites appear show continued trends in epilimnion total phosphorus (TP). In Missisquoi Bay (station 50 and 53), lowess smoothing regression shows a continued gradual decline in mean TP from 2015 through 2023 (Appendix B). By contrast, there was a slight continued increase in TP concentrations in the Inland Sea (station 34) and St. Albans Bay (station 40), and there are signs of recent increases in TP in the Otter Creek Segment (Station 09).

Chloride concentrations across all segments of Lake Champlain have had synchronous trends over the last 30 years. Chloride concentrations have been increasing sharply at every monitoring station, particularly from 2010 to 2023. At most stations, chloride was lower in 2023 than in recent years, likely owing to dilution from the extremely wet summer. Chloride concentrations were highest and most variable in the South Lake sites, followed by the Main Lake, with relatively lower concentrations in Missisquoi Bay, the Inland Sea, and Mallett's Bay. Chloride concentrations are also rising in most monitored tributaries (Appendix C).

The South Lake continued to have declining secchi depth at both stations (particularly South Lake A). South lake had markedly lower chlorophyll than recent years (particularly South Lake B), which is likely due to high turbidity at these sites associated with suspended sediments from the July flood and other storm events, which may have reduced light availability and primary production. Dissolved organic carbon was also high in the South Lake in 2023, which is again likely attributable to the high precipitation, and which could have further reduced light availability and limited pelagic primary production.

Sampling Activities During 2023

The project QAPP outlines sampling frequency and methodology for all target parameters. In 2023, the QAPP was approved as a five-year document. Sampling and analytical methods are summarized annually; events impacting data quality are also noted. Table 1 lists the number of 2023 sampling visits to each lake and tributary station in relation to the target frequencies specified in the project work plan. Table 2 lists the number of samples collected and analyzed for each monitoring parameter. The New York lake and tributary field sampling was conducted by the Lake Champlain Research Institute at SUNY Plattsburgh under an MOU between NYSDEC and SUNY.

The frequency of lake sampling exceeded workplan targets at all stations during 2023. The frequency of tributary sampling was below the workplan targets for all NY stations, and at or close to targets at VT stations. The number of tributary samples obtained each year depends to some extent on the number and timing of high flow events, since sampling is geared toward capturing the highest flow conditions when loading of phosphorus and other materials is greatest. 2023 was a wet year, with many potential discharge events to sample. Because of the consistently high discharge, it was difficult to find suitable baseflow conditions to sample, particularly during summer. Figure 1 shows that sampling at each tributary captured most peak flow events during 2023.

The lake sampling for the 2023 season ran from April 14th to October 21st for VT DEC and from May 24th to October 25th for LCRI at SUNY Plattsburgh. Tributary sampling ran from March 8th to December 8th for VT DEC and March 7th to November 8th for LCRI at SUNY Plattsburgh. The

VT DEC team was able to sample most tributaries during the winter season as well, collecting samples in January, February, and December of 2023, seasons which have rarely been sampled by the monitoring program.

Table 1. Number of sampling visits during 2023 at each lake and tributary station in comparison with workplan targets.

Number of Lake Sampling Visits					**Number of Tributary Sampling Visits**				
Lake Station	**NY**	**VT**	**Total**	**Workplan Target[1]**	**Tributary Station**	**Crew**	**All Parameters** TP, DP, TSS, Cl, TN	**Total Phosphorus**	**Workplan Target[2]**
2	9	8	17	12	AUSA01	NY	9	9	14/17
4	9	8	17	12	BOUQ01	NY	12	12	14/17
7	9	7	16	12	GCHA01	NY	11	11	14/17
9	9	7	16	12	LAMO01	VT	14	16	14/17
16	9	8	17	12	LAPL01	VT	16	17	14/17
19	9	8	17	12	LAUS01	NY	12	12	14/17
21	9	8	17	12	LCHA01[3]	NY	11	11	14/17
25	9	8	17	12	LEWI01	VT	16	17	14/17
33	9	7	16	12	LOTT01[7]	VT			0
34	9	8	17	12	LOTT03[7]	VT	16	14	14/17
36	8	8	16	12	METT01	VT	13	14	14/17
40	9	8	17	12	MISS01	VT	14	16	14/17
46	8	8	16	12	OTTE01	VT	16	17	14/17
50	9	8	17	12	PIKE01	VT	12	15	14/17
51[6]	0	0	0	0	POUL01	VT	13	14	14/17
53	8	8	16	12	PUTN01[4]	VT	0	0	14/17
					ROCK02	VT	14	16	14/17
					SALM01	NY	11	11	14/17
					SARA01	NY	11	11	14/17
					WINO01	VT	15	17	14/17
					JEWE02	VT	14	16	14/17
					STEV01[5]	VT	15	17	14/17
					MILL01	VT	14	16	14/17

[1] Workplan target for lake sampling (12) applies to most chemical parameters and to phytoplankton, zooplankton, and zebra mussel veligers. Sampling for zebra mussel juveniles in Lake Champlain and for veligers in tributaries and inland lakes is done once annually.

[2] The project workplan calls for 14 samples per year for most chemical parameters, including 10 samples at high flow and four samples at low flow. Additional sampling for total phosphorus only should occur on 3 other dates under high flow conditions, for a target of 17 samples per year for total phosphorus.

[3] Little Chazy flow gage was discontinued in 2014 but was re-established on 9-25-2015.

[4] Putnam Creek sampling was discontinued in 2015 due to lack of funding for the flow gage.

[5] The USGS gage at Stevens Brook was discontinued at the end of June 2017. A new gage was operated by Stone Environmental between 2017 and 2021 (http://vt-ms4-flow.stone-env.com/FlowDev/index.html) but is now discontinued.

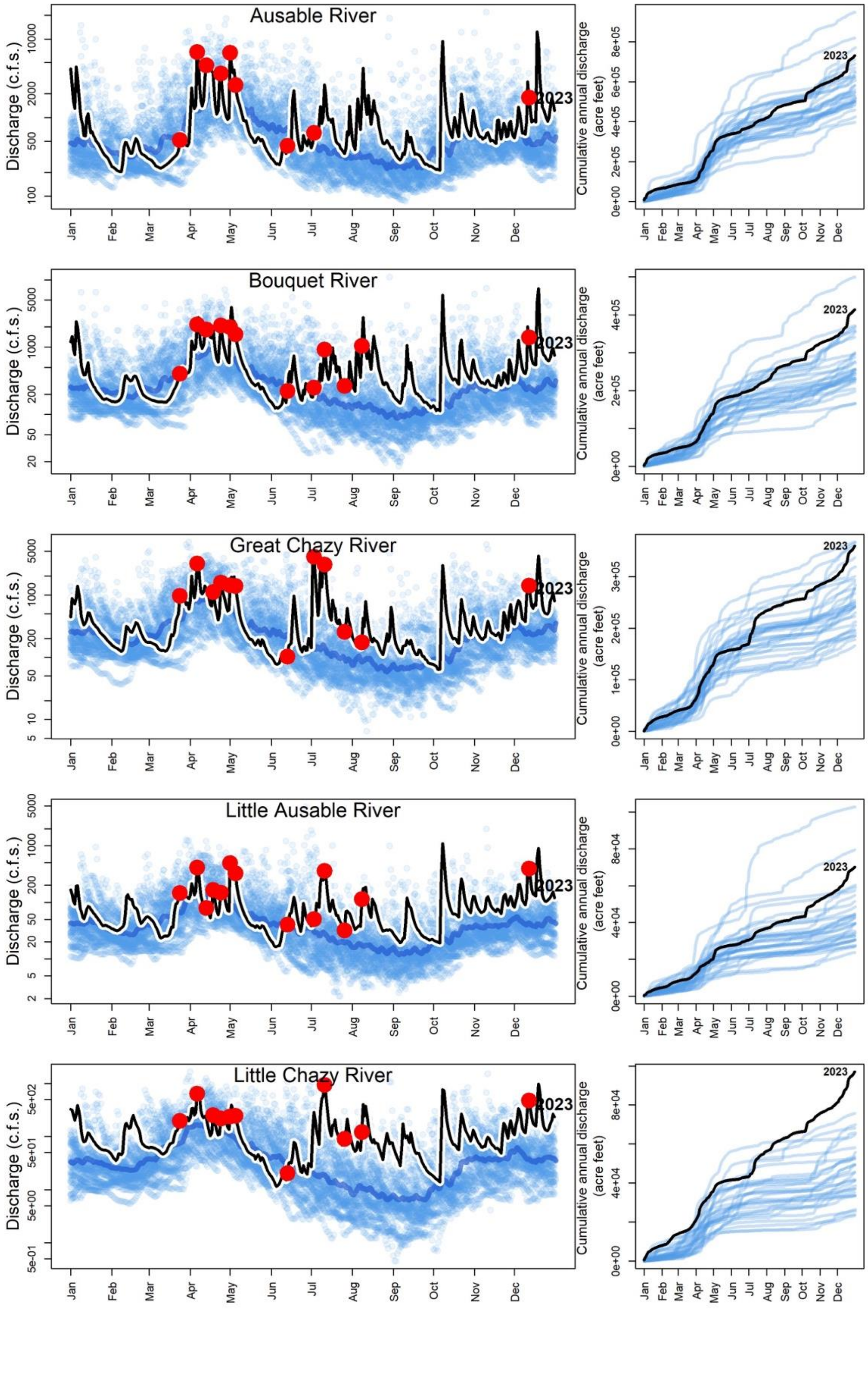
[6] In 2019, field crews were found to have different coordinates for LTM 51. All data have been re-assigned to the correct station and all both crews will sample at LTM 53 in the future.

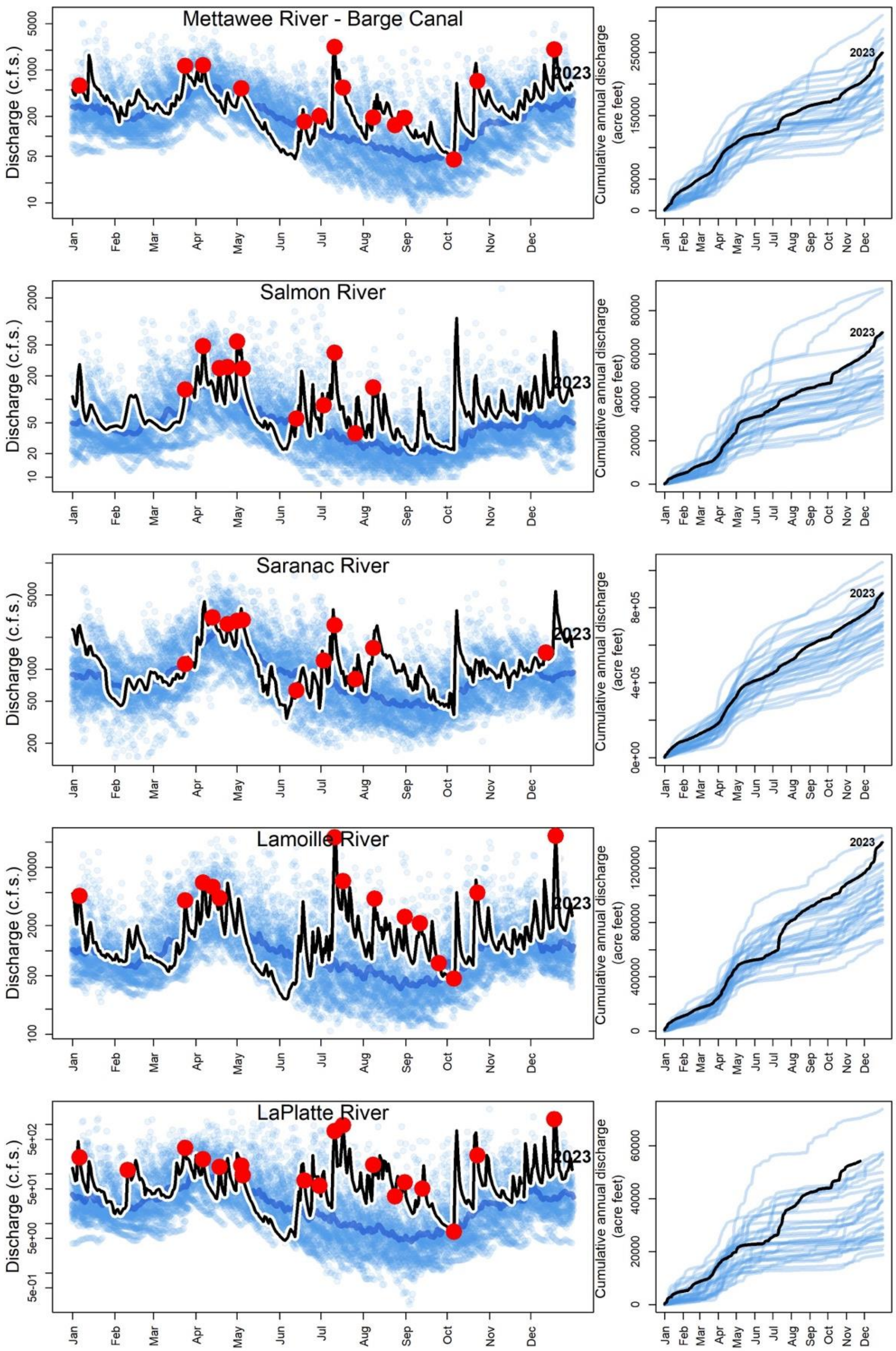
[7] Beginning in 2019, field crews now sample at LOTT03 on Satterly Road, Ferrisburg due to safety concerns after the original location (LOTT01) became overgrown. Concurrent sampling indicated water quality was very similar at the two locations.

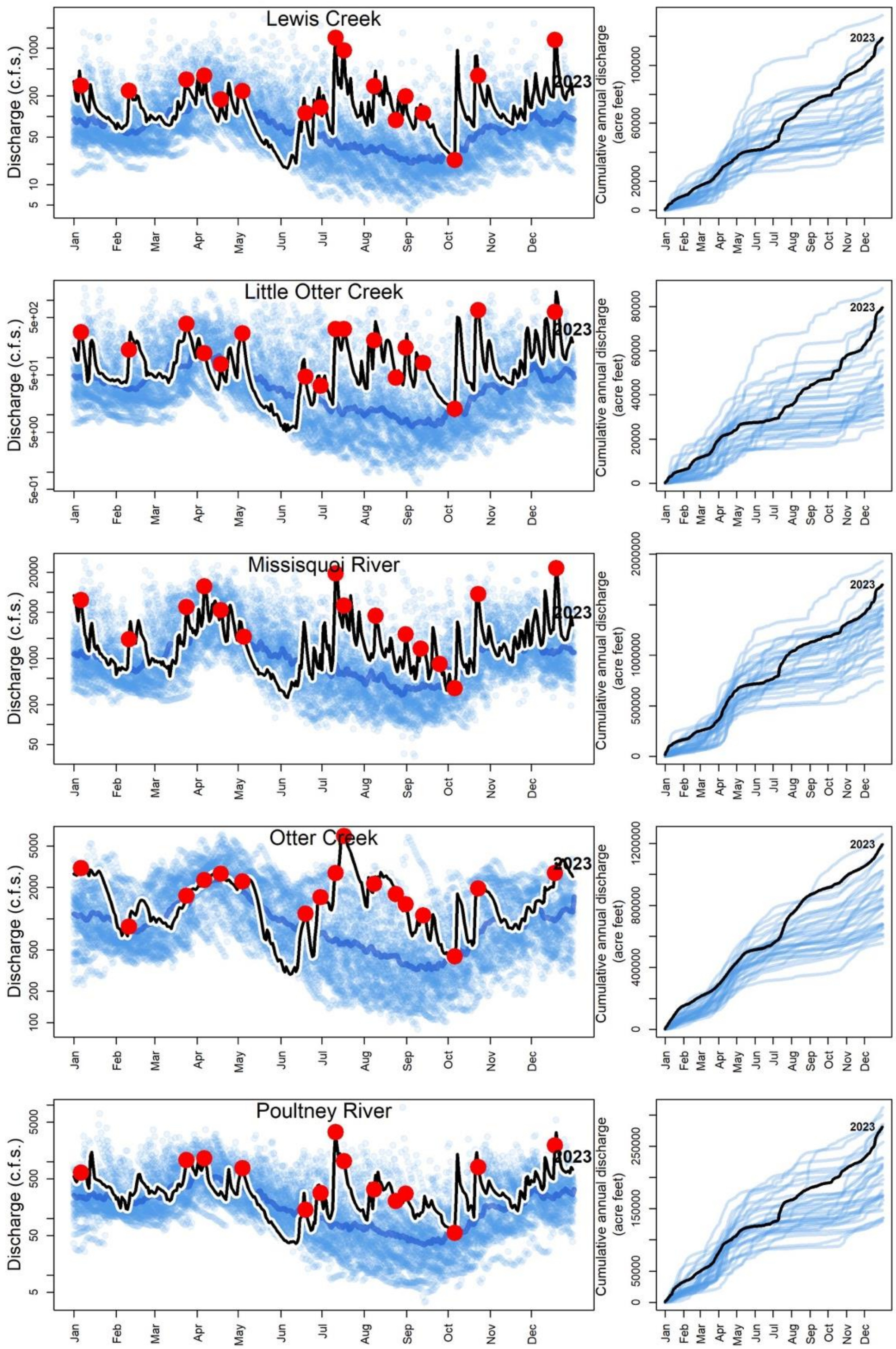
Table 2. Number of samples collected and analyzed for each monitoring parameter during 2023.

Parameter	**Lake**	**Tributaries**	**Total**
TP	389	365	754
DP	389	322	711
Cl	388	338	726
TN	390	319	709
Ca	49	66	115
Alkalinity	51	66	117
SiO2	389	-	389
K	49	66	115
Na	49	66	115
Mg	49	66	115
Al	49	66	115
Mn	49	66	115
Fe	49	66	115
Total Calculated Hardness	49	66	115
NPOC/DOC	380	329	709
Chl-a	283	-	283
TSS	-	301	301
Temperature	-	182	182
Conductivity	-	182	182
pH	-	151	151
Secchi depth	237	-	237
Multiprobe depth profiles	237	-	237
Zebra mussel veligers	85	-	85
Zebra mussel settled juveniles	0	-	0
Mysids	72	-	64
Zooplankton	131	-	135
Phytoplankton	131	-	135
Spiny/Fishhook waterflea	131	-	135

Figure 2. Left: Sampling dates during 2023 in relation to daily flows at each tributary station. Daily discharge (note log-scaled axis) in 2023 are shown as the black line lines, and sampling dates are shown by red circles. Blue points in background represent all daily flow observations during the period of record, with the thick blue line representing median daily flow for each date. Right: Cumulative annual discharge, with the current year shown in black and all previous years shown in blue lines.




Mettawee River - Barge Canal
Salmon River
Saranac River
Lamoille River
LaPlatte River
Discharge (c.f.s.)
Cumulative annual discharge (acre feet)
2023
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Lewis Creek
Little Otter Creek
Missisquoi River
Otter Creek
Poultney River
Discharge (c.f.s.)
Cumulative annual discharge (acre feet)
2023
Jan
Feb
Mar
Apr
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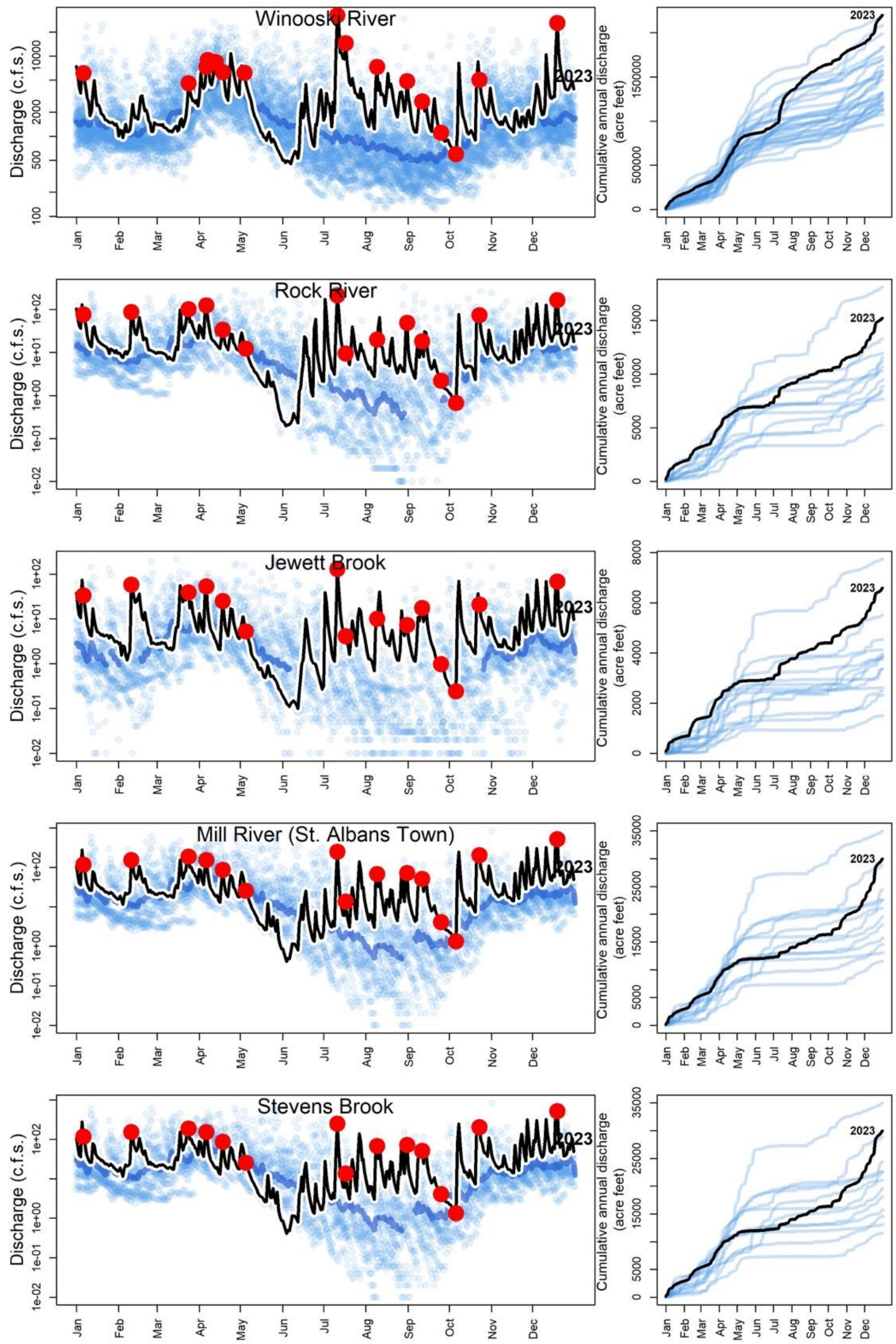
Nov
Dec



***** The Stevens Brook USGS Gage is not in operation, therefore Mill River USGS gage data was used alternatively.

** The dates for Pike River sampling were 2023-02-10, 2023-03-24, 2023-04-06, 2023-04-18, 2023-05-05, 2023-07-11, 2023-07-1, 2023-08-09, 2023-08-31, 2023-09-11, 2023-09-25, 2023-10-06, 2023-10-23, and 2023-12-19

Data Quality Assurance Results

As described in the program's Quality Assurance Project Plan, field equipment blanks and field duplicate samples are obtained on each sampling run. The results for the blank samples are summarized in Table 3. Seventeen of the 310 blank samples analyzed during 2023 (5.4%) had concentrations above the analytical detection limits. Results for field duplicate samples are summarized in Table 4 for the chemical analyses.

Table 3. Field equipment blank results during 2023 for lake and tributary samples.

Test	Detection Limit	Units	Number of Blanks Obtained	Number of Blanks Above Limit	High Blank Values
Alk	1.0	mg/l	6	2	1.4, 2
Cl	2.0	mg/l	49	1	30.6
TN	0.1	mg/l	48	2	.12, .13
TP	5.0	µg/l	51	4	5.6, 6.6, 8.2, 6.4
DP	5.0	µg/l	49	3	6.4, 6.6, 5.9
Chl-a	0.5	µg/l	19	1	2.2
TSS	2.5	mg/l	25	1	7.4
SiO2	0.2	mg/l	21	0	
Al	20	µg/l	6	0	
Fe	50	µg/l	6	0	
Ca	0.5	mg/l	6	0	
Na	0.5	mg/l	6	0	
K	0.1	mg/l	6	0	
Mg	0.02	mg/l	6	1	.03
Mn	5	µg/l	6	0	
NPOC	1	mg/l	48	2	1.3, 2.5
Total			310	17	

Table 4. Field duplicate results for chemical tests during 2023 showing the number of duplicates obtained (N) and the mean relative percent difference (RPD) between duplicate pairs.

Test	N	Mean RPD
Chl-a	27	16.84
Cl	53	11.60
NPOC	33	1.52
DP	52	6.11
Alk	11	1.56
TN	52	7.40
TP	53	7.82
TSS	23	18.11
SiO2	28	2.4
Al	11	16.16
Ca	11	4.03
Fe	10	6.59
K	11	6.64
Na	11	5.57
Mg	10	6.46
Mn	11	4.05

Phytoplankton and Zooplankton Database

All phytoplankton data from 2006-2021 have been incorporated into the main Lake Champlain Monitoring Program database. Phytoplankton samples from 2016 were compromised by an initially undetected field error and were not analyzed. Zooplankton data are currently available for the project period of 1993-2022. The data available for download from the web interface include phytoplankton cell densities and biovolumes, and zooplankton densities grouped by major taxonomic category. Counts by individual taxa are available by request. Zooplankton data from 2014-2022 and phytoplankton data from 2017-2022 are available by request but have not been added to the project database. Kayleen Snyder a recent MS Student at SUNY Plattsburgh recently completed a thesis focusing on Long-Term patterns of Phytoplankton Community Composition and Abundance in Lake Champlain.

Wastewater Phosphorus Discharge Data

The project workplan requires an annual compilation of wastewater phosphorus discharge data for all treatment facilities in the Vermont and New York portions of the Lake Champlain Basin. Data on annual mean flow, total phosphorus concentration, and phosphorus load at each facility have been compiled for 2023 along with data from previous years and are available electronically in spreadsheet form on request. The total loads and flows from Vermont and New York wastewater treatment facilities during 2007-2023 are summarized in Table 5.

Table 5. Annual wastewater facility phosphorus loading and flows for Vermont and New York.

State	Number of Facilities	Year	Phosphorus Load (mt/yr)*	Mean Flow Rate (mgd)**	Phosphorus Divided by Mean Flow Rate (mg/L)***
Vermont	60	2007	20.7	51.3	0.29
	60	2008	20.8	49.2	0.31
	60	2009	20.2	42.5	0.34
	60	2010	18.2	39.7	0.33
	59	2011	18.6	41.5	0.32
	59	2012	16.8	42.5	0.29
	59	2013	17	39.9	0.31
	59	2014	17.5	42.2	0.30
	59	2015	13.4	37.2	0.26
	59	2016	11.6	33.9	0.25
	59	2017	13.8	32.3	0.31
	59	2018	13.2	39.8	0.24
	59	2019	11.9	43.1	0.20
	59	2020	9.7	34.7	0.20
	59	2021	10.1	35.5	0.21
	59	2022	11.5	34.8	0.24
	59	2023	11.7	36.1	0.23
New York	29	2007	28.5	33.2	0.62
	29	2008	26.5	34.3	0.56
	29	2009	20.9	31.5	0.48
	29	2010	22	32.8	0.49
	29	2011	23	34.4	0.48
	29	2012	22.6	30.4	0.54
	29	2013	22.9	30.3	0.55
	29	2014	24.7	30.3	0.59
	29	2015	23.7	29.6	0.58
	29	2016	22.2	30.2	0.53
	29	2017	18.7	31.1	0.43
	29	2018	21.3	31.8	0.48
	29	2019	21.7	31.9	0.50
	29	2020	17.2	29.9	0.42
	29	2021	17.8	32.4	0.40
	29	2022	20.0	33.5	0.43
	29	2023	20.4	35.8	0.41

* The annual phosphorus load represents the total of average monthly loads from all facilities in each state. Represented in metric tons (mt) per year.

** The annual mean flow rate represents the total of average monthly flow rates from all facilities in each state. Represented in millions of gallons per day (mgd).

*** Calculated by dividing the annual phosphorus load (in mt/yr) by the annual mean flow rate (in mgd), and multiplying by a conversion factor of 0.723264 to produce a concentration in milligrams per liter (mg/L).

Rock River Monitoring Project

A Rock River Watershed Targeted Best Management Practice (BMP) Implementation Project was initiated in 2010 with funding provided by the Lake Champlain Basin Program (LCBP). It operates under oversight provided by a coordinating committee including the U.S. Natural Resource Conservation Service (NRCS), the Vermont Agency of Agriculture, Food, and Markets (AAFM) and the Vermont Department of Environmental Conservation (DEC). The initial purpose of the project was to demonstrate water quality improvements from focused agricultural BMP implementation in a small watershed where very high rates of phosphorus loading to Lake Champlain have been documented. Ag BMP implementation got underway in 2010 and new installations continue to be added each year.

In order to document water quality improvements resulting from the targeted Ag BMP implementation in the Rock River watershed, the Vermont DEC established monitoring stations immediately upstream and downstream of the BMP implementation area in late 2010 and funded the construction and operation of a U.S. Geological Survey (USGS) stream flow gage (04294140) at the downstream site. The DEC issues grants to the Friends of Northern Lake Champlain (FNLC) to support sample collection activities by trained local residents, and the DEC Laboratory conducts the sample analyses. The LCBP financially supports the laboratory analytical efforts and supported the stream gaging through September 2014. The State of Vermont now supports the Rock River stream gage through a cooperative agreement with the USGS.

In 2018, project oversight committee members recognized that the original paired watershed study design was no longer valid – NWQI projects as well as Vermont's Required Agriculture Practices (RAPs) and forestry Accepted Management Practices (AMPs) had been implemented in both watersheds for several years. Vermont's new Municipal Roads General Permit requirements will also affect the watershed in the near future. Members felt strongly, however, that monitoring should continue because information on water quality changes in response to BMP implementation at this watershed level are critical to understanding the success of management efforts. The updated study design was focused on the detection of change over time in load and concentration of TP, DP, TSS and particulate phosphorus (PP) following the approach used to evaluate change over time in the major tributaries monitored by the Long-Term Monitoring Project. Partners will track BMP implementation and provide periodic summaries to document cumulative improvement in the targeted watershed.

A map of the revised study area and sampling station is shown in Figure 2. The area is approximately 29.3 km^2 in size on the upper Rock River in the towns of Highgate and Franklin, VT. A USGS continuous stream flow gage is co-located with the sampling station (RR14). Sampling was discontinued at RR 20 in 2018.

Beginning in 2023, the Friends of Northern Lake Champlain began work on a separate LCBP award to monitor a number of sites in the Rock River watershed, including the core RR14 site that had been sampled as part of this study. To avoid duplication of efforts, a new contract for the RR14 sampling was not issued for the season, and sampling under the LTM program was paused. After discussion with the LCBP project officer and LTMP project manager, it is recommended that the future of the Rock River monitoring project be reconsidered pending the results of the separate Basin Program project. Sampling of a downstream site on the Rock River closer to the river mouth will continue as part of the LTMP.

Year	Number of sample pairs	Number of samples (RR14 only)
2008	10	
2009	2	
2010	18	
2011	66	
2012	55	
2013	55	
2014	51	
2015	27	
2016	33	
2017	42	
2018	5	23
2019		17
2020		18
2021		19
2022	14	24
Total	378	101

Table 6. Numbers of samples obtained from 2008-2022.

Lake Champlain High Frequency Monitoring Project

The 2023 field season was the second complete season of monitoring for the first two buoys in the Lamoille River and Mallett's Bay. The LCBP also supported UVM to deploy two profiling buoys in Missisquoi Bay and St. Alban's Bay, as part of the high-frequency monitoring project. While the pilot season of the project (2022) had some issues associated with programing of the sensor in the Lamoille River buoy which affected data quality, the sensor data for the 2023 field season was generally sound. The buoy was submerged for several days at the peak of the July floods, but while this caused some slight structural damage to the buoy (bent rods and deformed foam casing), it did not affect the operation of the buoy, and the data collection was uninterrupted during the flood and for the remainder of the field season. The nitrate probe continued to be problematic. It was difficult to calibrate, yielded unreasonable values, and was subject to considerable drift between calibration events. It is likely that the range of nitrate concentrations observed in the Lamoille River is lower than the effective range of the sensor.

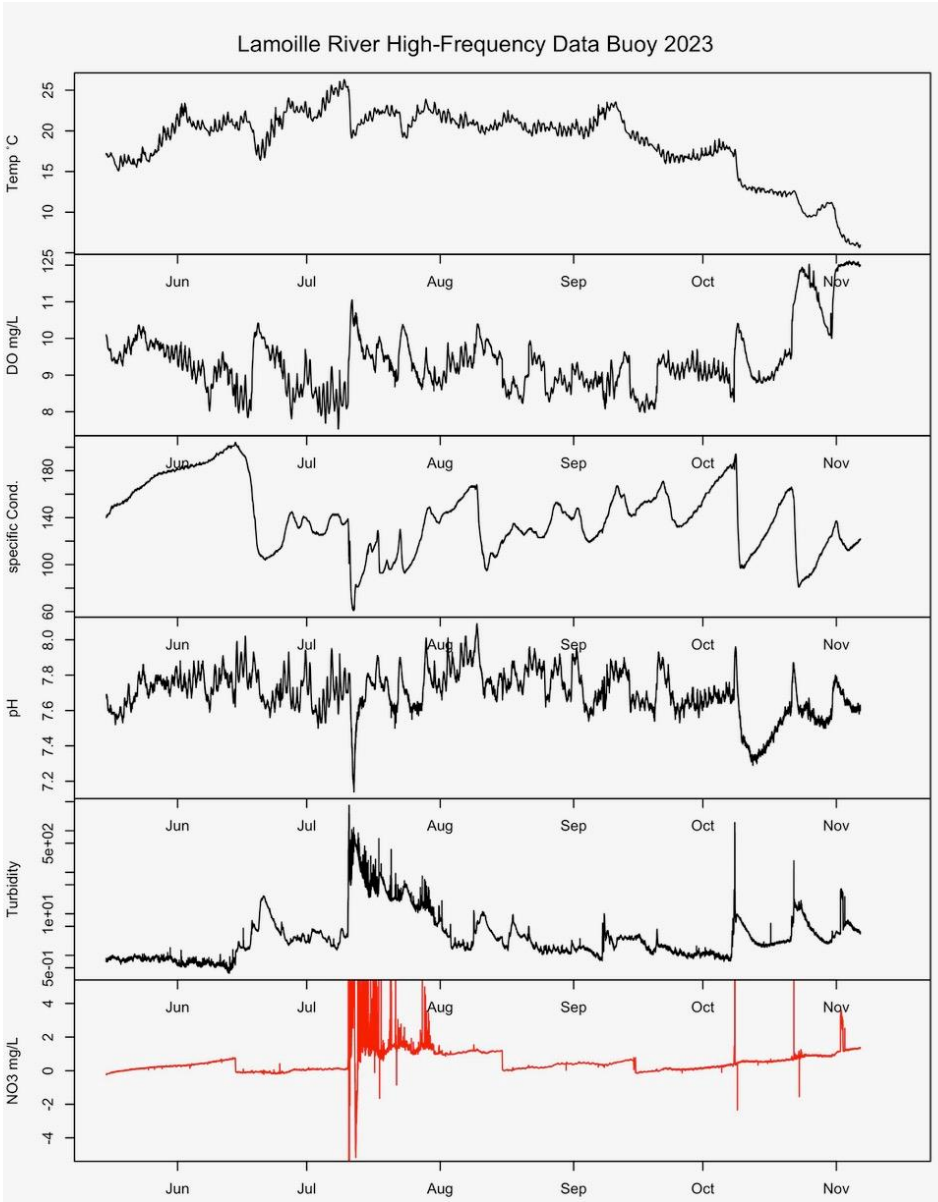


Figure 3: Parameters measured by the EXO sonde on the Lamoille River Buoy. Note that the y-axis scale is truncated for the Nitrate (NO3) sensor plot to allow readability of the data because extreme values were recorded during major discharge events. The nitrate data (in red) is considered unreliable.

The Mallett's Bay buoy generally performed without any major challenges. Data from the temperature chain presents a detailed picture of variations in lake thermal structure in the bay, including the impact of heatwaves on upper water column thermal structure, which may be important in predicting cyanobacteria bloom formation. They also show periodic oscillations in

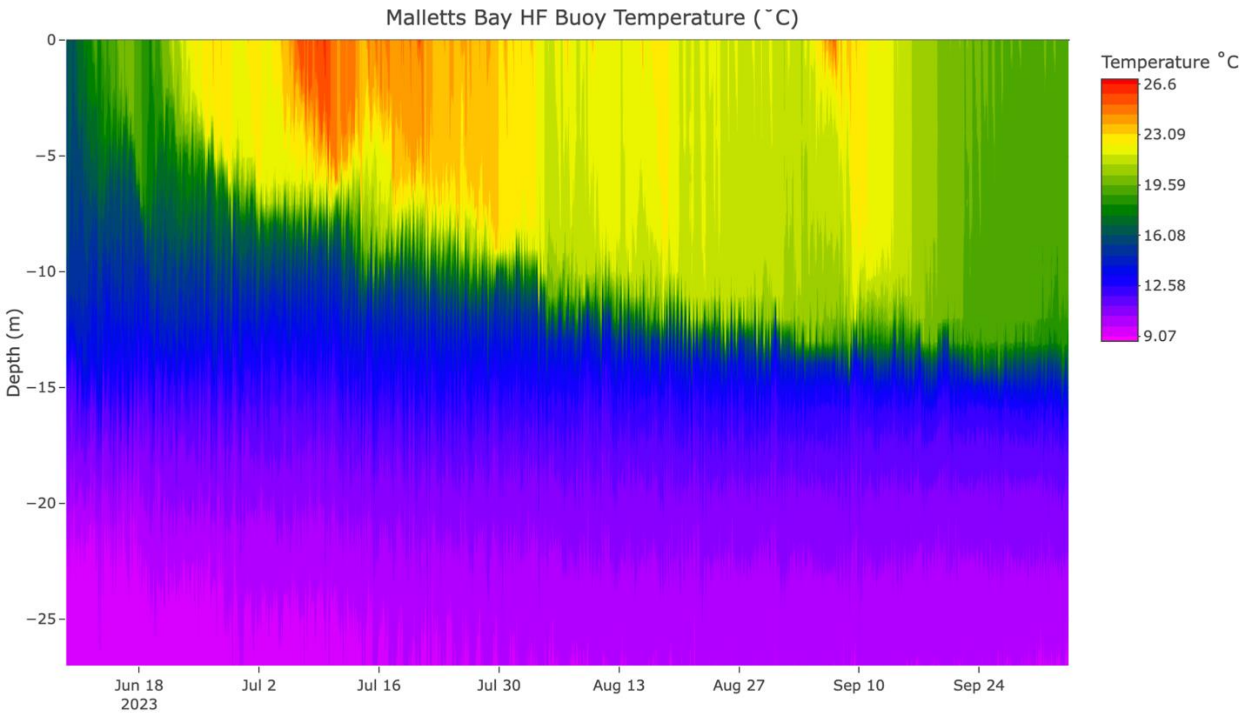


Figure 4: Contour plot of water temperature from the Malletts Bay high-frequency buoy.

The sonde data from the Mallett's Bay buoy also showed some interesting patterns. The turbidity sensor in the bay gives a clear signal of the influx of water from the July floods, and may be helpful in estimating settling velocities. The specific conductivity sensor also shows a clear signal of the flood water. As with the Lamoille River buoy, the nitrate sensor data appears unreliable, with most readings showing negative concentrations.

In 2023, The LCBP also funded the deployment of two profiling buoys owned by UVM in Missisquoi Bay and St. Alban's Bay. Issues related to software updates created complications during the 2023 season, so data were only sporadically available for the 2023 season. Data are undergoing QAQC, and will be available on the basin program website at data.lcbp.org. Monitoring will be continued at these sites in 2024. In addition, the Basin Program purchased a new buoy which will be deployed at Station 34 (Inland Sea) in 2024. This buoy is similar in design to the Malletts Bay buoy, but has additional oxygen sensors located at 5 m intervals to the bottom of the lake, which will facilitate improved estimates of hypoxia and internal loading in the Inland Sea.

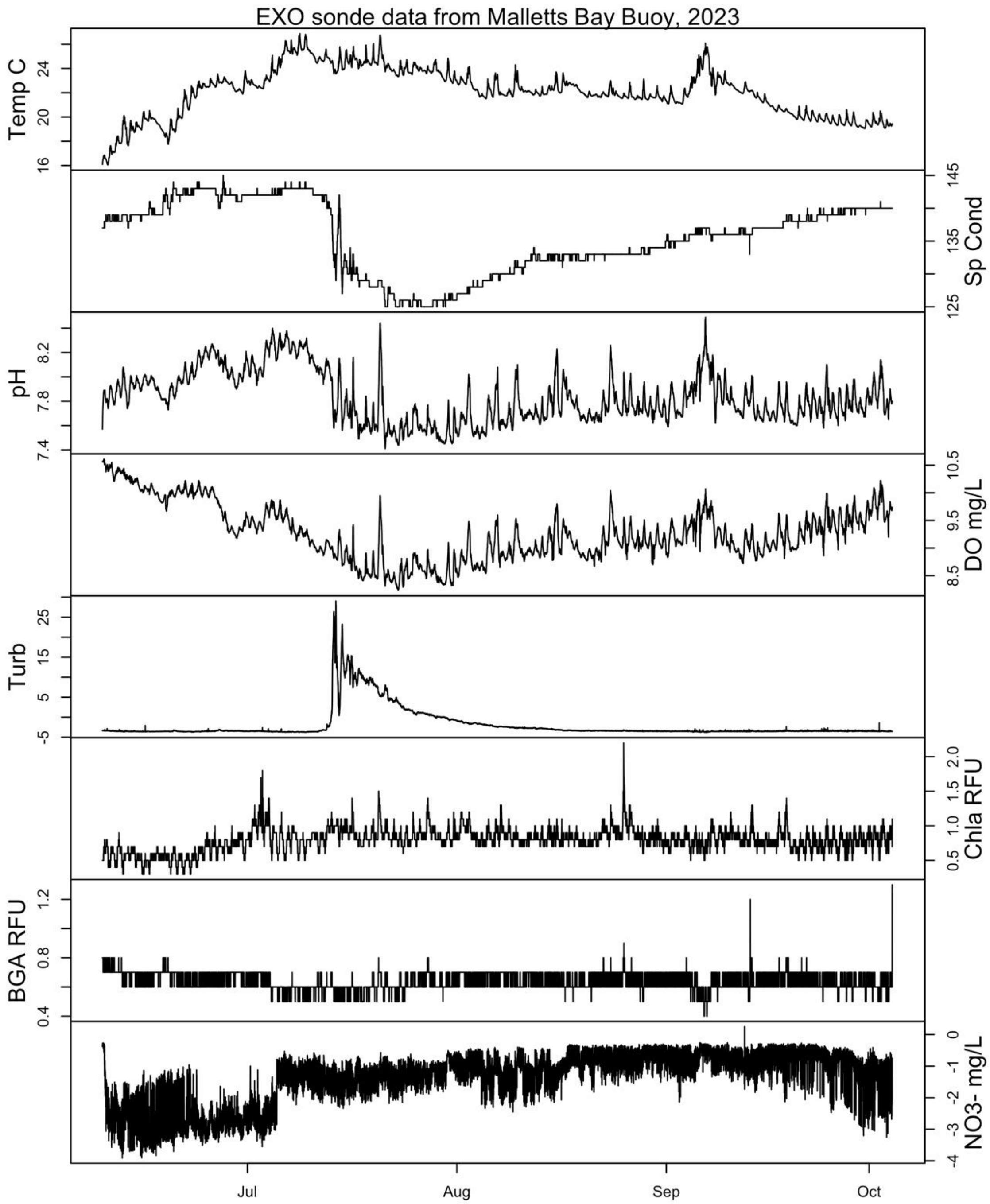


Figure 5: Sensor data from the Malletts Bay buoy in 2023. All readings are taken roughly 1.5 meters below the surface. Note that the nitrate (NO3-) data are considered unreliable.

Phosphorus Instrument Change Comparison

In 2023, the VAEL laboratory, which processes all chemistry samples for the long-term monitoring program, replaced its instrument used in analysis of TP samples. Preliminary data released by the lab suggested that the new instrument may underestimate phosphorus at low concentrations, so an effort was made in 2023 to quantify what effect, if any, this change would have on analyses of trends in TP and DP. A total of 108 samples were taken to run on both instruments by the Vermont team during normal LTM sampling events. These samples included both Total and Dissolved phosphorus samples (which are run on the same instrument). The old instrument was a Lachat, and the new instrument is a flow injection analyzer. Plots comparing the duplicate samples are shown below. The results of our comparison show that the two instruments yielded very similar results, and there appeared to be no clear bias from the new instrument relative to the old. Similar results were found by other Vermont lake monitoring programs who also conducted comparative analyses. It was concluded that the instrument change should have minimal impact on the monitoring data.

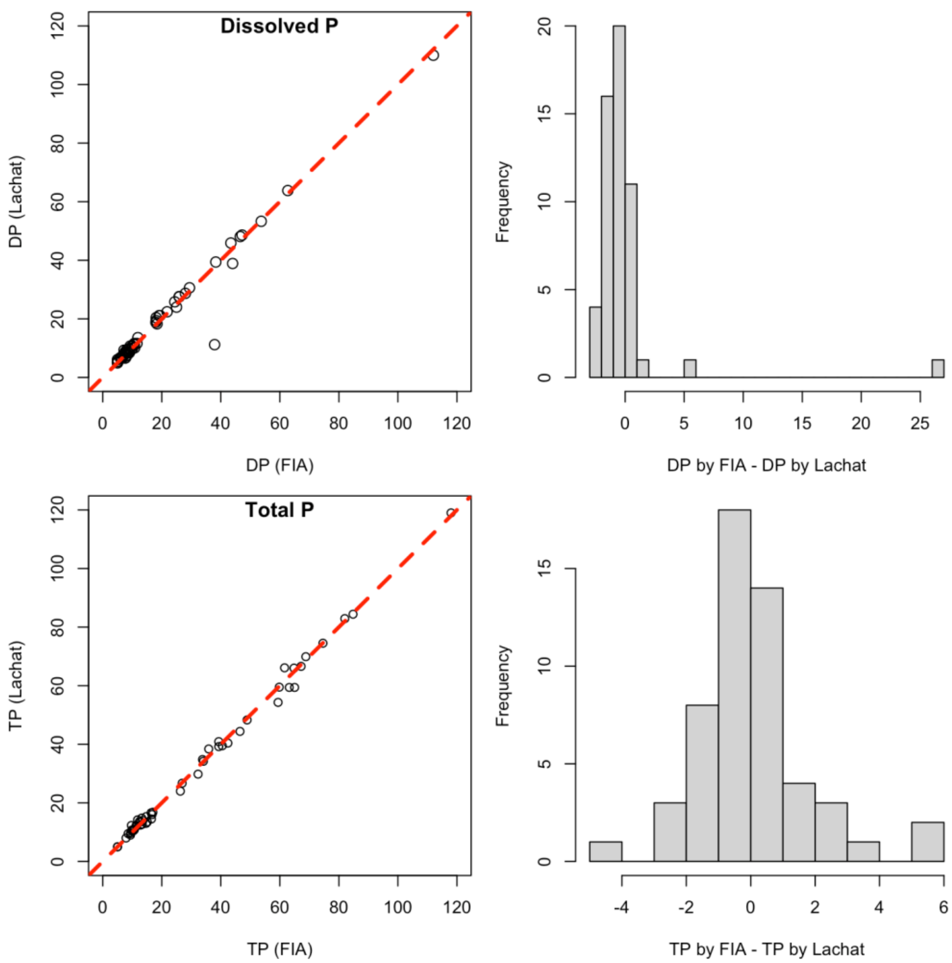


Figure 6. Phosphorus instrument comparion. Plots on right show comparisons of the new machine (x axis) to the old machine (y axis). Red dashed line is 1:1. Plots on the rights show histograms of the difference between the new instrument and the old instrument. Histograms centered around 0 indicate no bias.

Appendix A. Invasive Species Monitoring in Lake Champlain

Cercopagis pengoi (fish hook waterflea), an invasive predatory cladoceran in the same family as Bythotrephes longimanus (spiny waterflea), was first detected in Lake Champlain in August 2018. A total of 131 zooplankton samples were scanned for Cercopagis and Bythotrephes from monitoring stations on Lake Champlain in 2023 (Table 7, Figures 4 & 5). Cercopagis was first detected in May, with densities greatly increasing into July and August before decreasing in the fall (Figures 3.1 - 3.4). Bythotrephes densities remained lower than Cercopagis densities throughout the season (Figures 4.1 – 4.4). Whole water vertical tows were taken at each monitoring station using a 250 µm mesh 50 cm plankton net. Samples were then taken to the laboratory where they were visually scanned under a dissecting microscope to determine population densities. All samples were also scanned for other potential invasive invertebrates, including Hemimysis anomala (bloody-red shrimp).

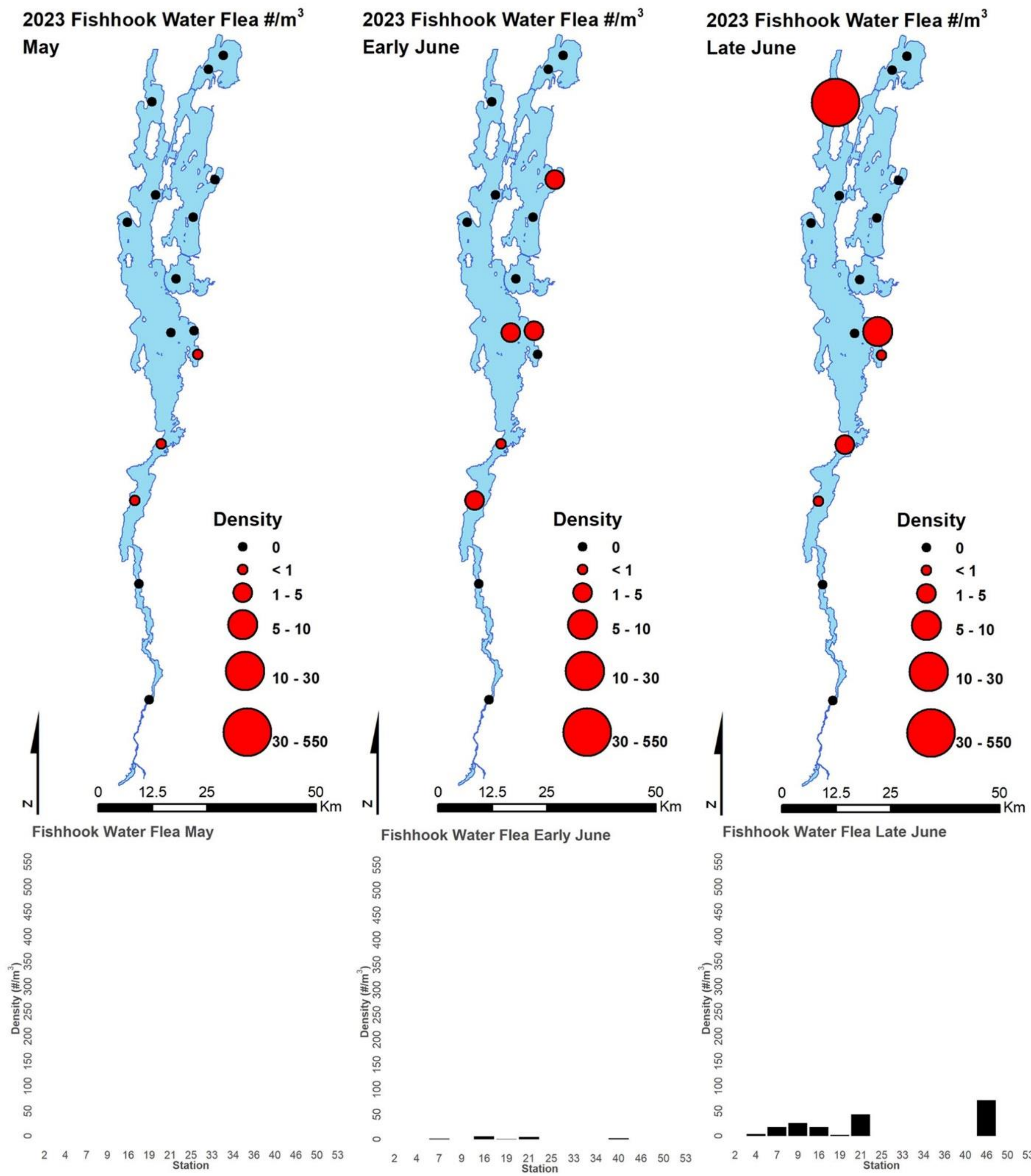


Figure 4.1 Fish hook water flea density from vertical whole water tows from May-June 2023

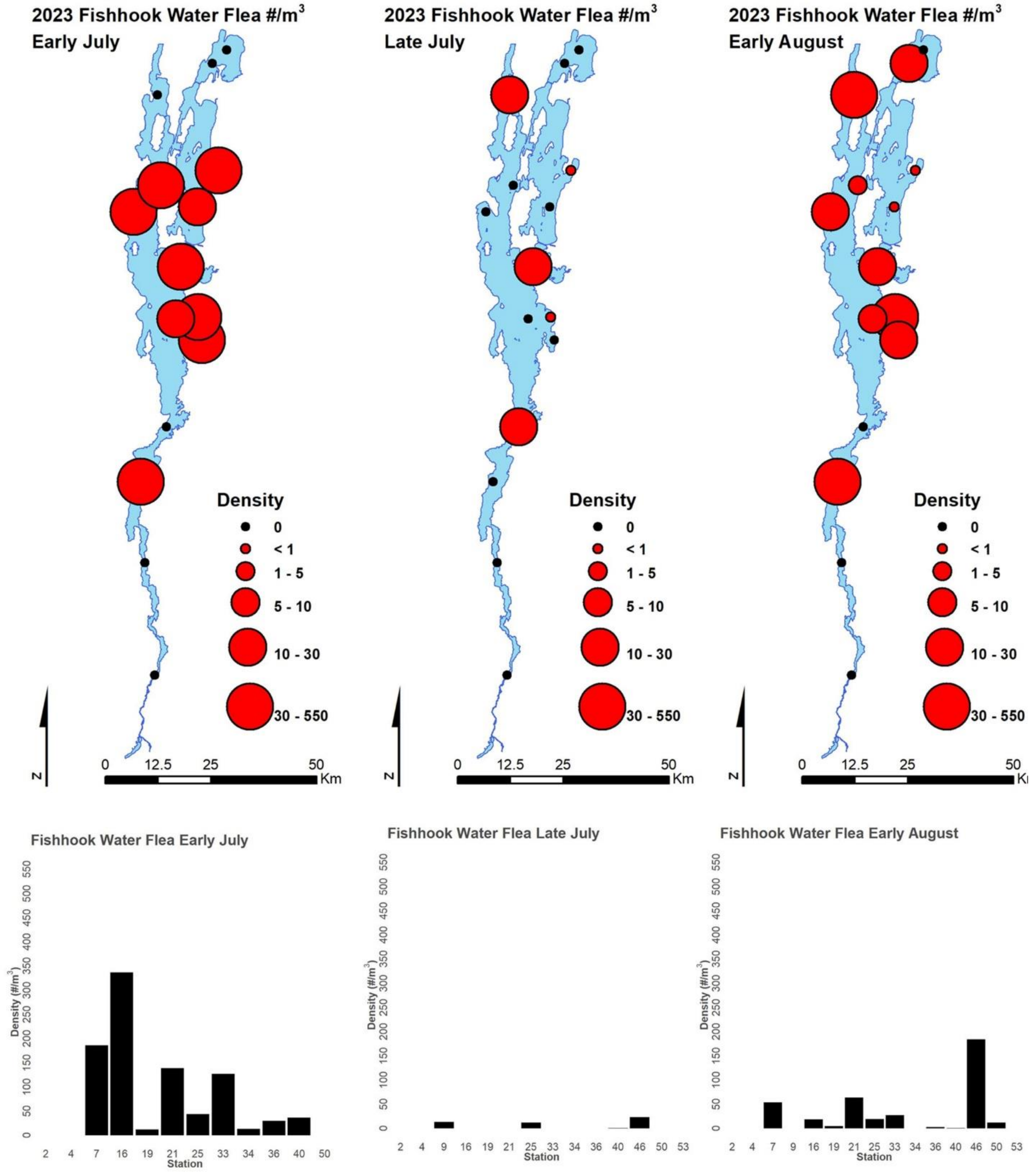


Figure 4.2 Fish hook water flea density from vertical whole water tows from July-Early August 2023

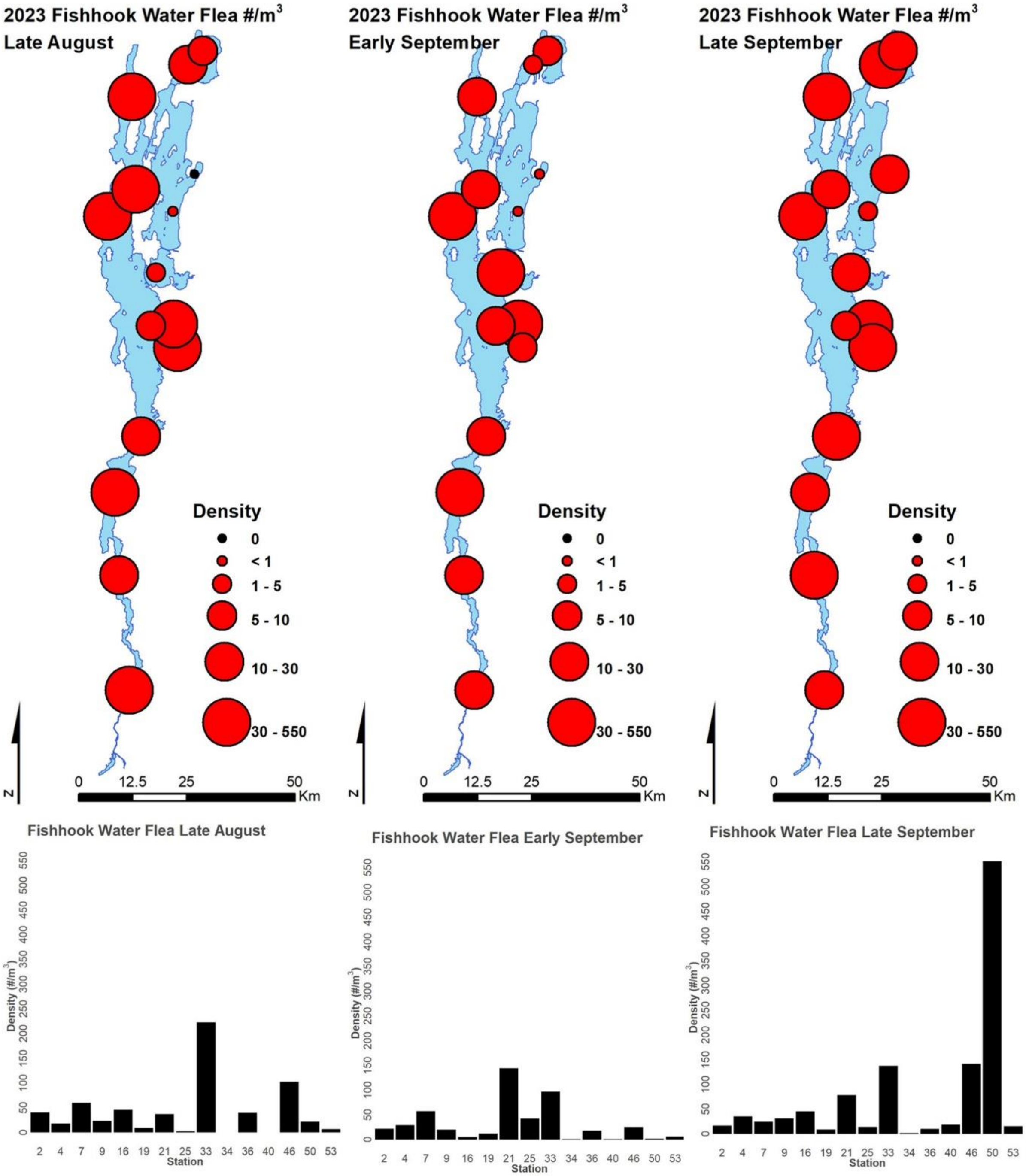


Figure 4.3 Fish hook water flea density from vertical whole water tows from Late August– Late September 2023

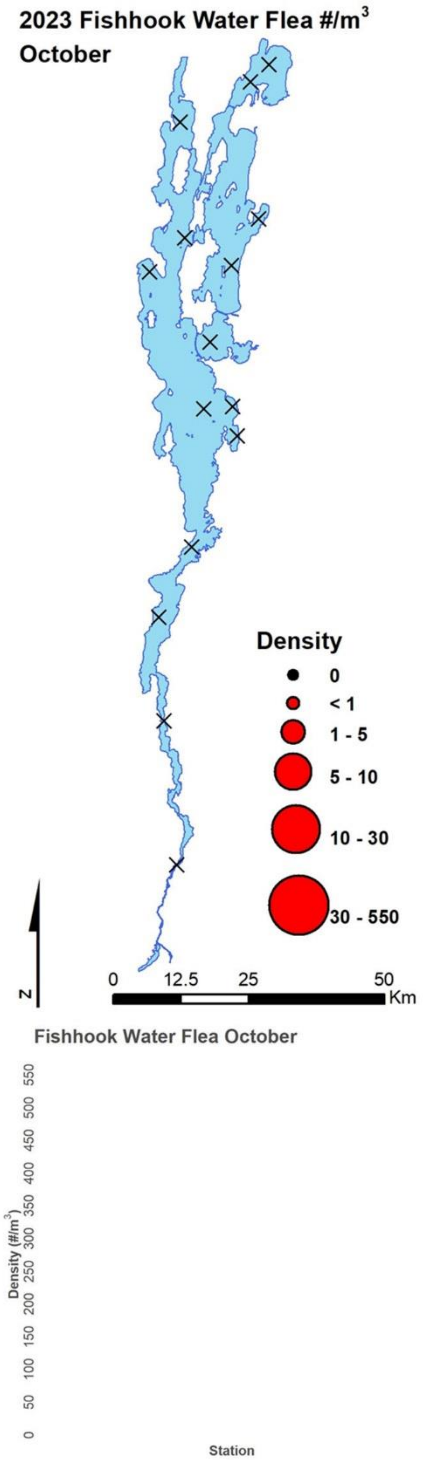


Figure 4.4 Fish hook water flea density from vertical whole water tows from October 2023

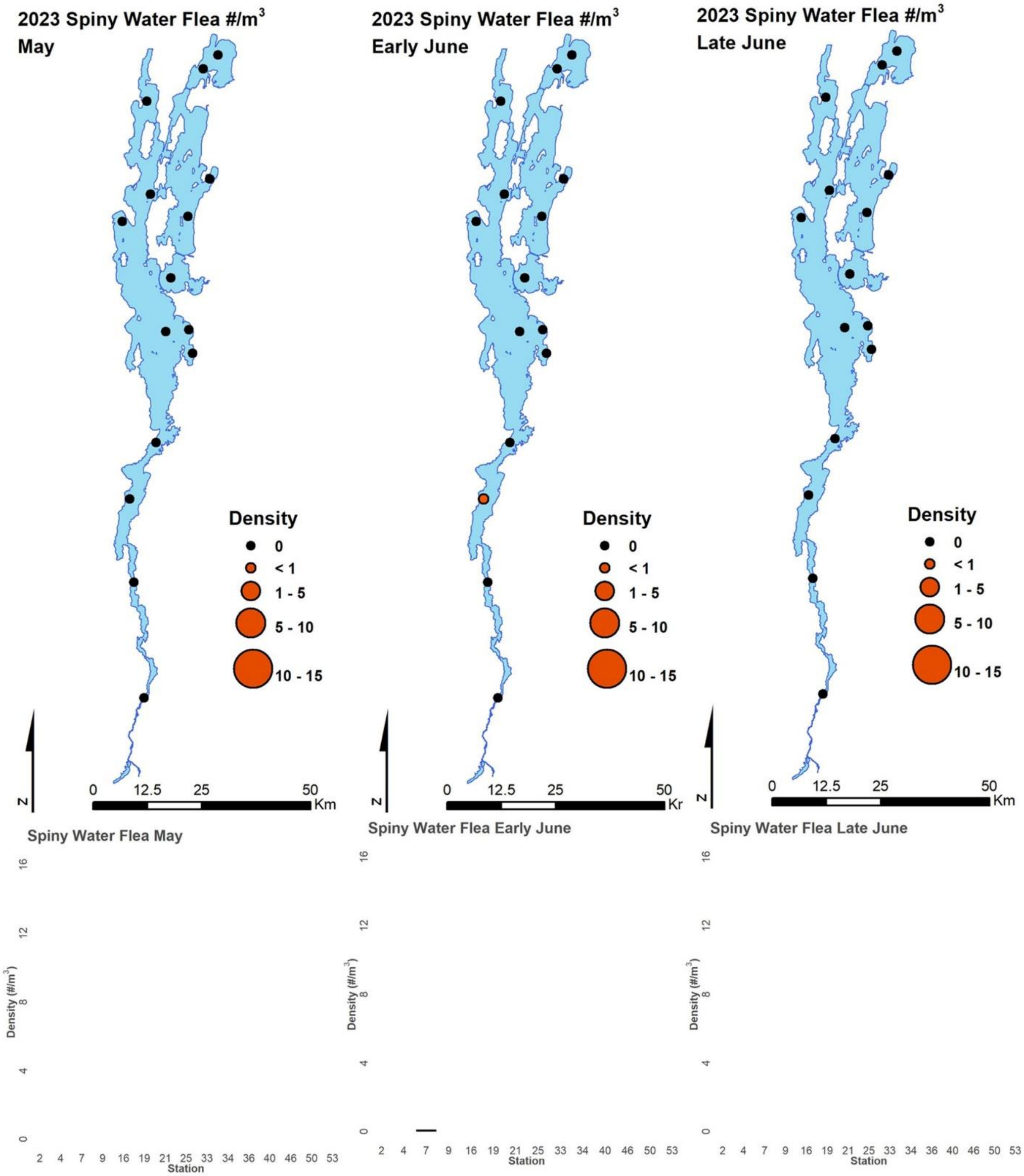


Figure 4.1 Spiny water flea density from vertical whole water tows from May-June 2023

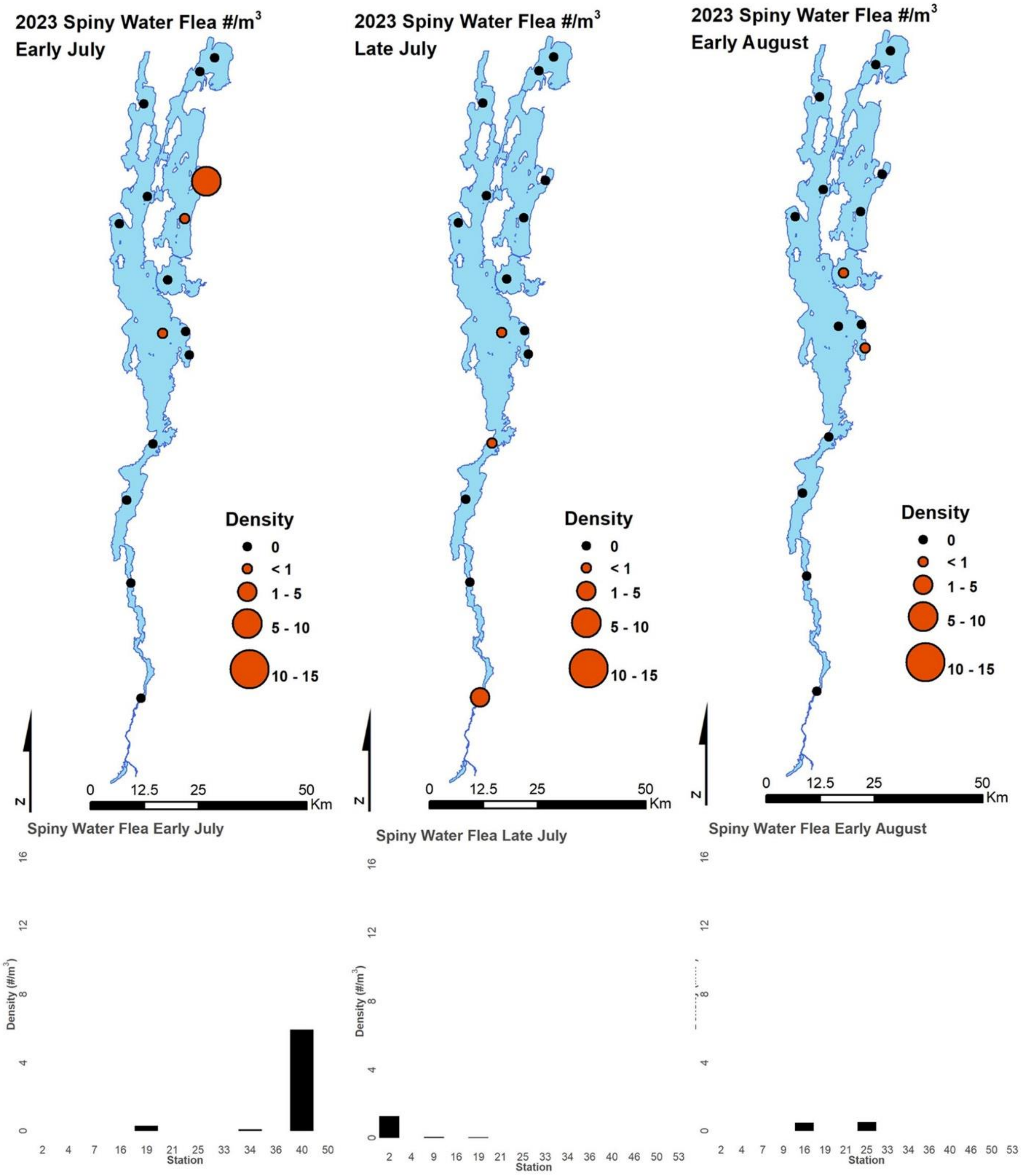


Figure 4.2 Spiny water flea density from vertical whole water tows from July-Early August 2023

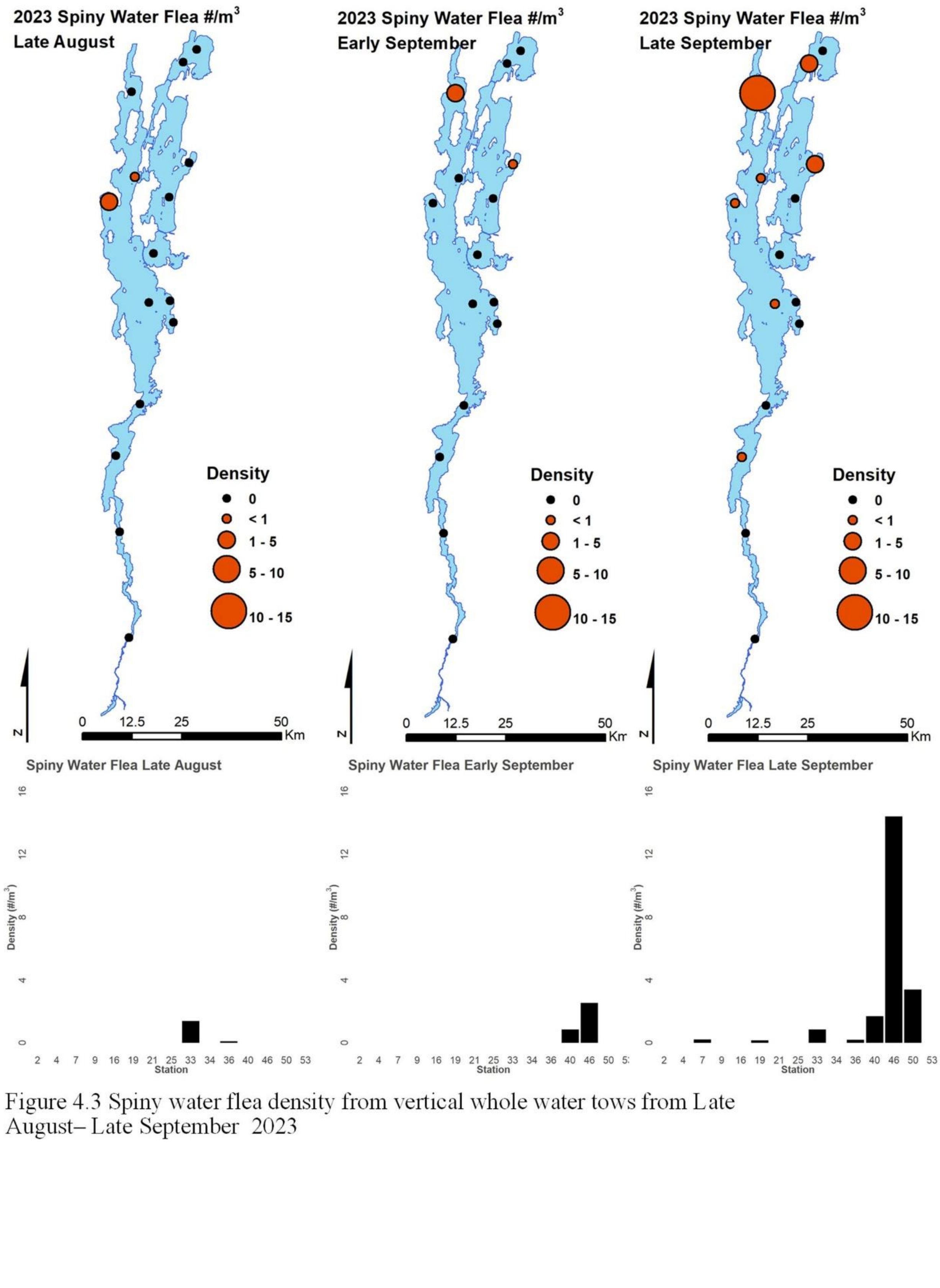


Figure 4.3 Spiny water flea density from vertical whole water tows from Late August– Late September 2023

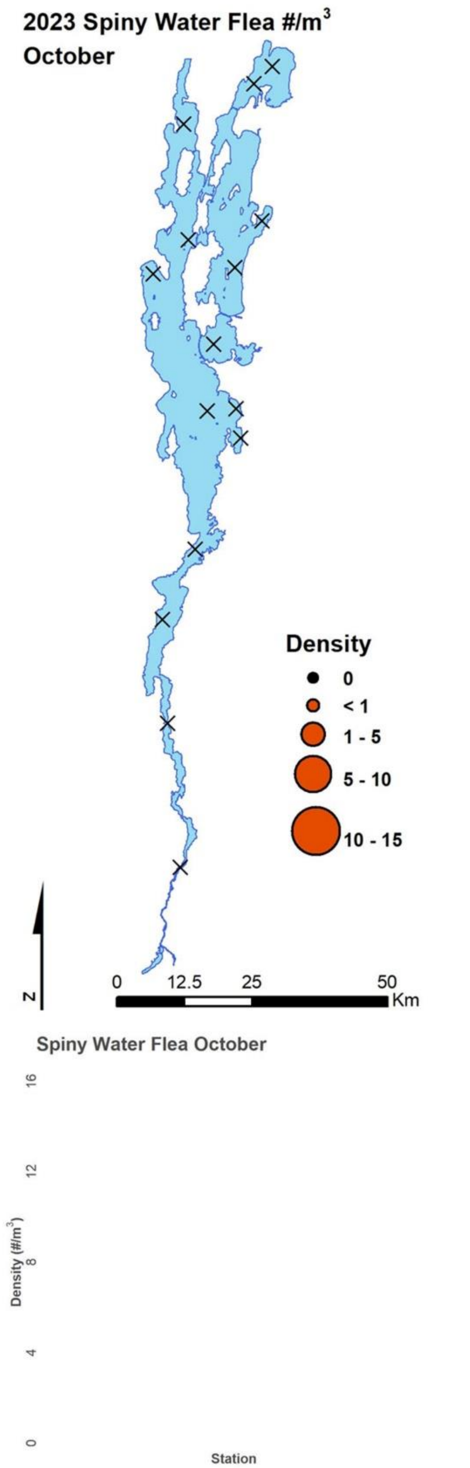


Figure 4.4 Spiny water flea density from vertical whole water tows from October 2023

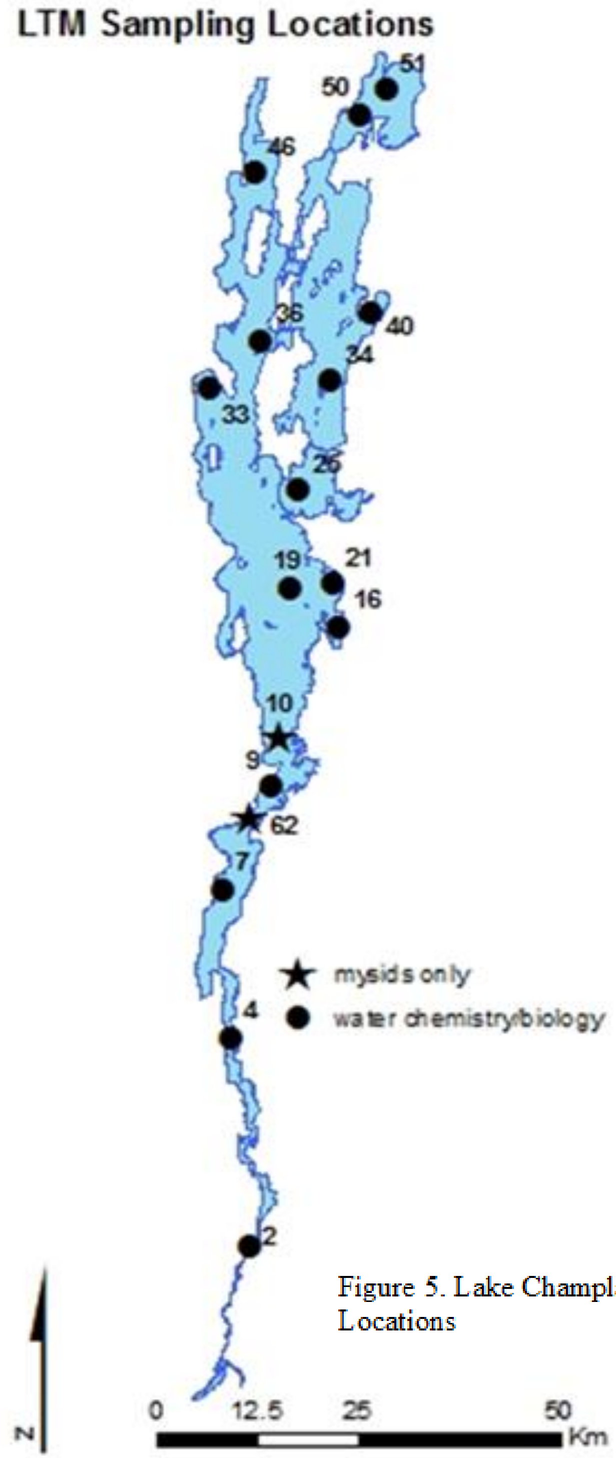
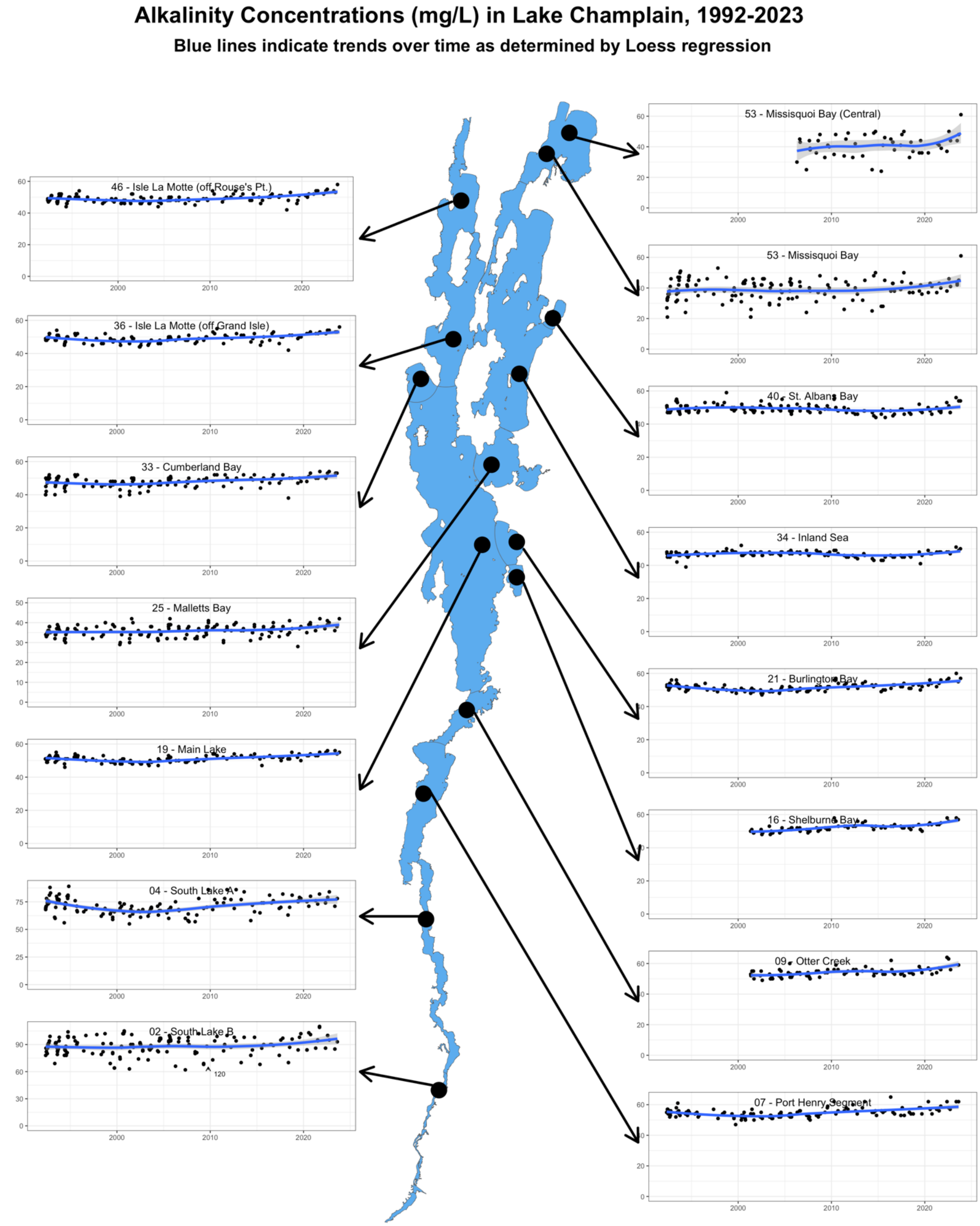


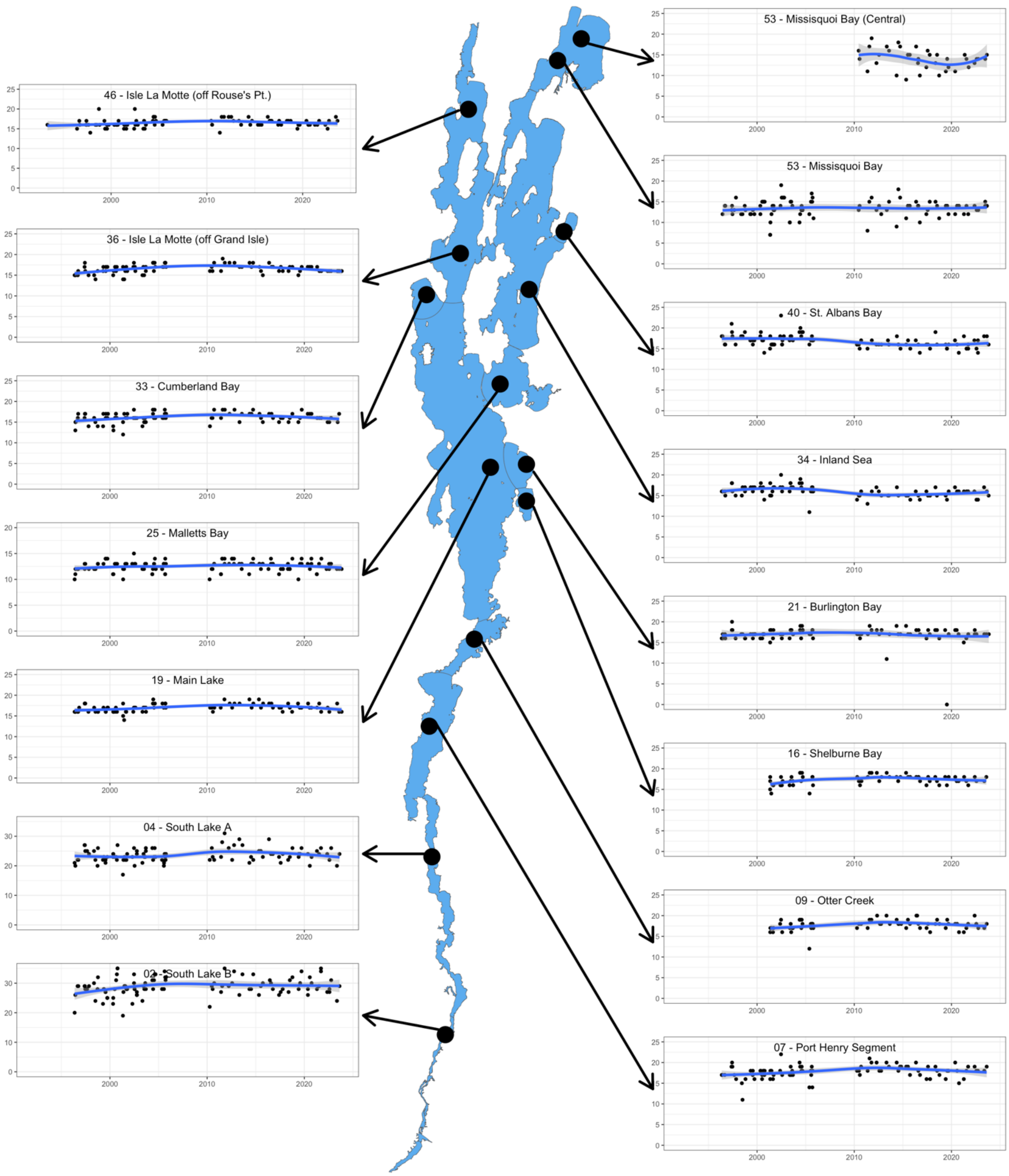
Figure 5. Lake Champlain LTM Sampling Locations

Appendix B. Lake Champlain Biogeochemical Monitoring Data



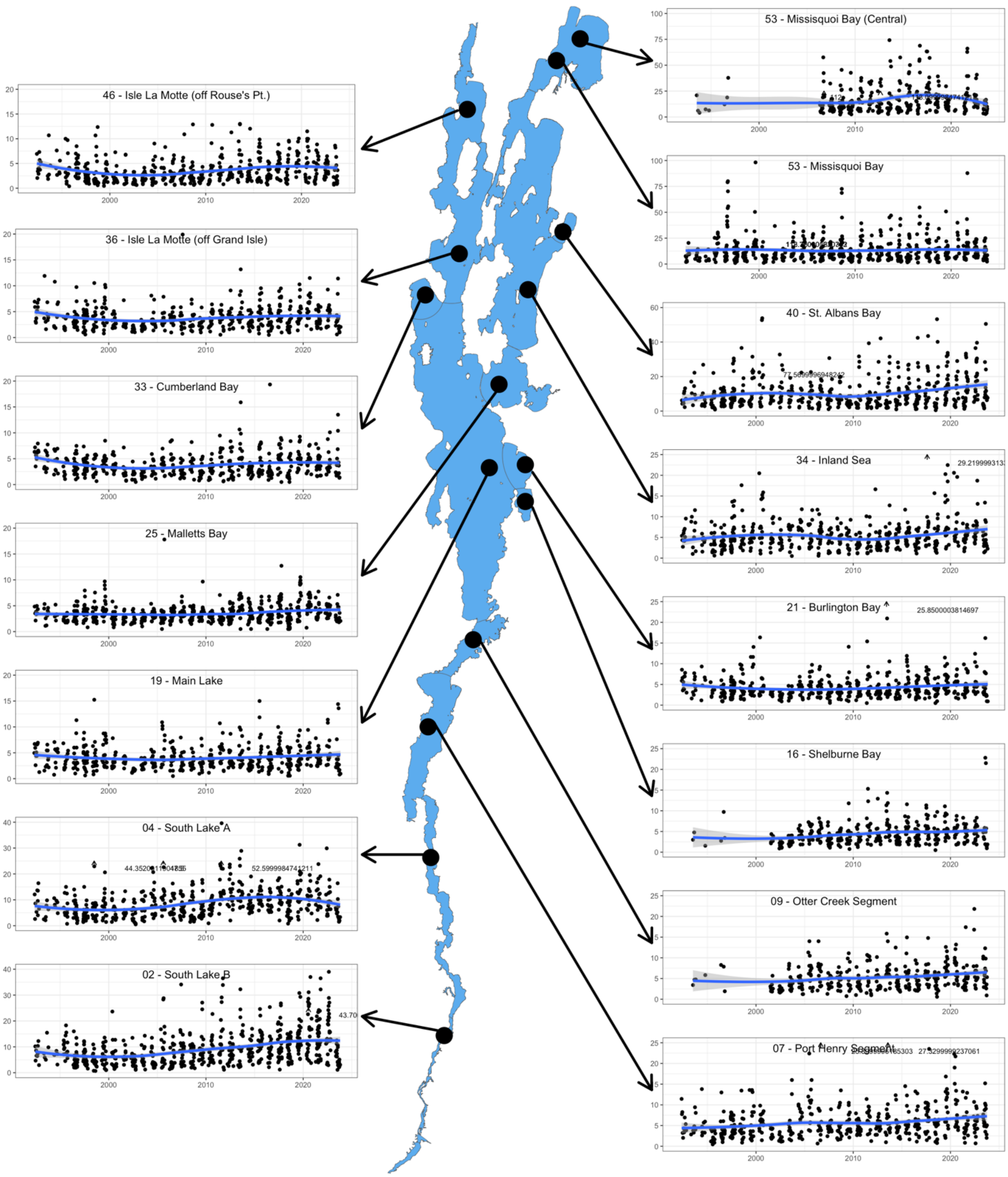
Calcium Concentrations (mg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



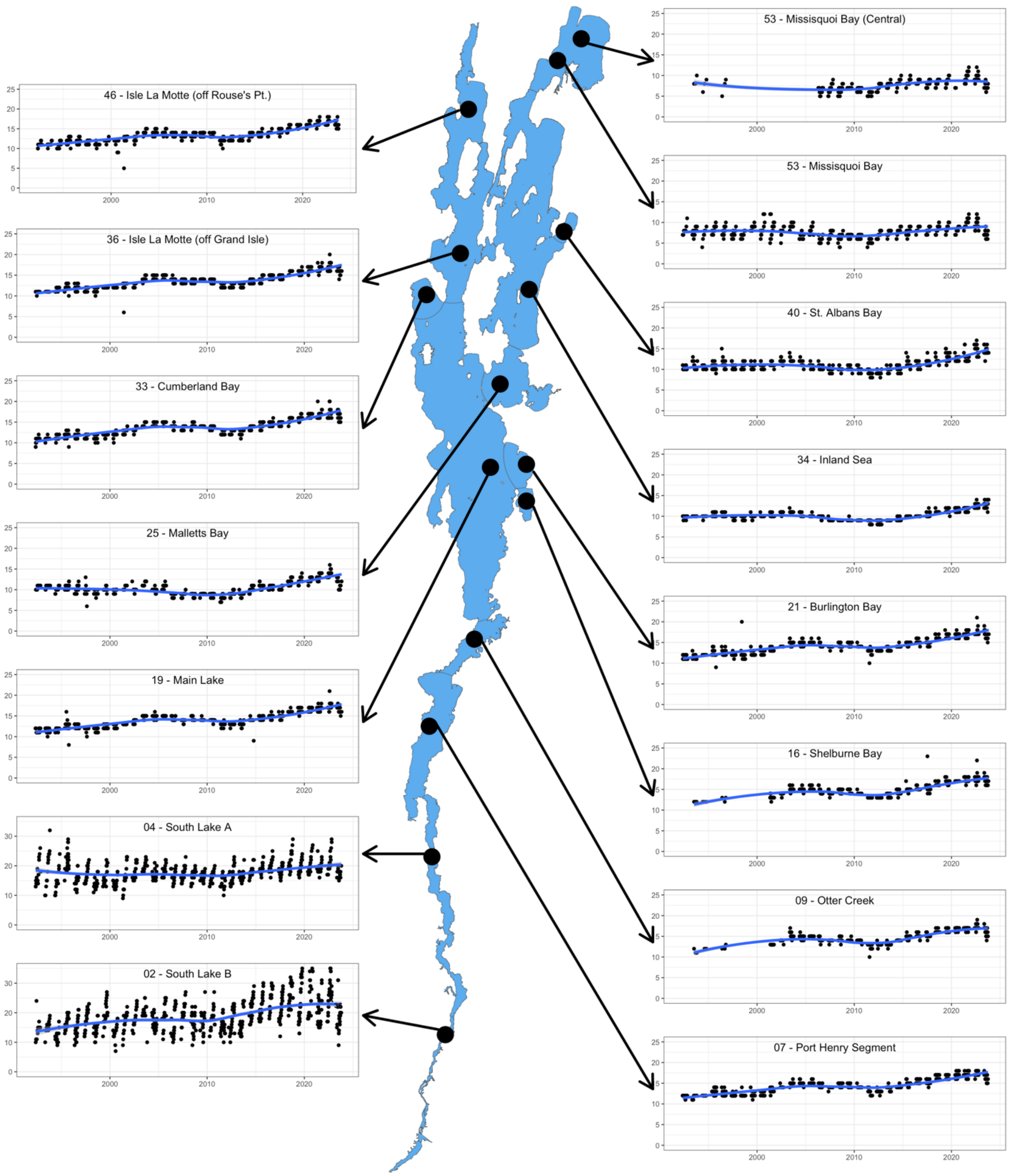
Chlorophyll-a Concentrations (µg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



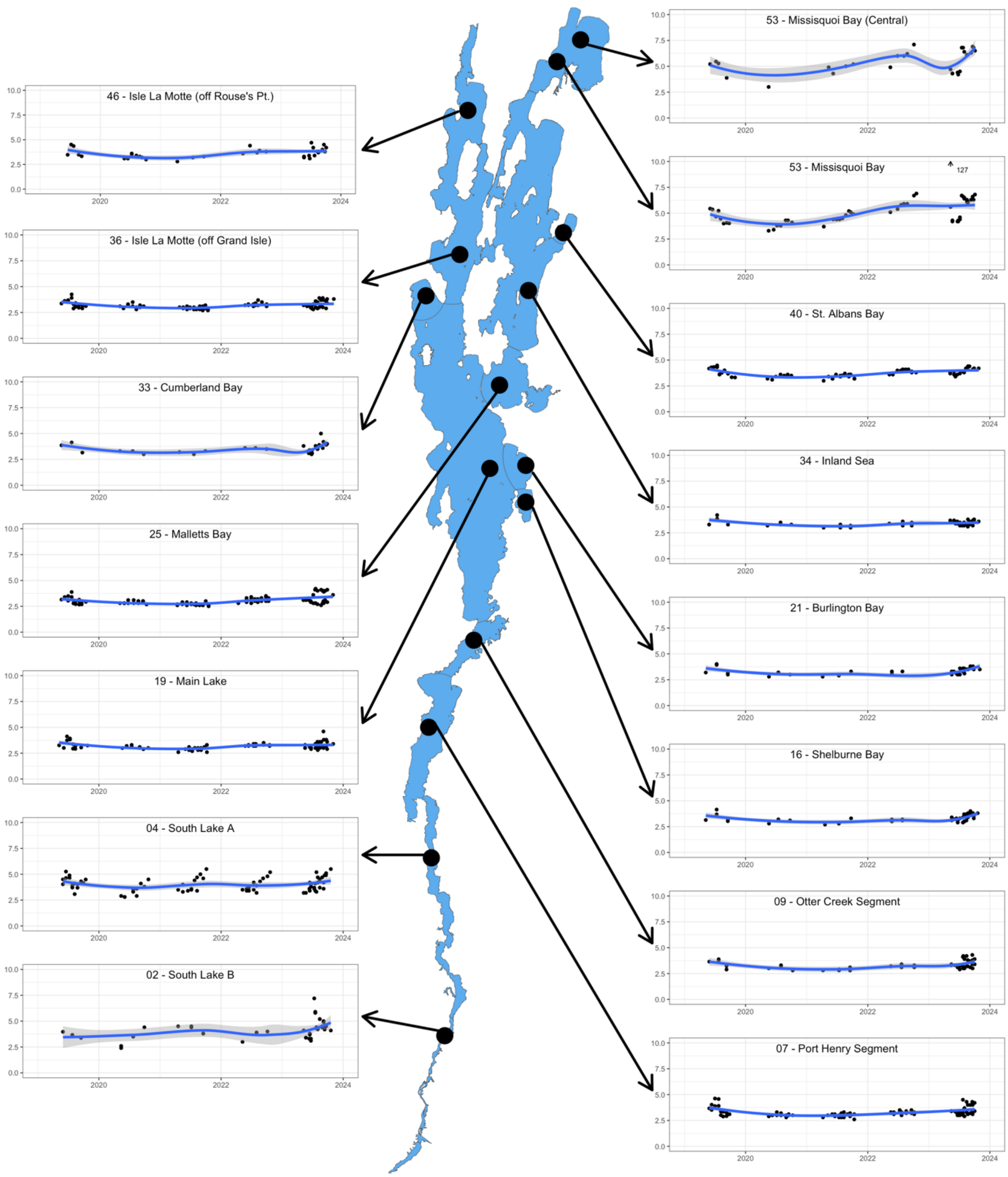
Chloride Concentrations (mg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



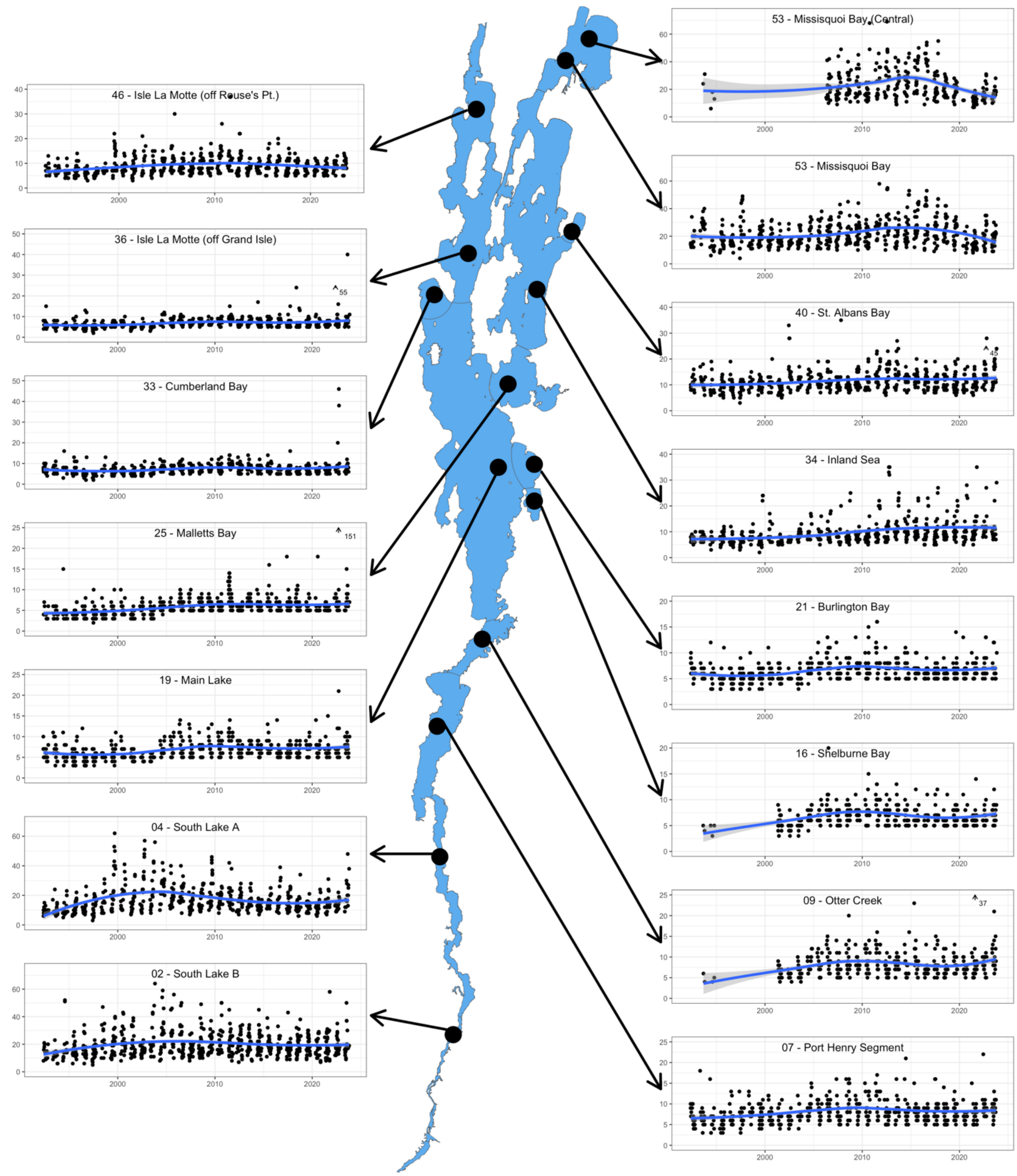
Dissolved Organic Carbon Concentrations (mg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



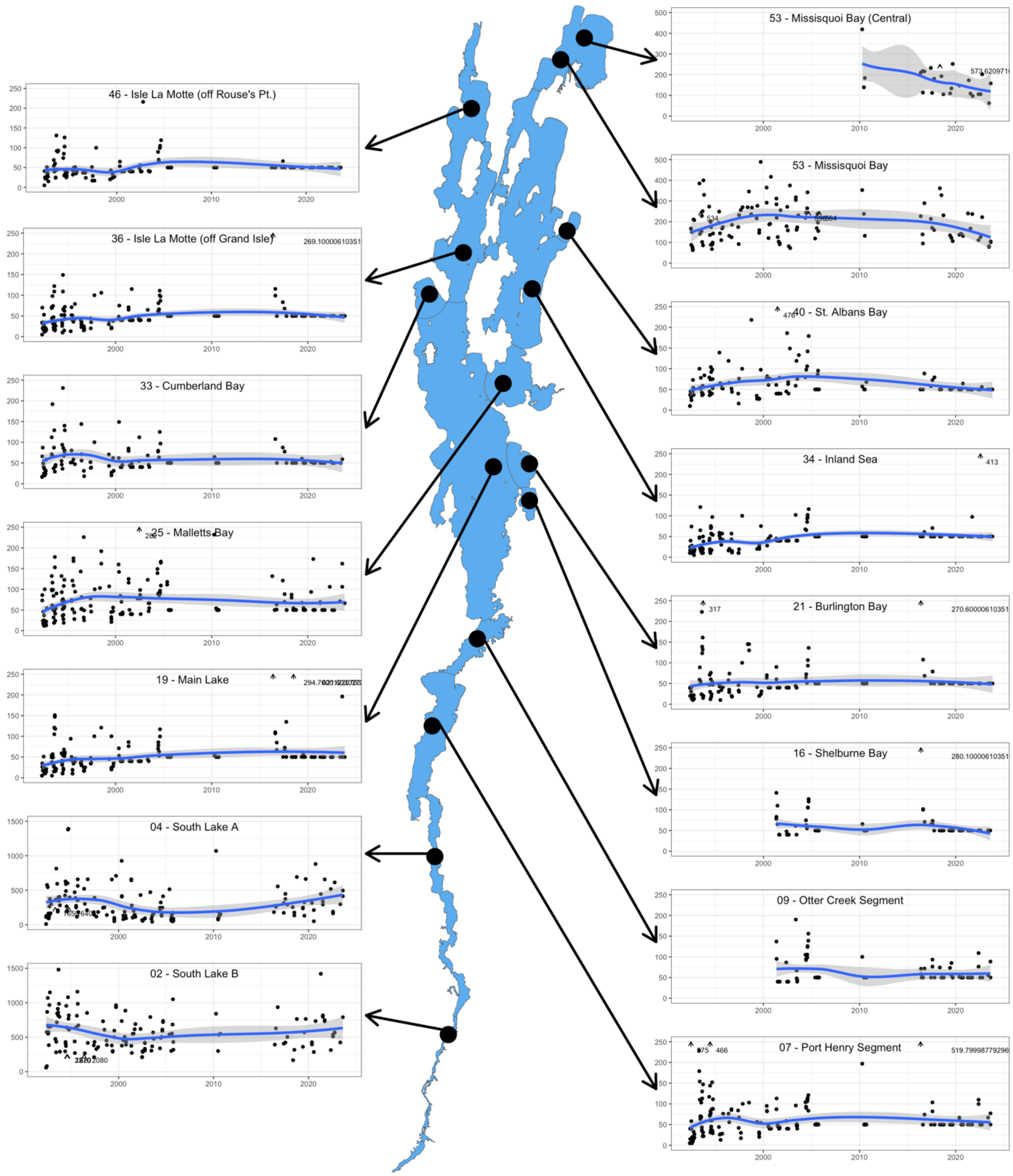
Annual Dissolved Phosphorus Concentrations (µg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



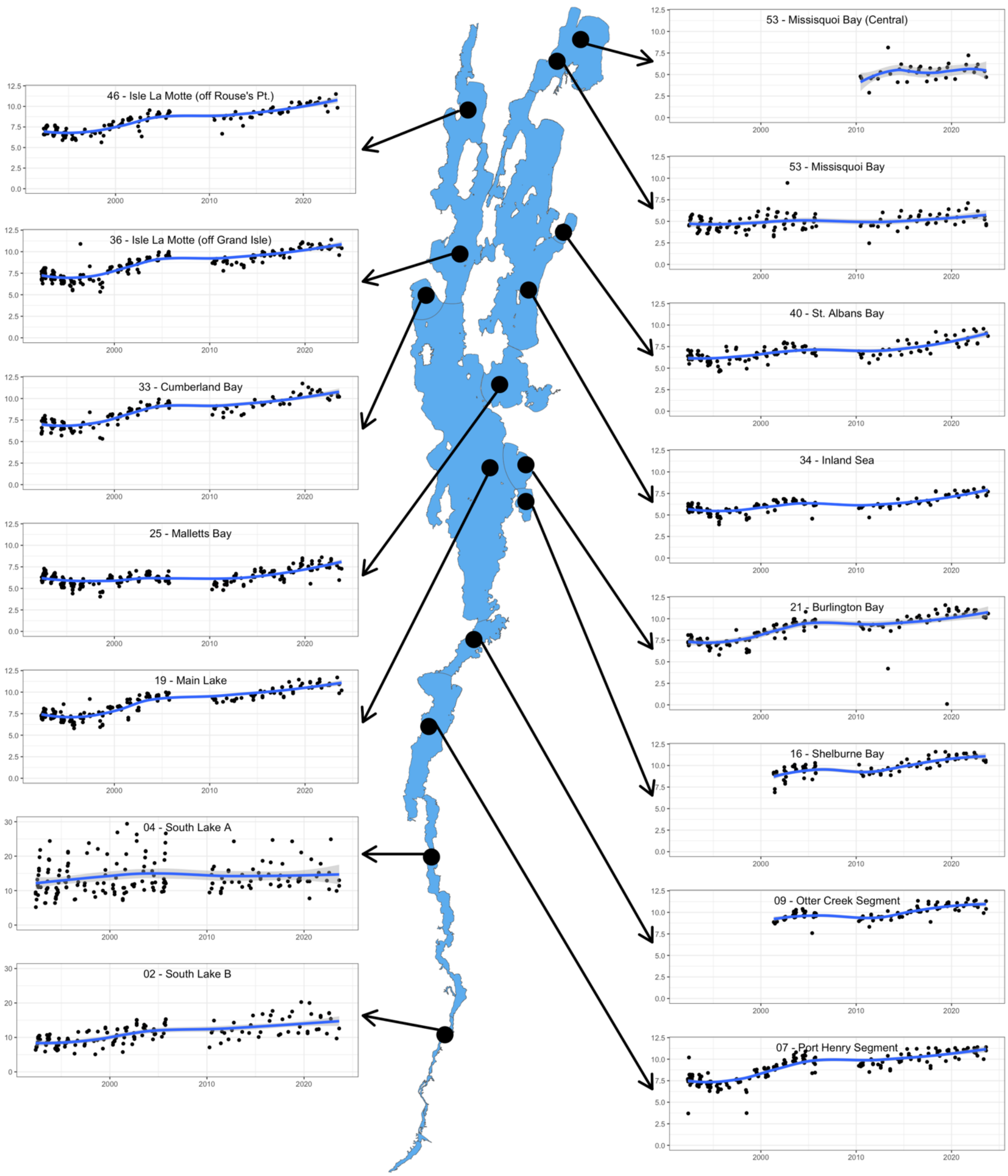
Iron Concentrations (mg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



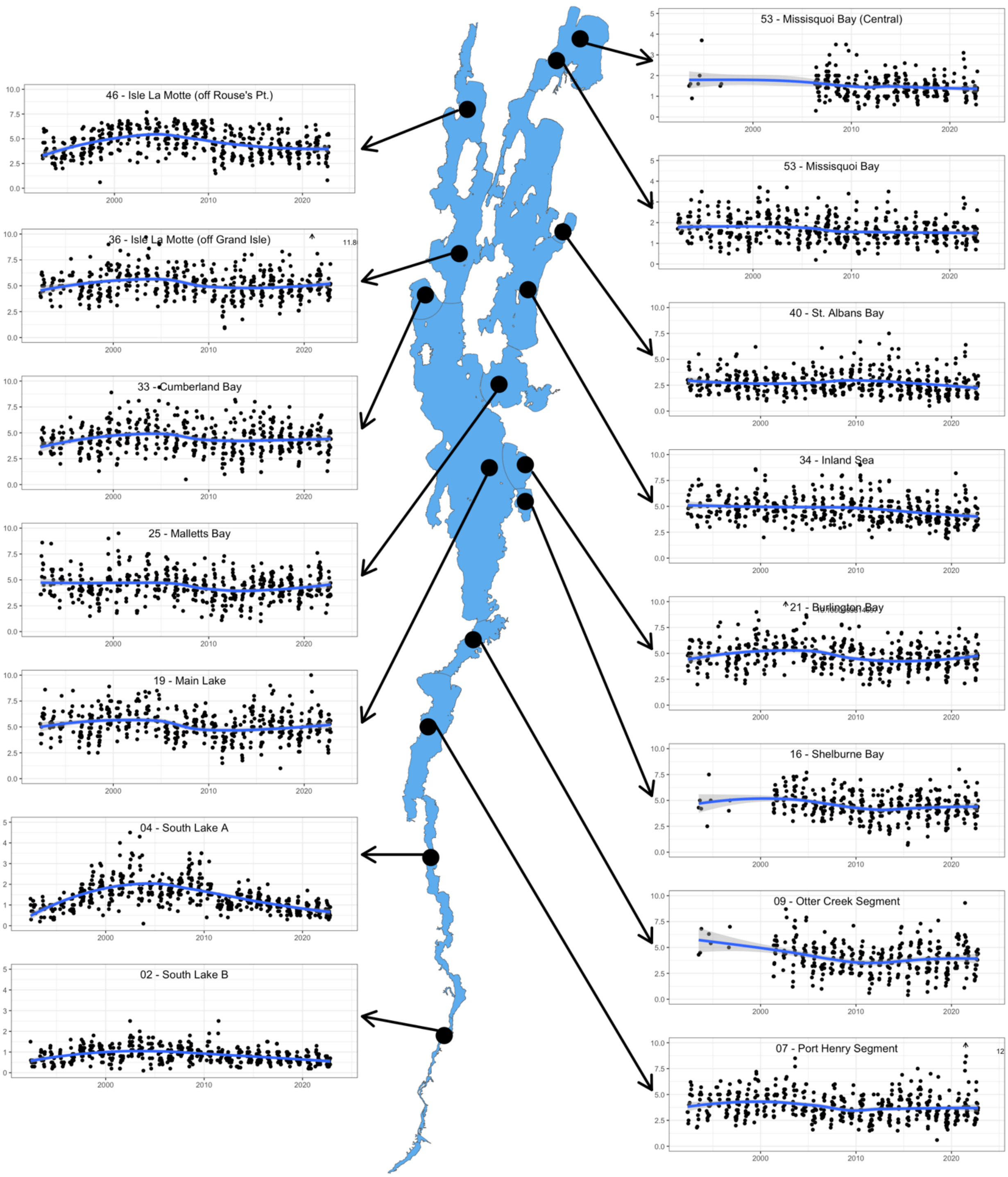
Total Sodium Concentrations (mg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



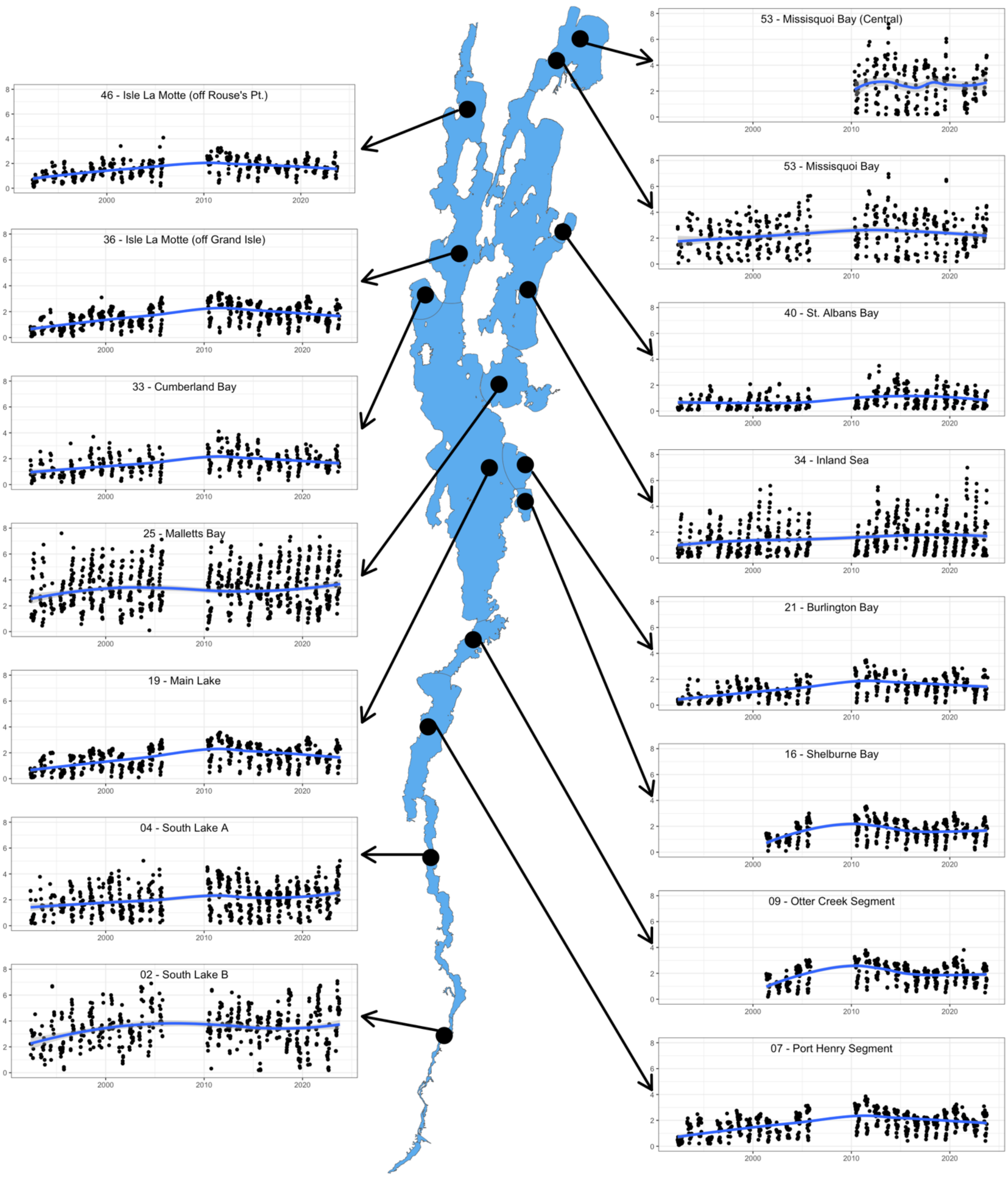
Secchi Depth (m) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



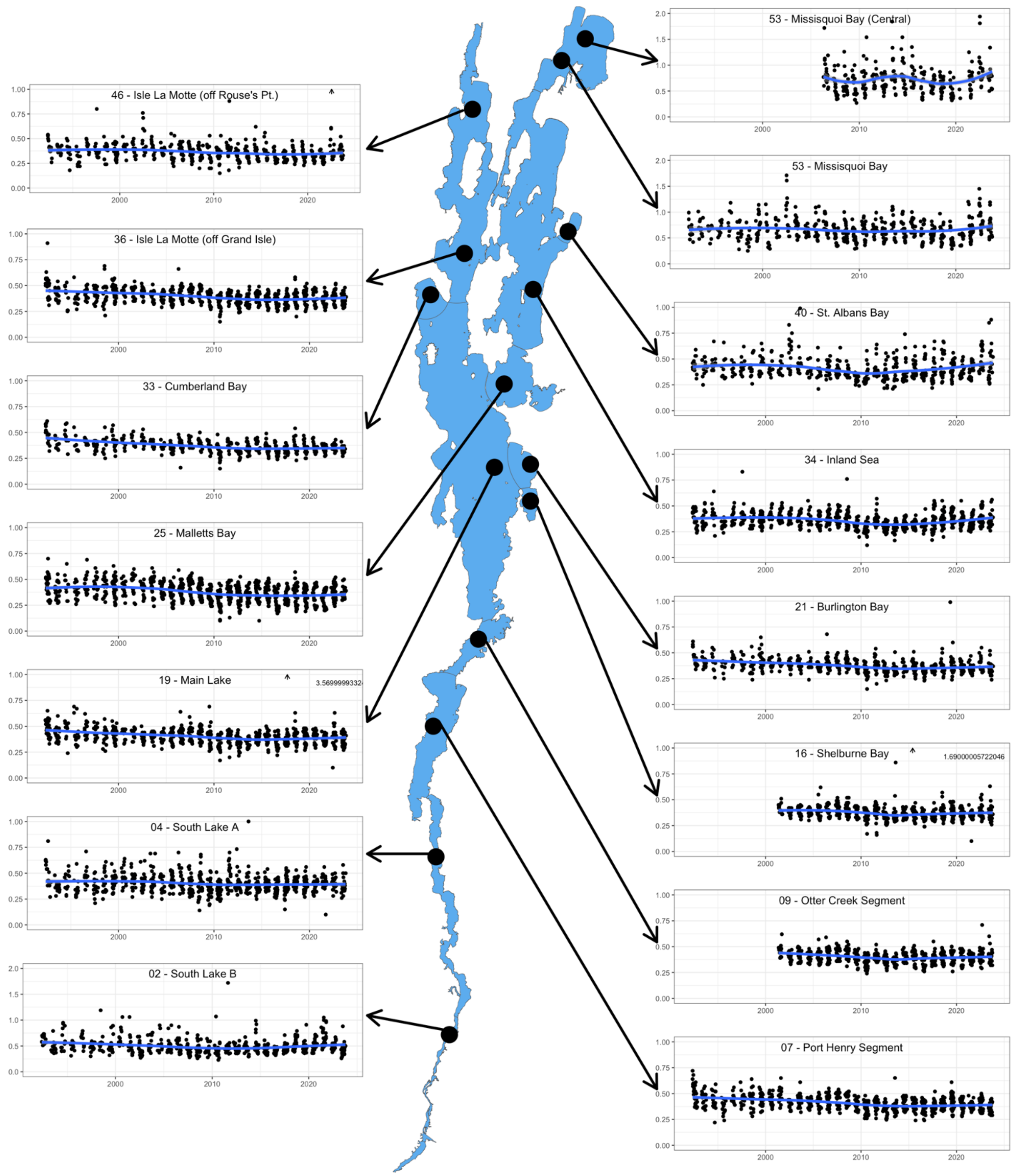
Silica Concentrations (mg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



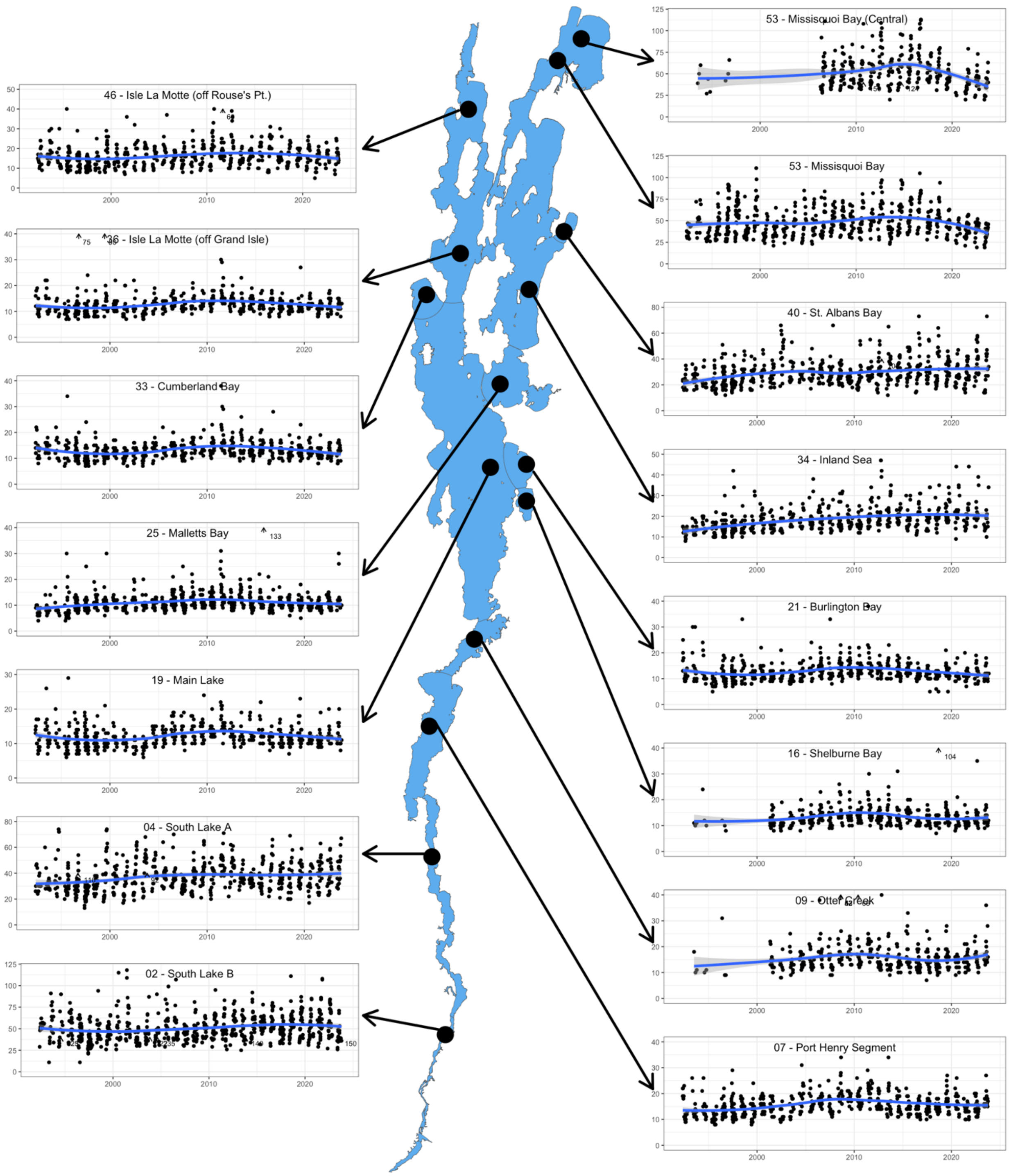
Total Nitrogen Concentrations (µg/L) in Lake Champlain, 1992-2023

Blue lines indicate trends over time as determined by Loess regression



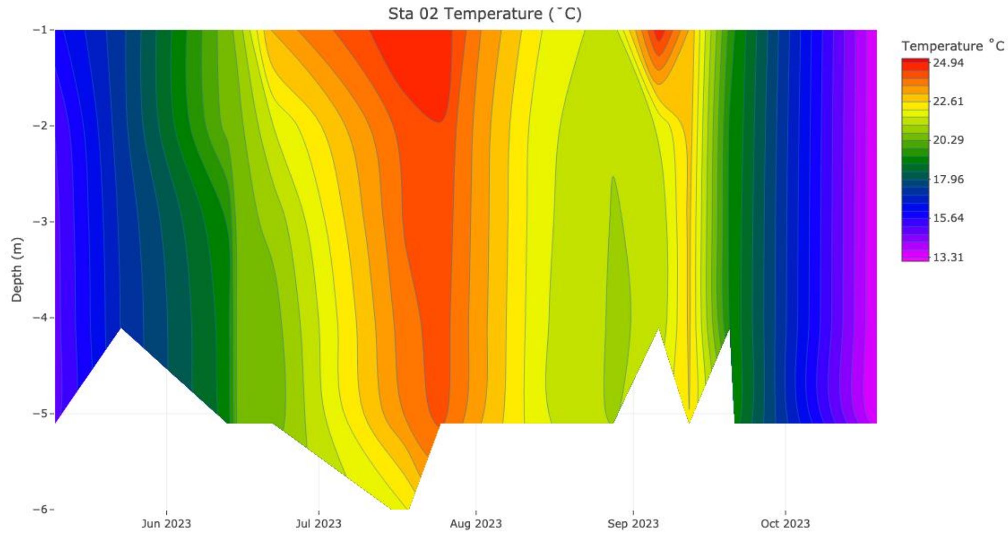
Annual Total Phosphorus Concentrations (µg/L) in Lake Champlain, 1992-2023

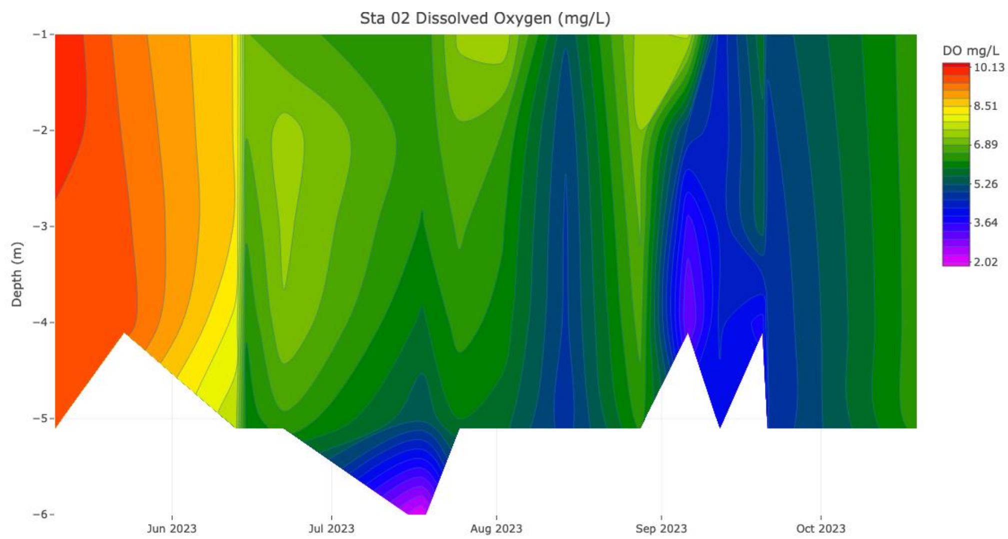
Blue lines indicate trends over time as determined by Loess regression

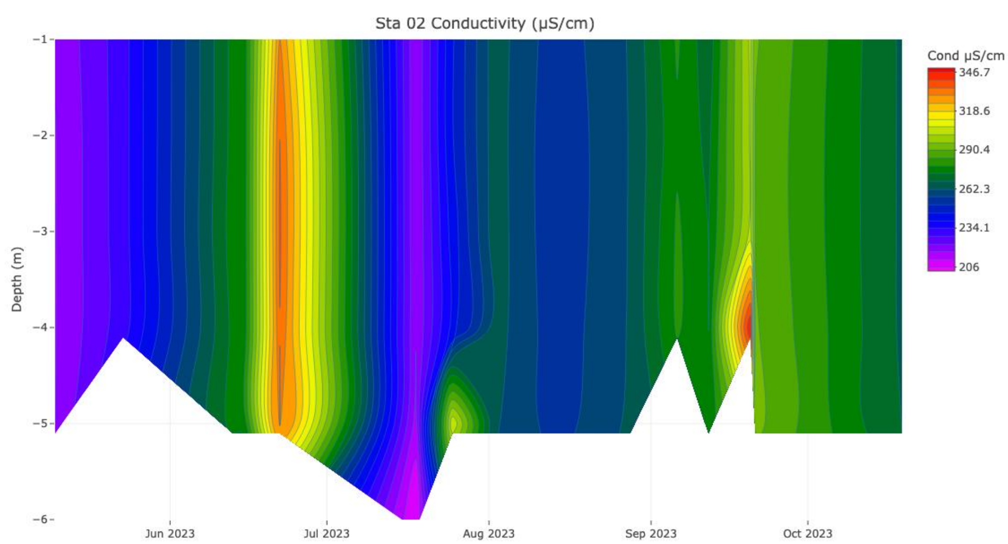


Appendix C: Hydrolab Profile Data from Lake Sites, 2023

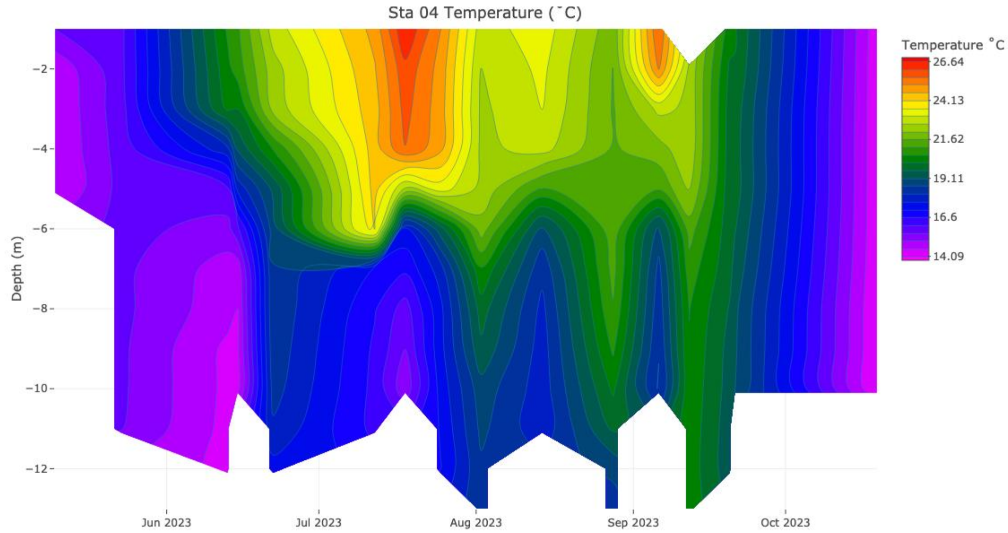
South Lake B

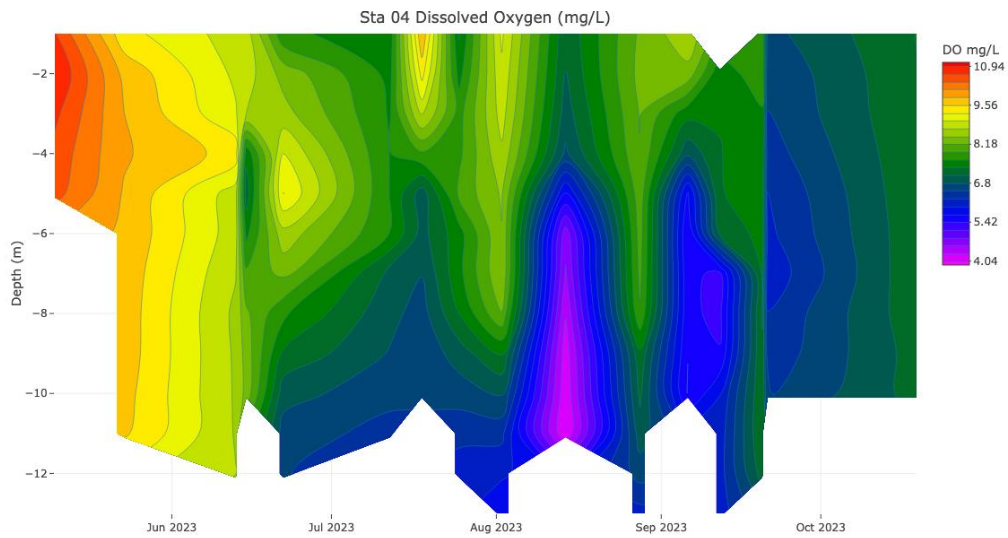


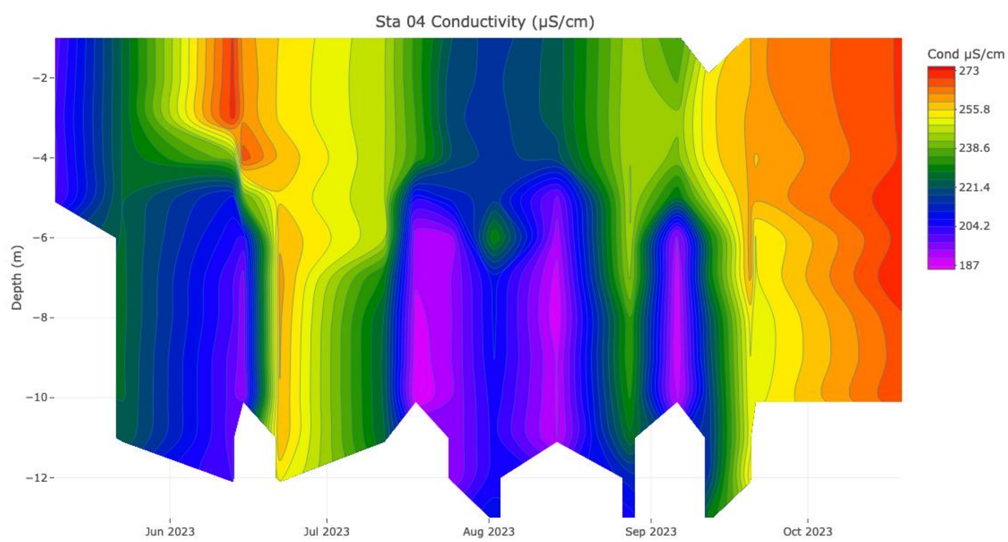




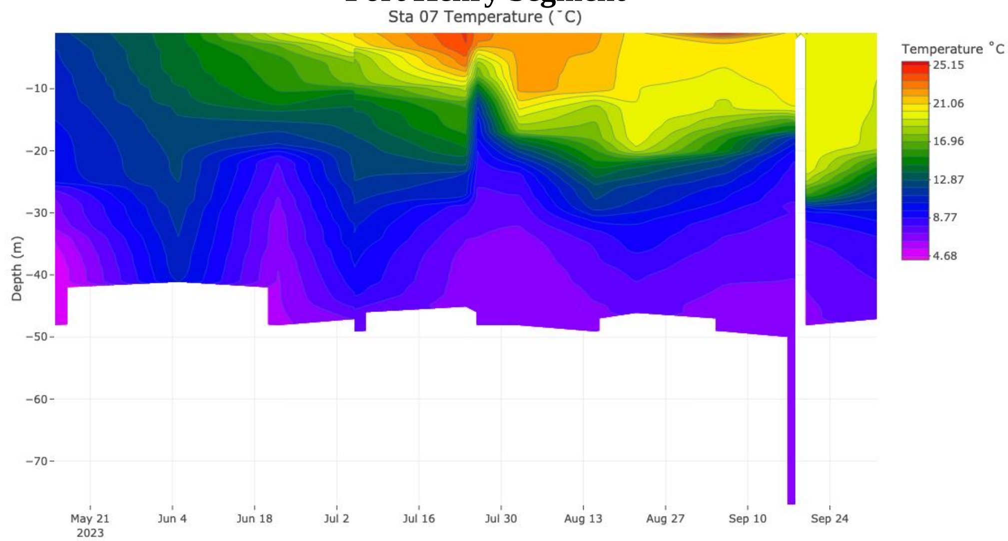
South Lake A

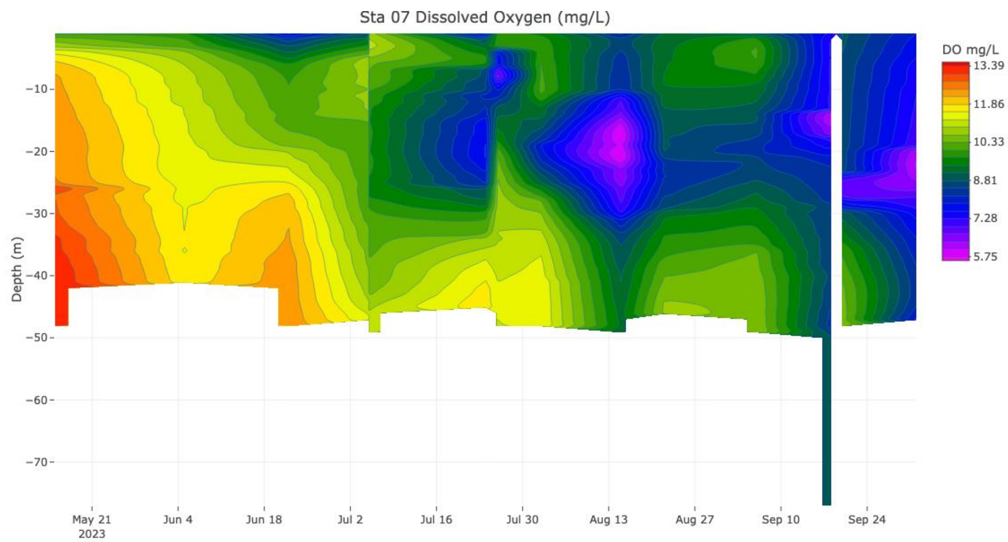

Sta 04 Temperature (˚C)
Temperature ˚C
26.64
24.13
21.62
19.11
16.6
14.09
Depth (m)
-2
-4
-6
-8
-10
-12
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023

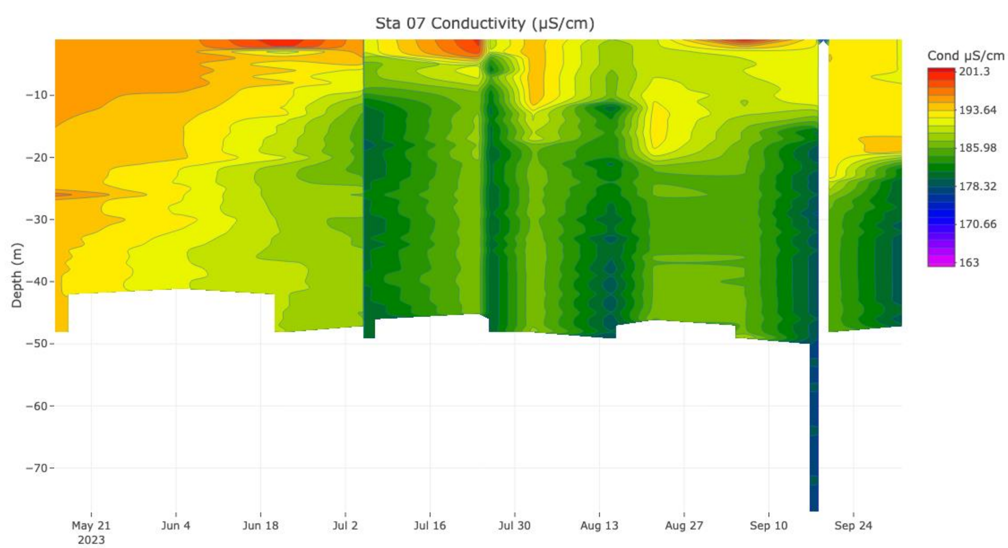

Sta 04 Dissolved Oxygen (mg/L)
DO mg/L
10.94
9.56
8.18
6.8
5.42
4.04
Depth (m)
-2
-4
-6
-8
-10
-12
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023


Sta 04 Conductivity (µS/cm)
Cond µS/cm
273
255.8
238.6
221.4
204.2
187
Depth (m)
-2
-4
-6
-8
-10
-12
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023

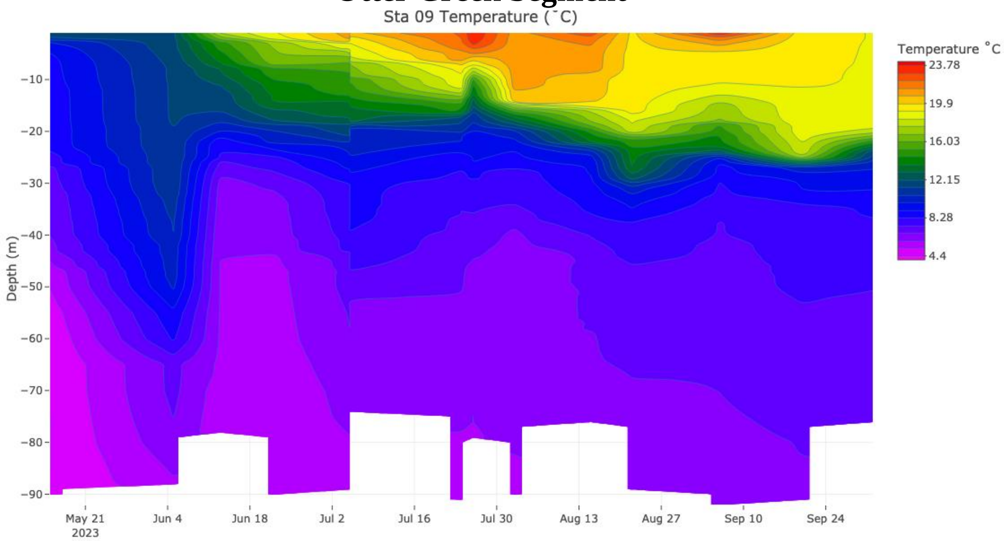
Port Henry Segment

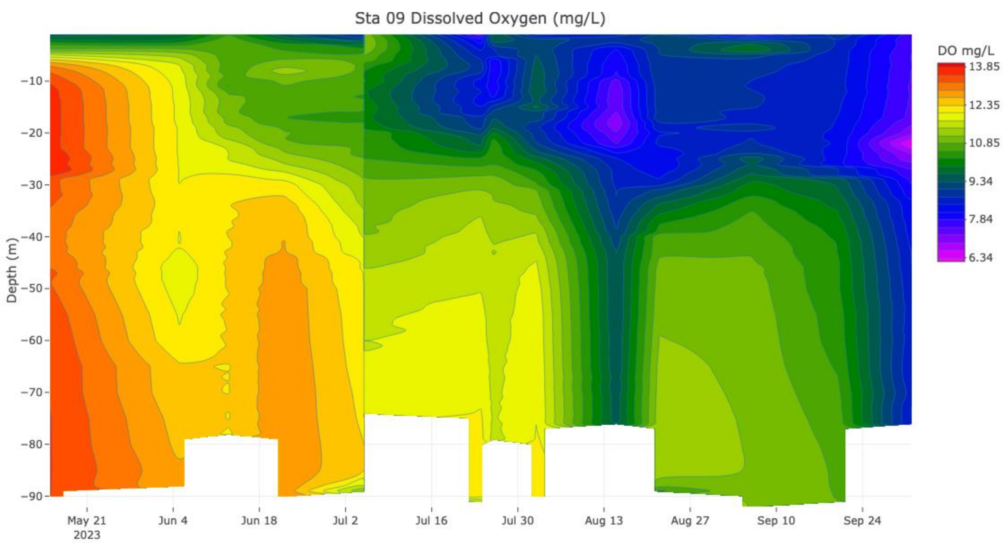


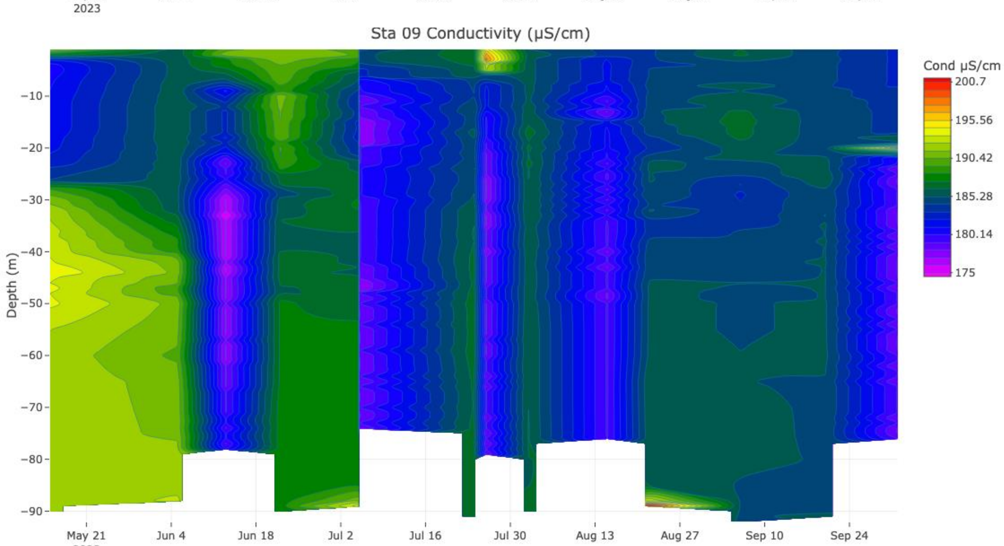




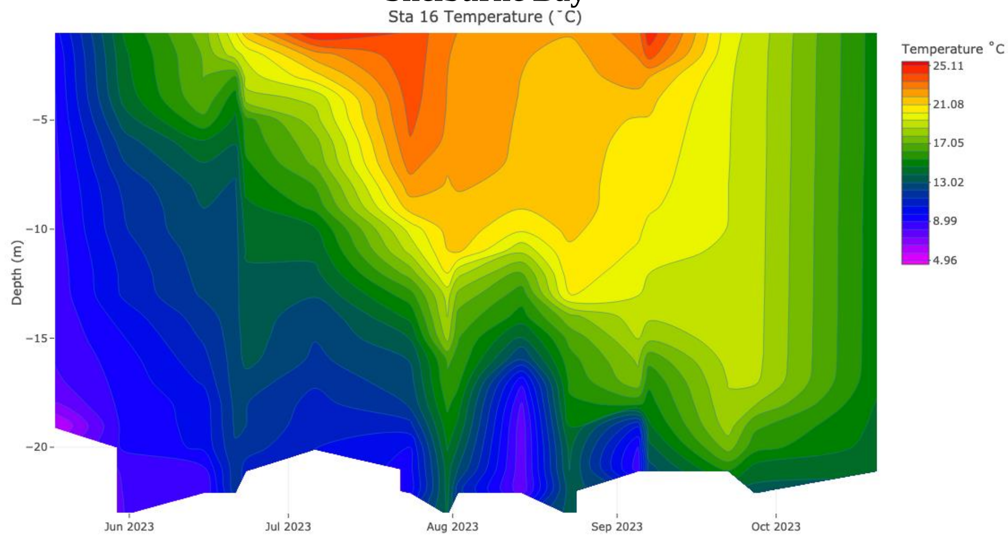
Otter Creek Segment

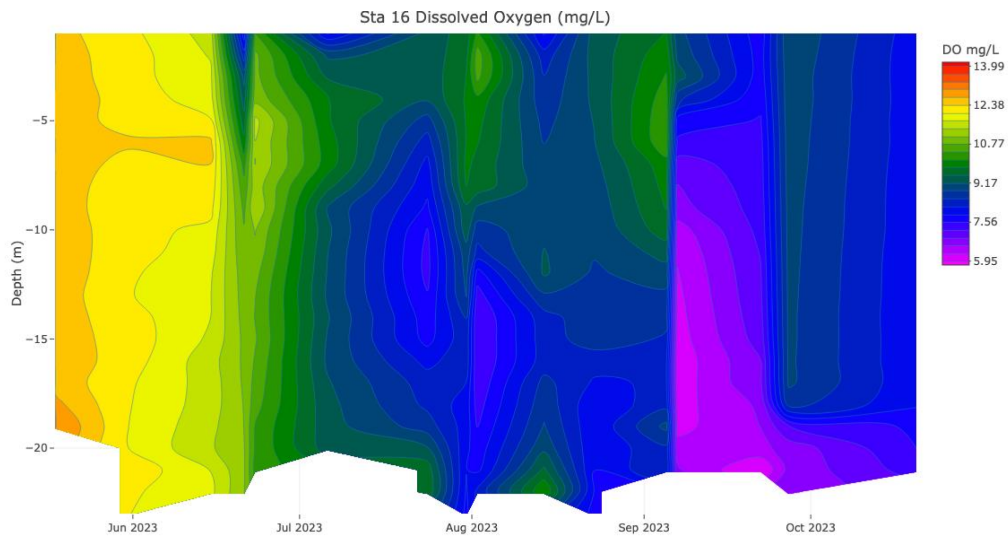


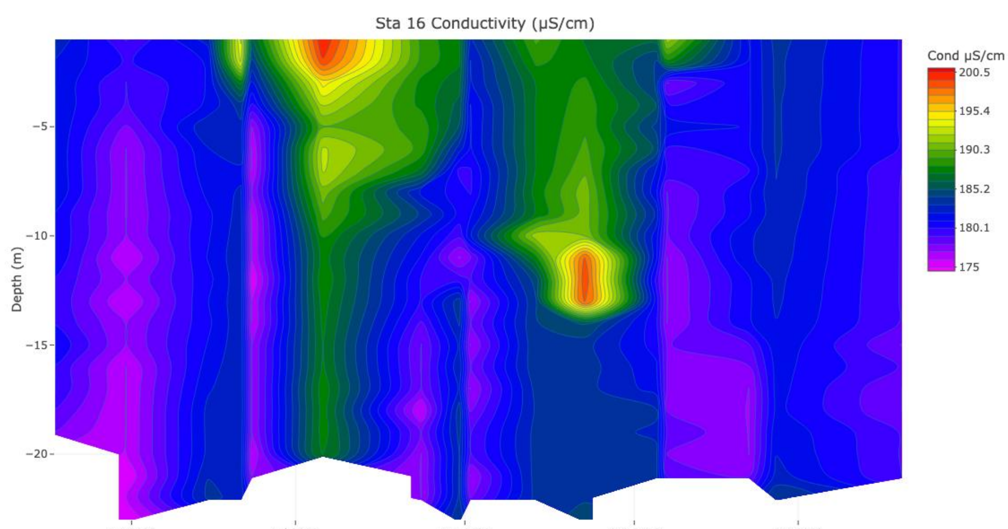




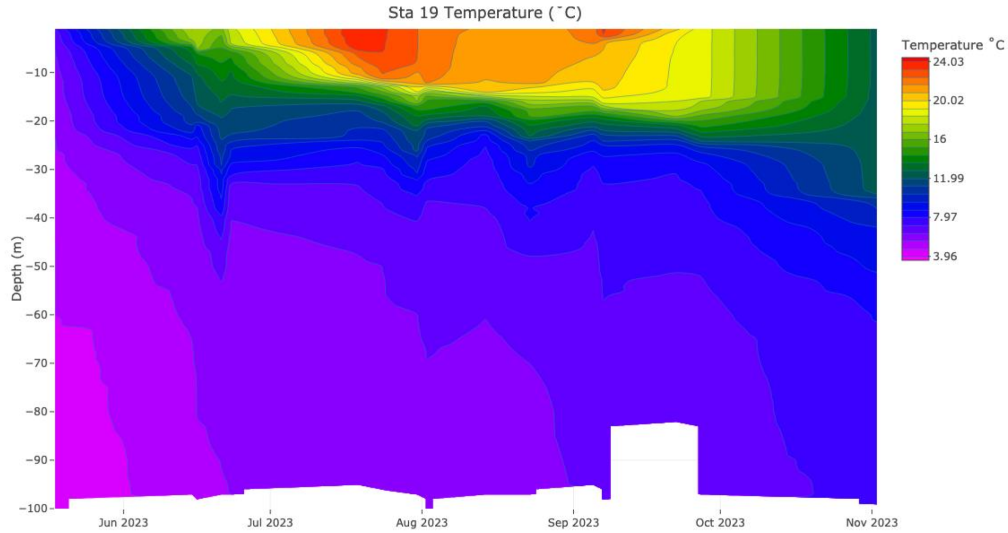
Shelburne Bay



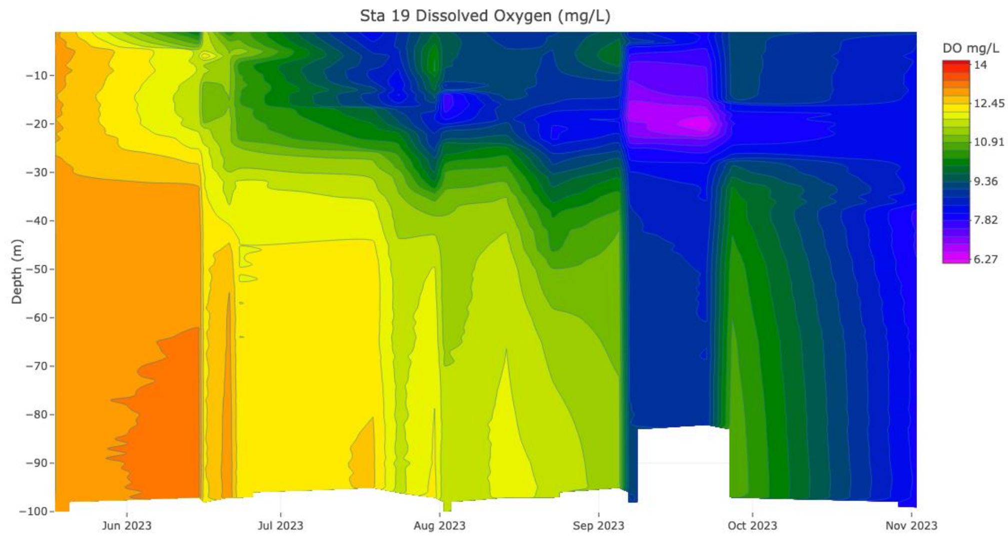




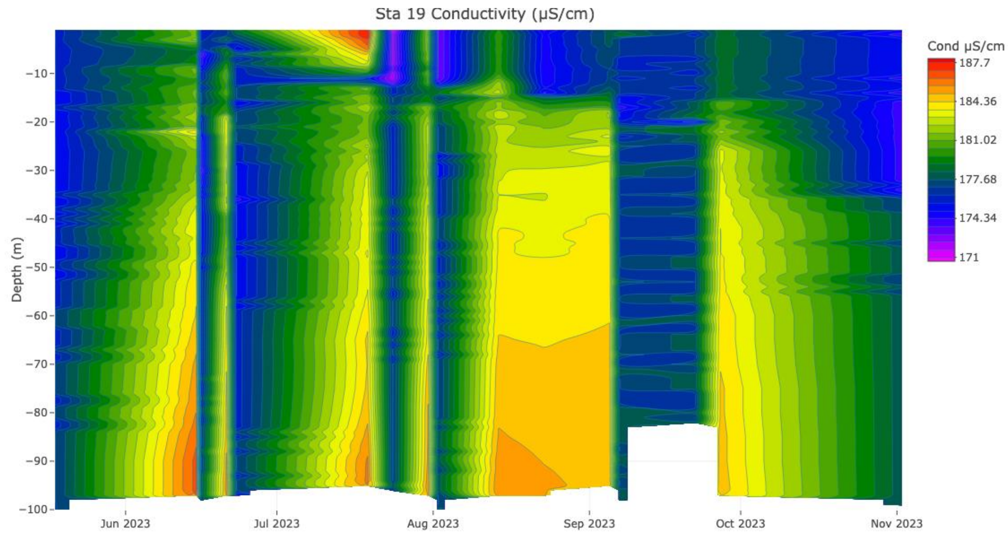
Main Lake



Sta 19 Temperature (˚C)
Temperature ˚C
24.03
20.02
16
11.99
7.97
3.96
Depth (m)
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023

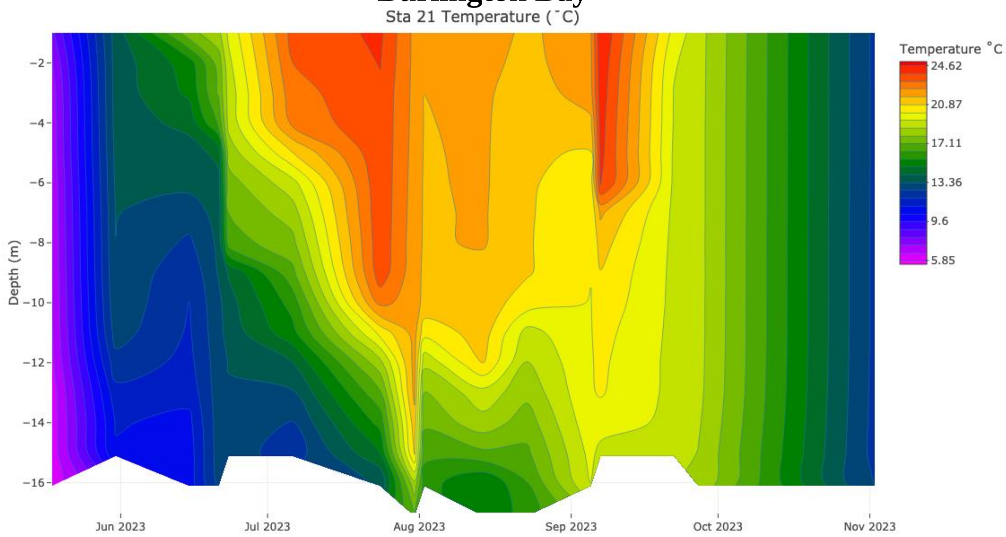


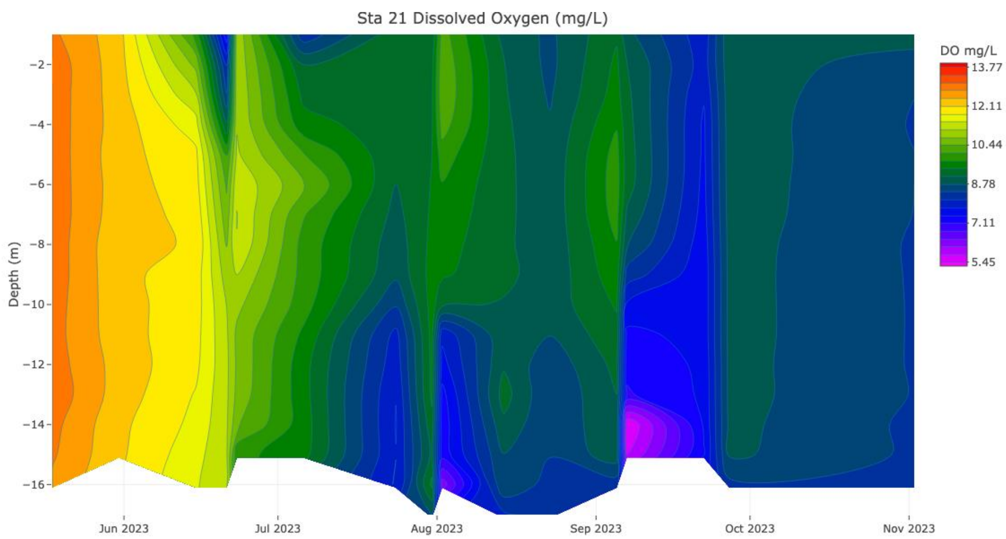
Sta 19 Dissolved Oxygen (mg/L)
DO mg/L
14
12.45
10.91
9.36
7.82
6.27
Depth (m)
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023

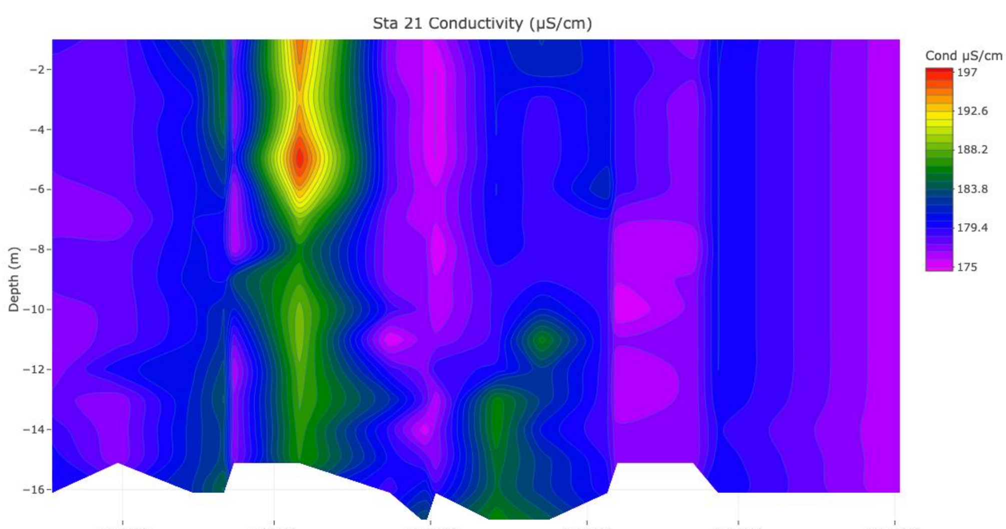


Sta 19 Conductivity (µS/cm)
Cond µS/cm
187.7
184.36
181.02
177.68
174.34
171
Depth (m)
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023

Burlington Bay

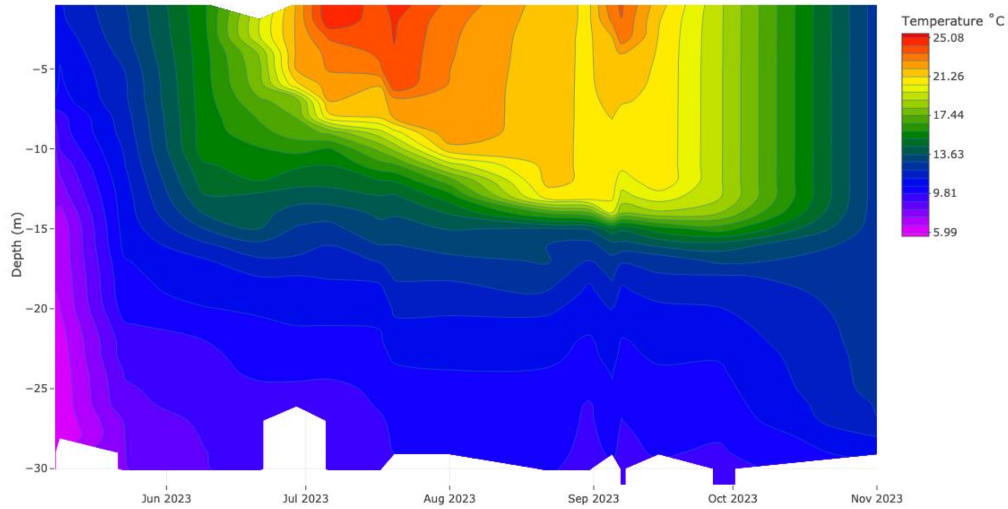




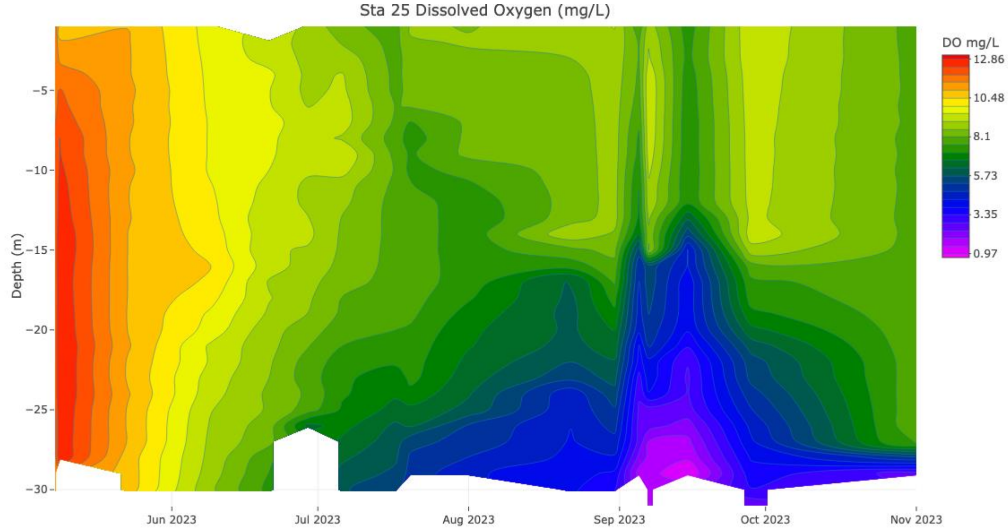


Malletts Bay

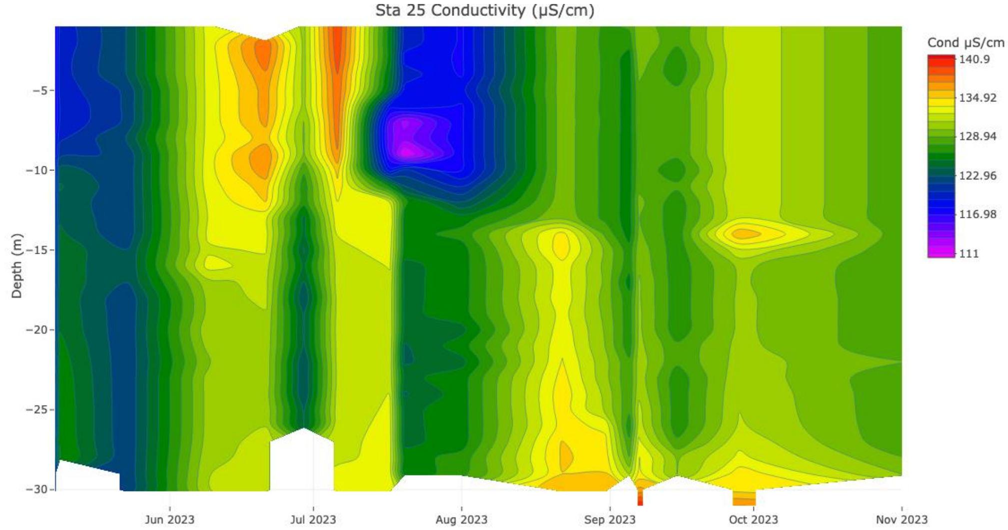
Sta 25 Temperature (˚C)



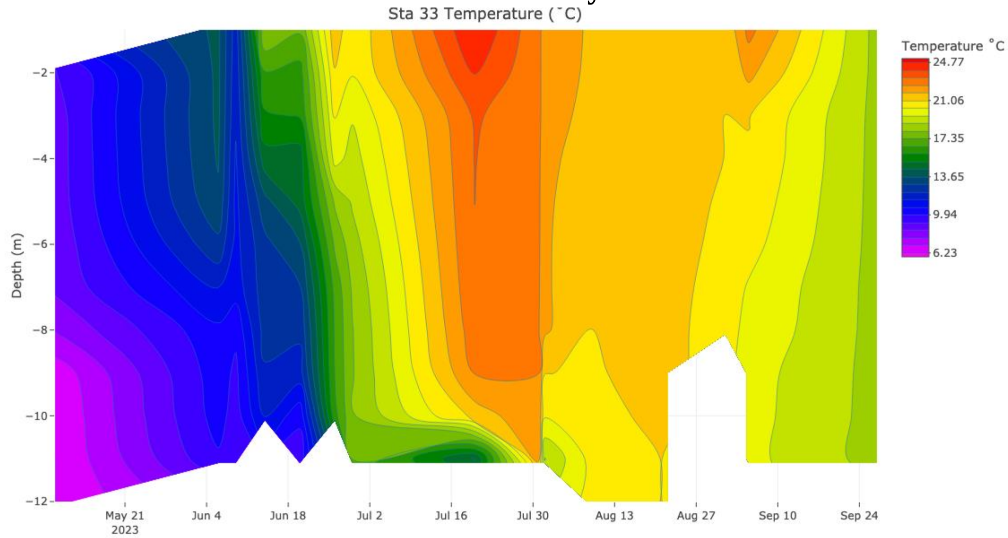
Sta 25 Dissolved Oxygen (mg/L)

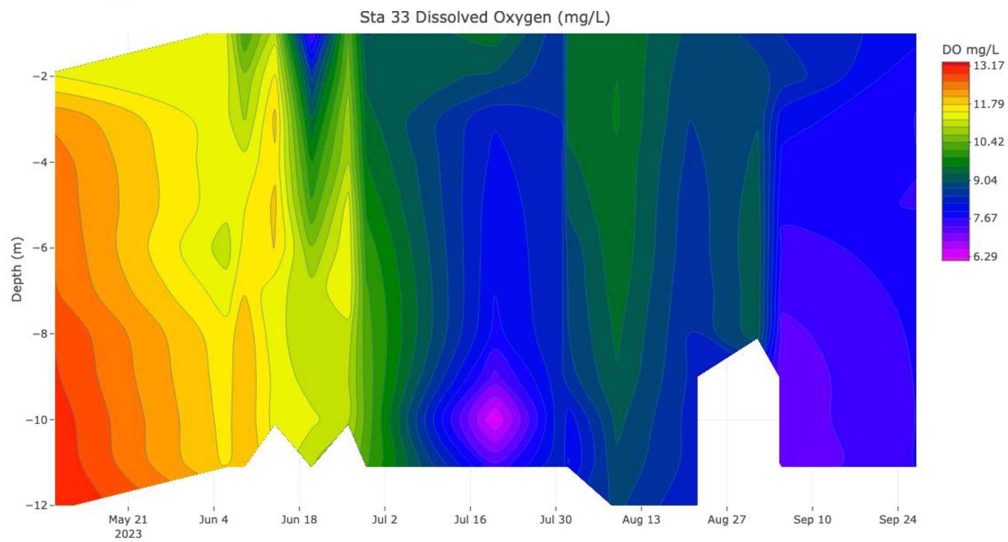


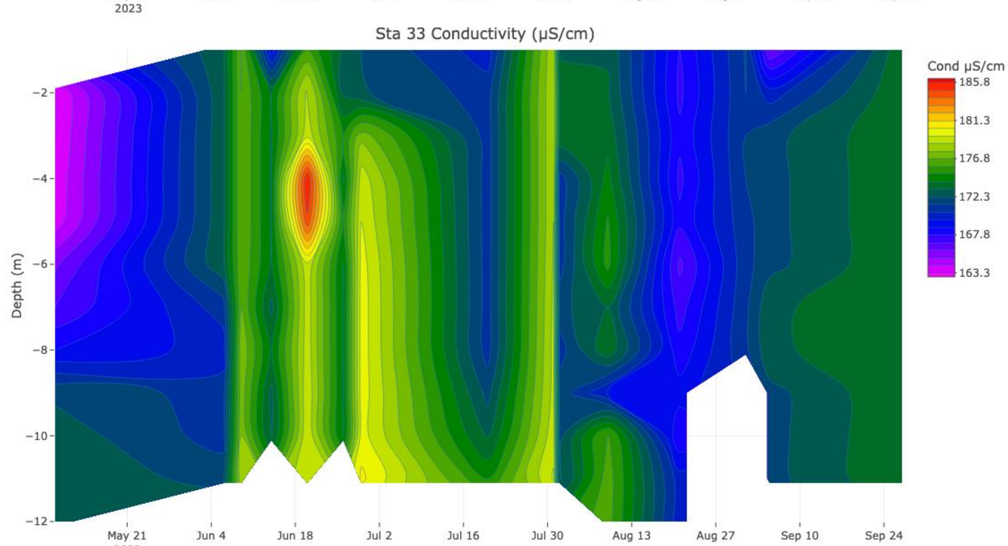
Sta 25 Conductivity (µS/cm)



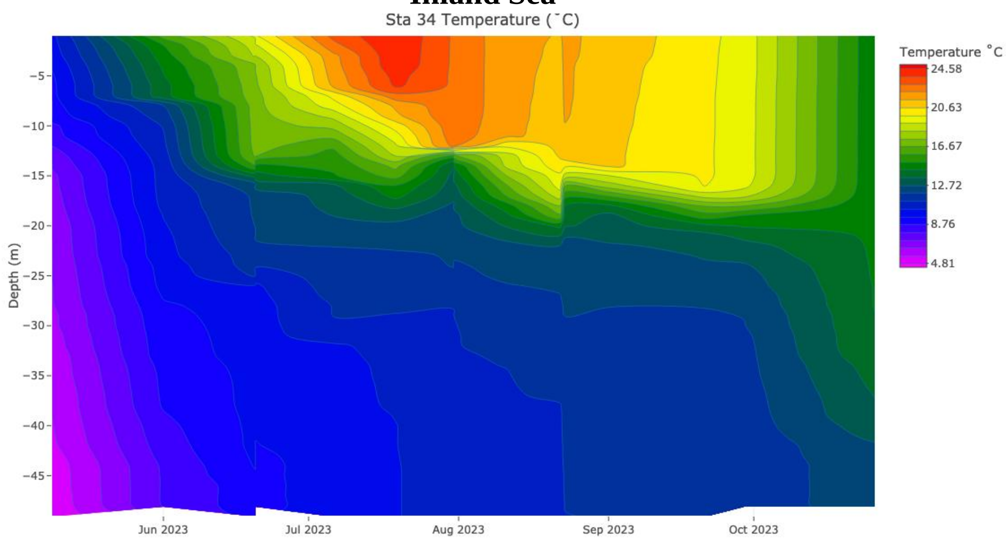
Cumberland Bay

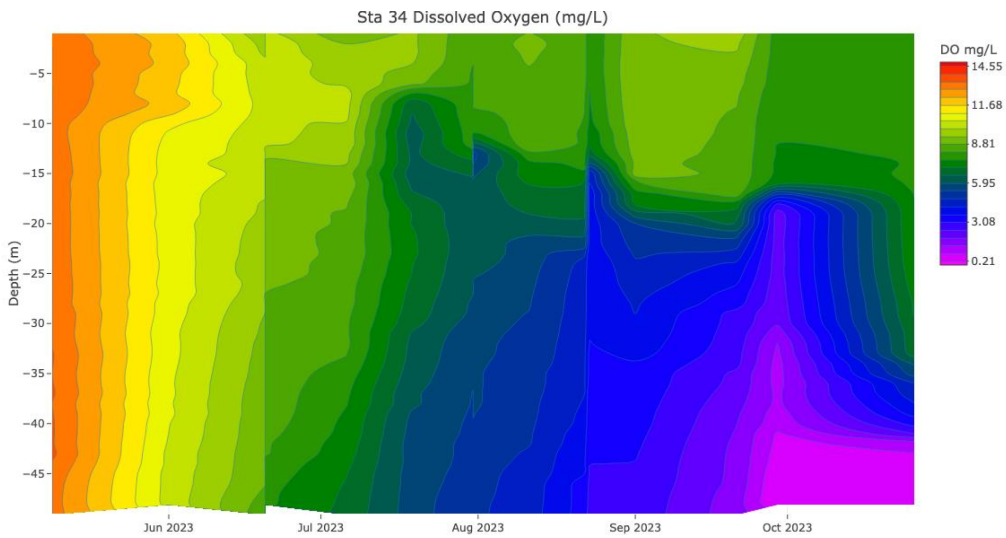


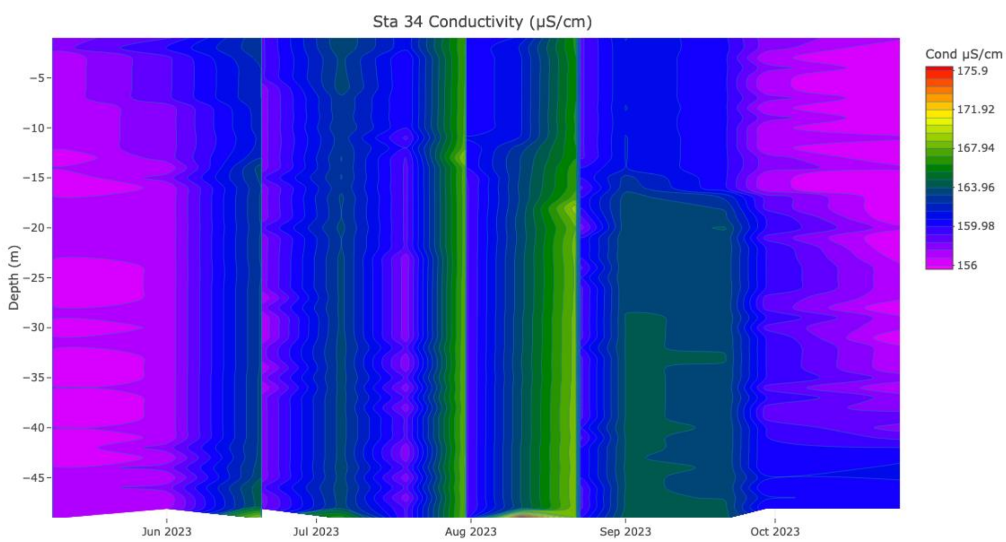




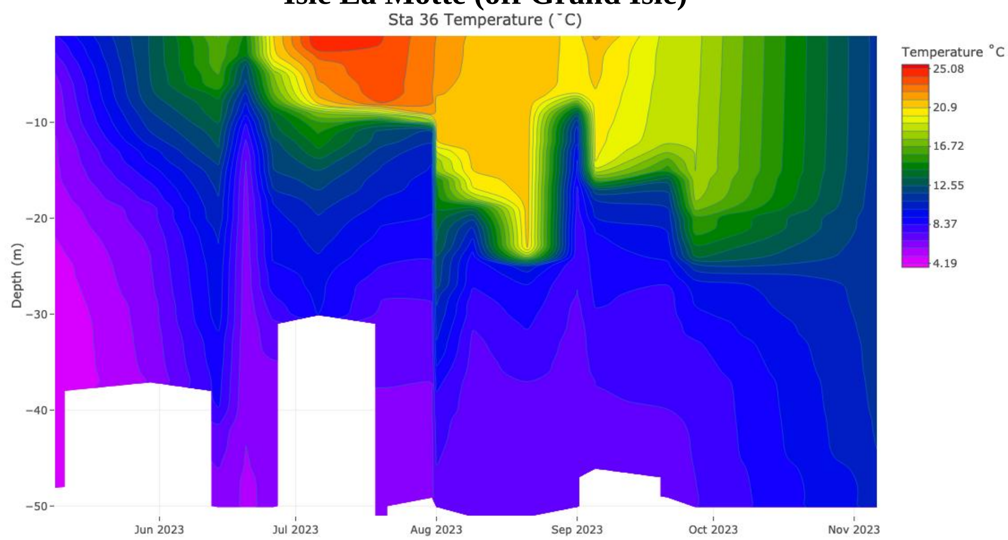
Inland Sea

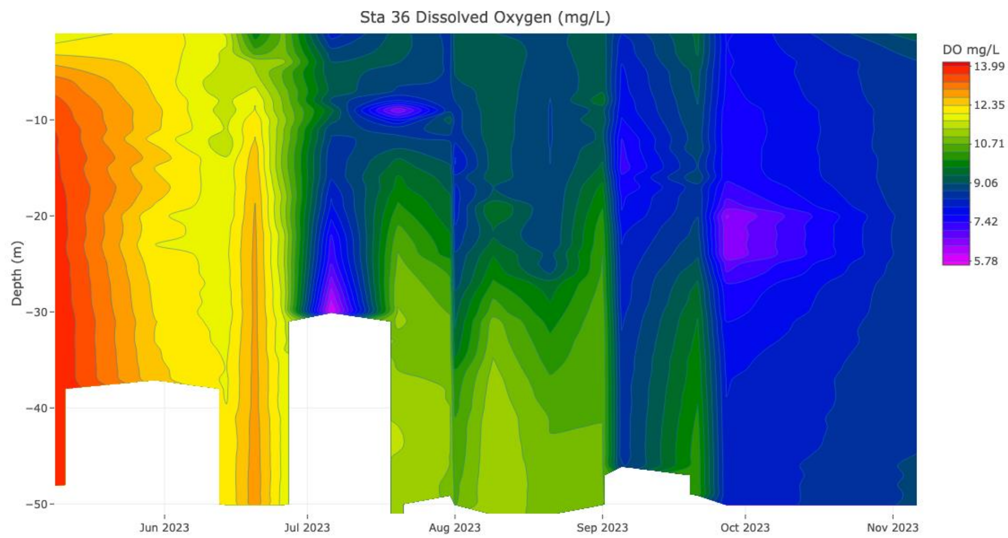

Sta 34 Temperature (˚C)
Temperature ˚C
24.58
20.63
16.67
12.72
8.76
4.81
Depth (m)
−5
−10
−15
−20
−25
−30
−35
−40
−45
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023

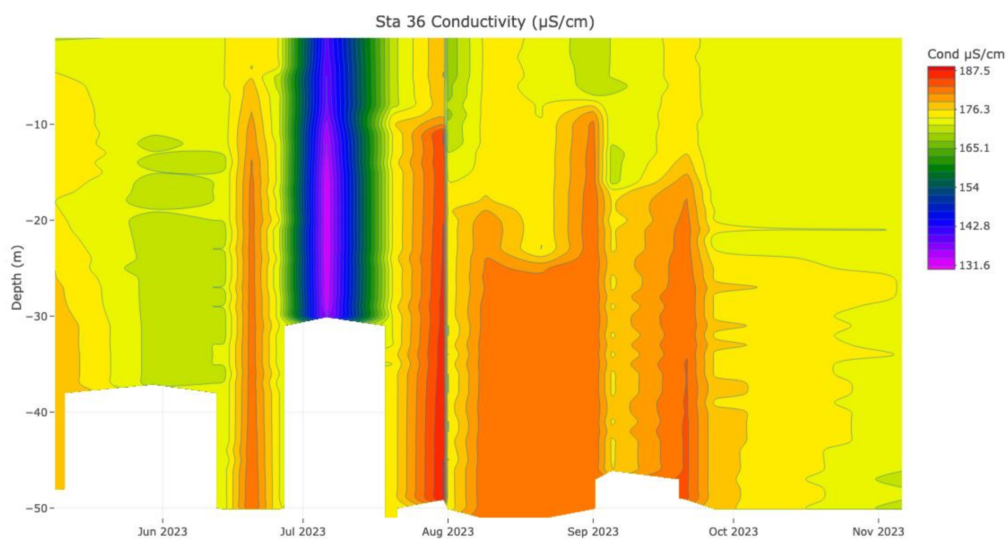

Sta 34 Dissolved Oxygen (mg/L)
DO mg/L
14.55
11.68
8.81
5.95
3.08
0.21
Depth (m)
−5
−10
−15
−20
−25
−30
−35
−40
−45
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023


Sta 34 Conductivity (μS/cm)
Cond μS/cm
175.9
171.92
167.94
163.96
159.98
156
Depth (m)
−5
−10
−15
−20
−25
−30
−35
−40
−45
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023

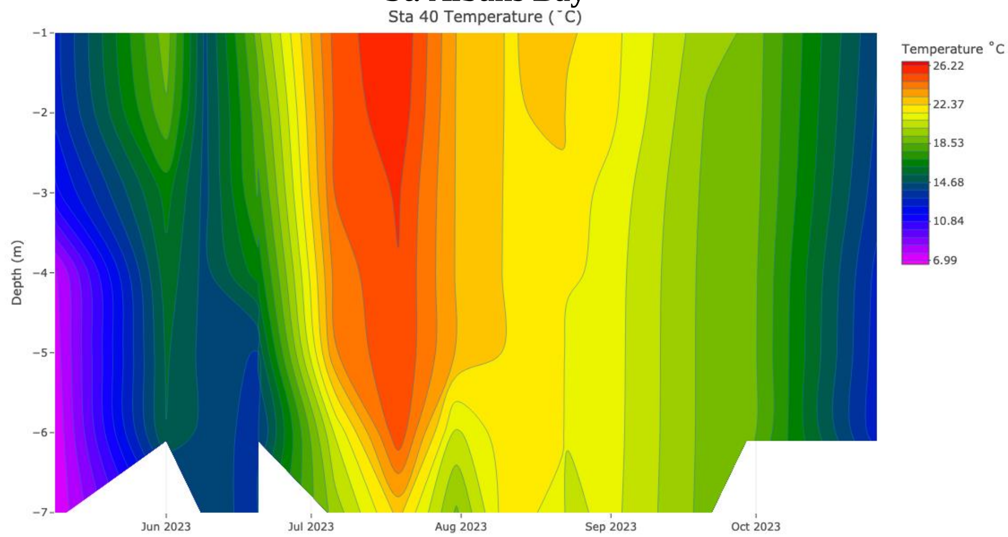
Isle La Motte (off Grand Isle)

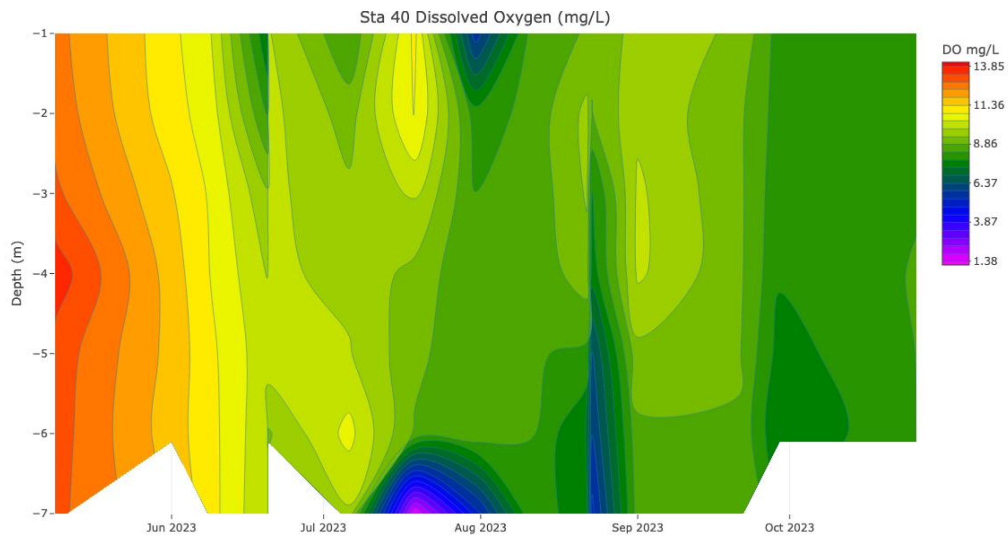


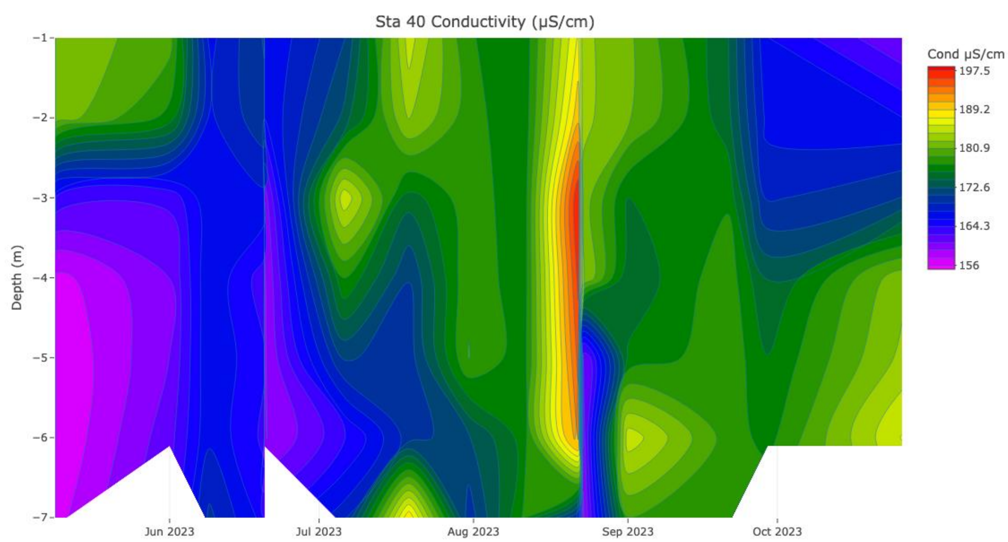




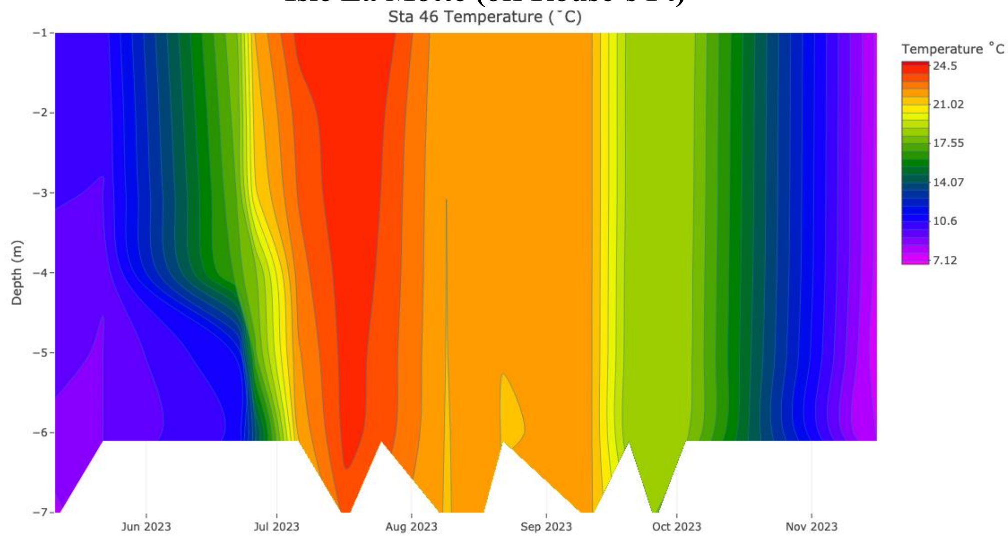
St. Albans Bay

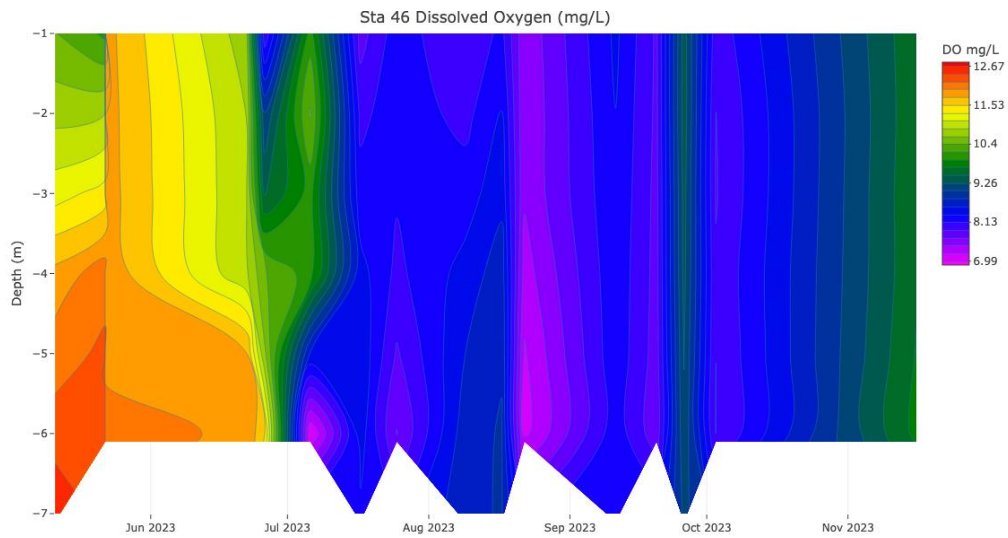


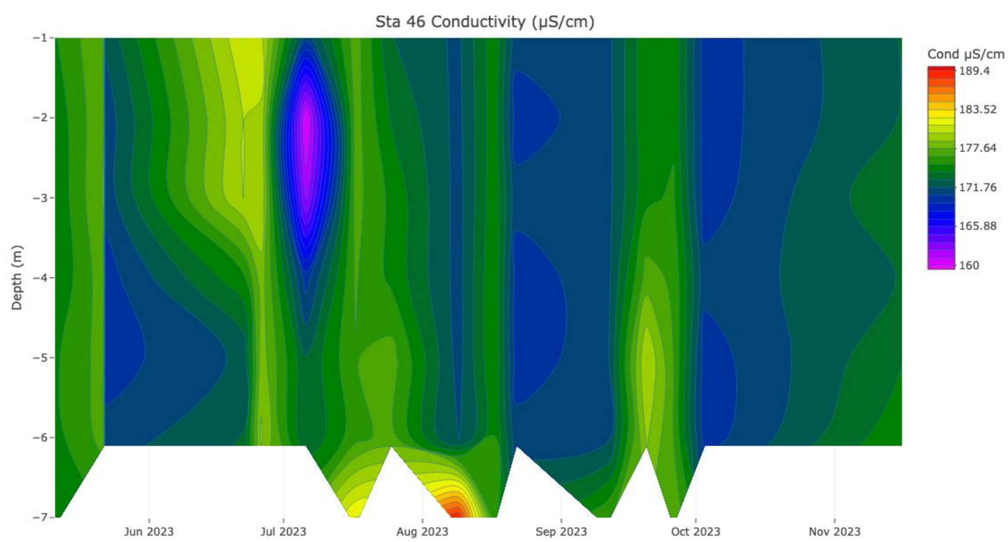




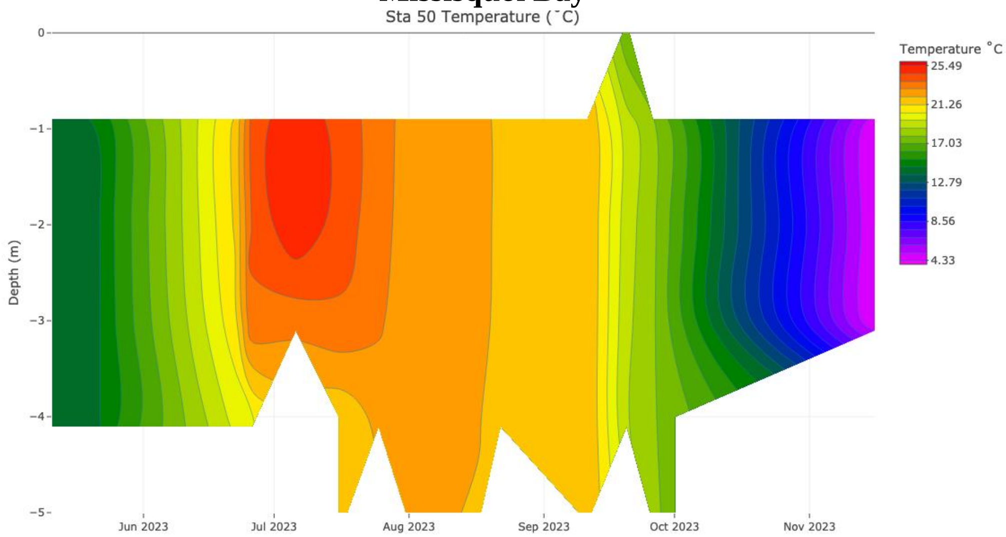
Isle La Motte (off Rouse's Pt)

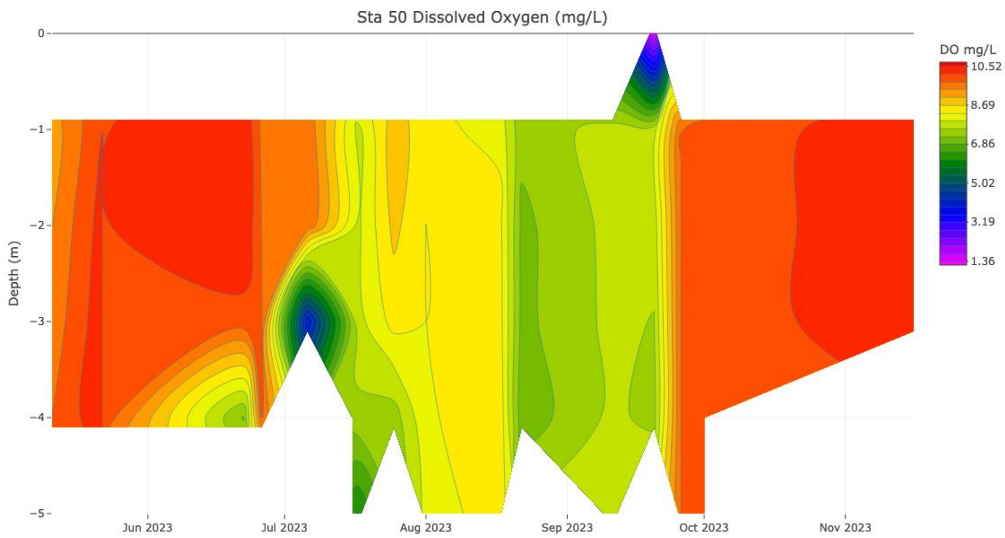


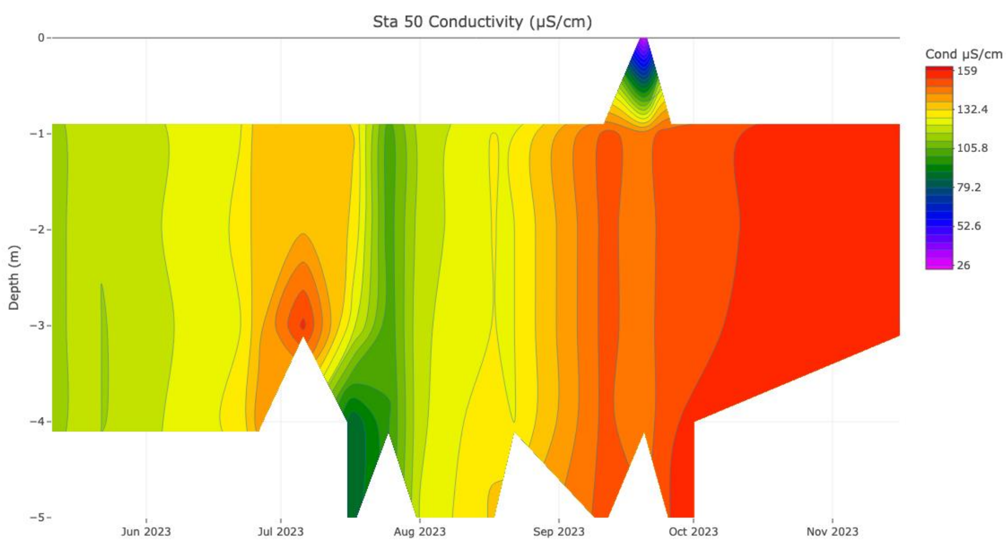




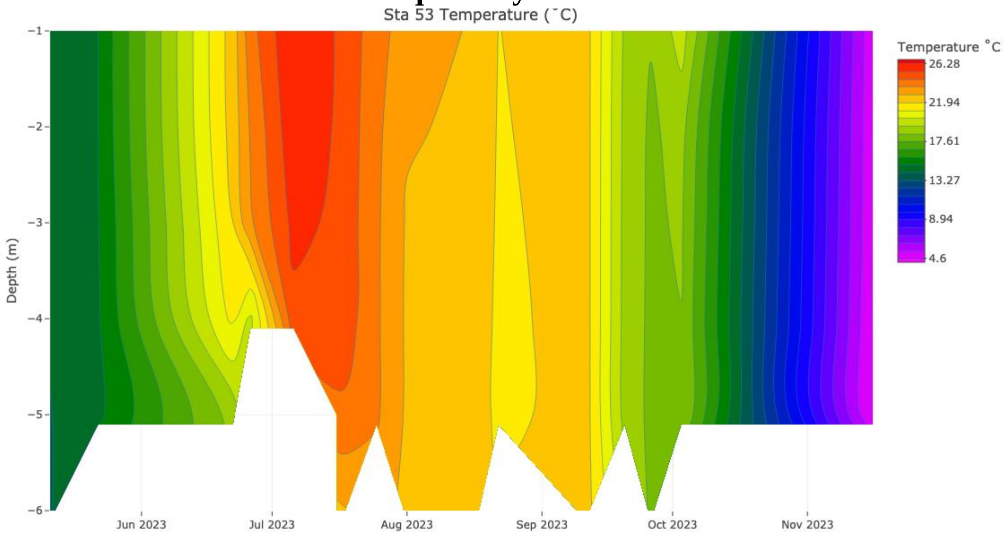
Missisquoi Bay

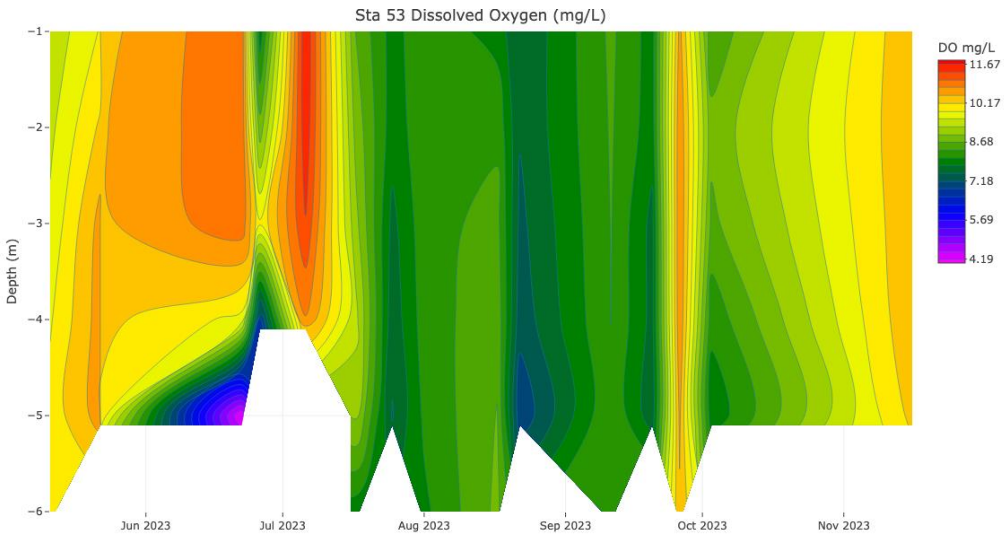


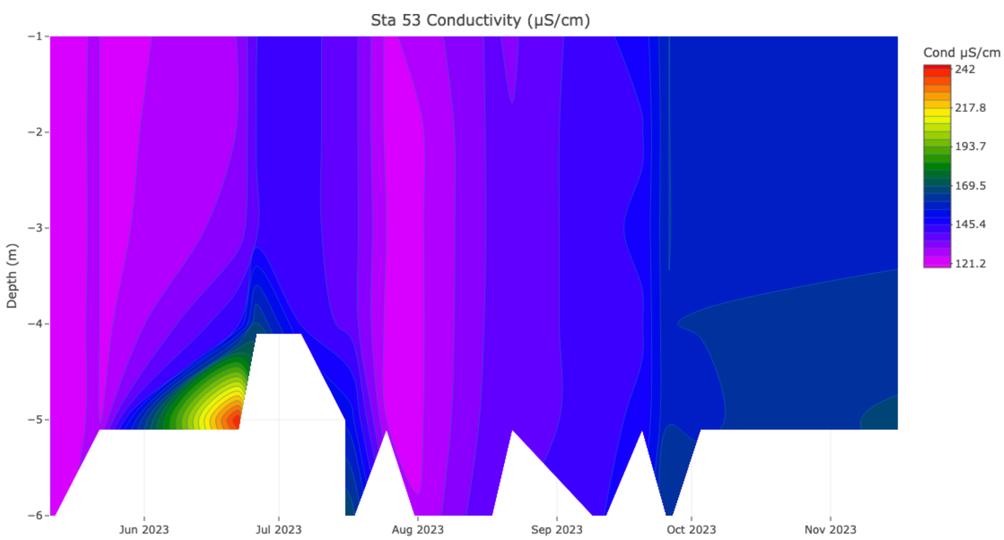




Missisquoi Bay Central

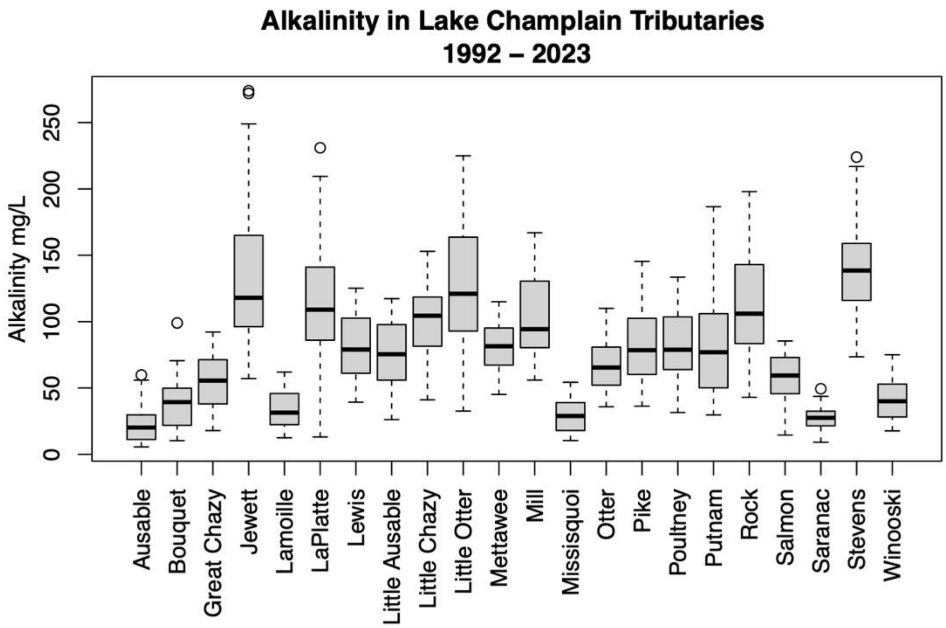


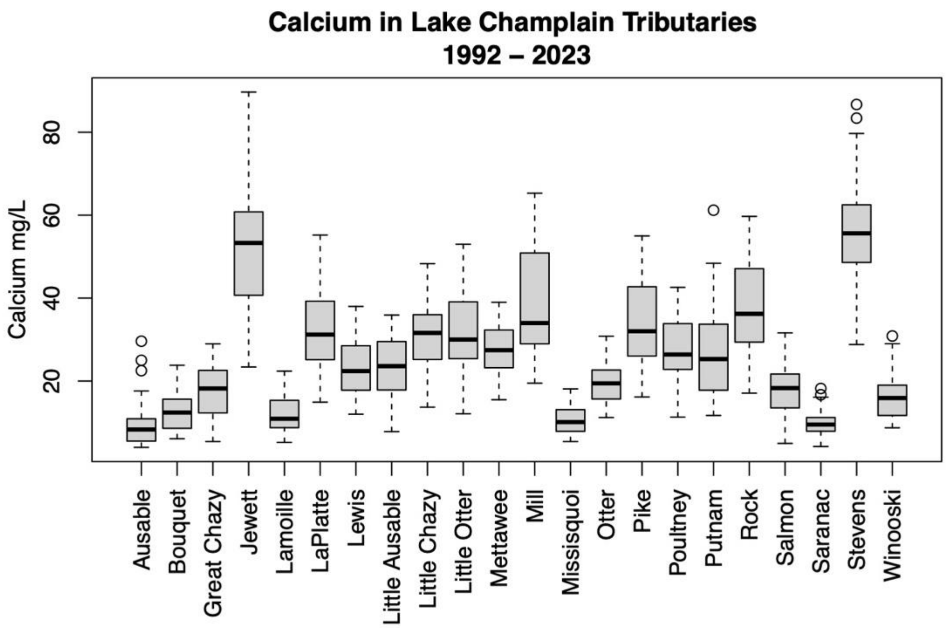




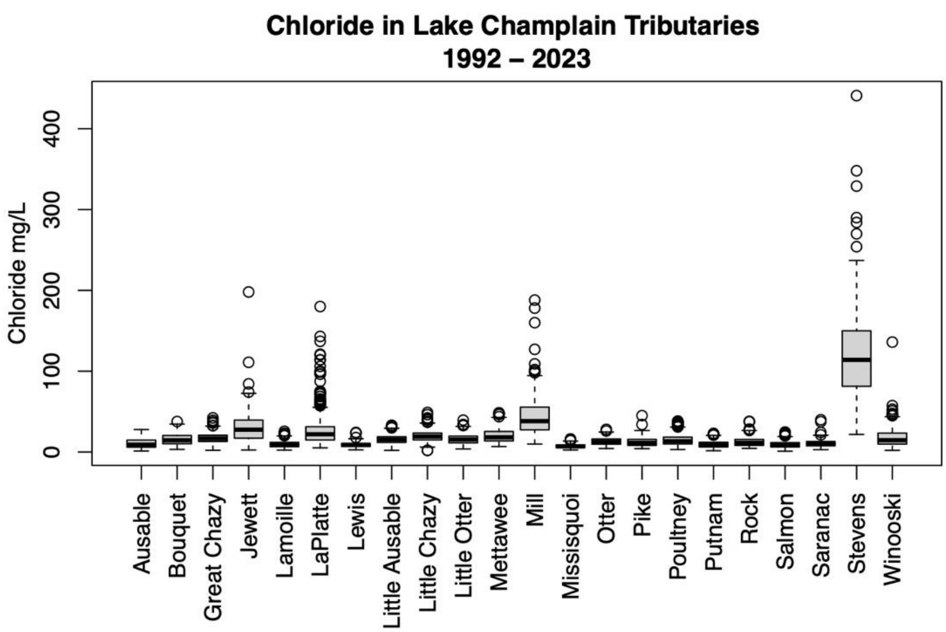
Appendix D. Lake Champlain Tributary Monitoring Data Figures

Fig. C1: Total solute concentrations in Vermont tributaries. Concentrations are not adjusted for flow. The center line of the boxplot represents the median concentration (50th percentile). The bottom and top of the box represent the 25th and 75th quantiles of the data, respectively, and the lower and upper whiskers represent the 10th and 90th percentiles of the data. All available data from each site are used in the boxplots, for most sites from 1992-2023. Sampling began at Steven's Brook and Mill River in 2008, at the Rock River in 2007, and at the Mill River in 2010. Sampling at Putnam Creek was discontinued in 2019.

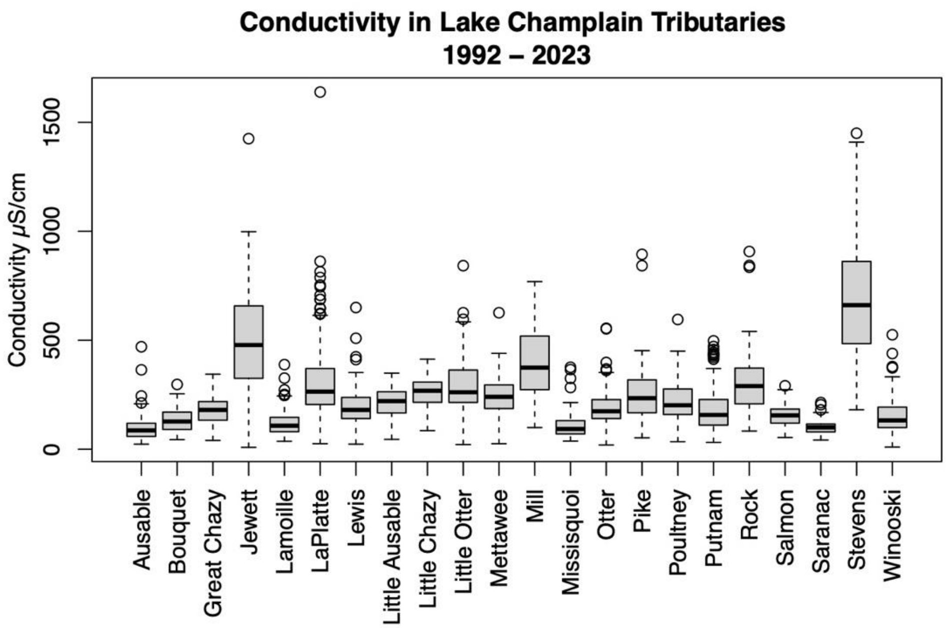


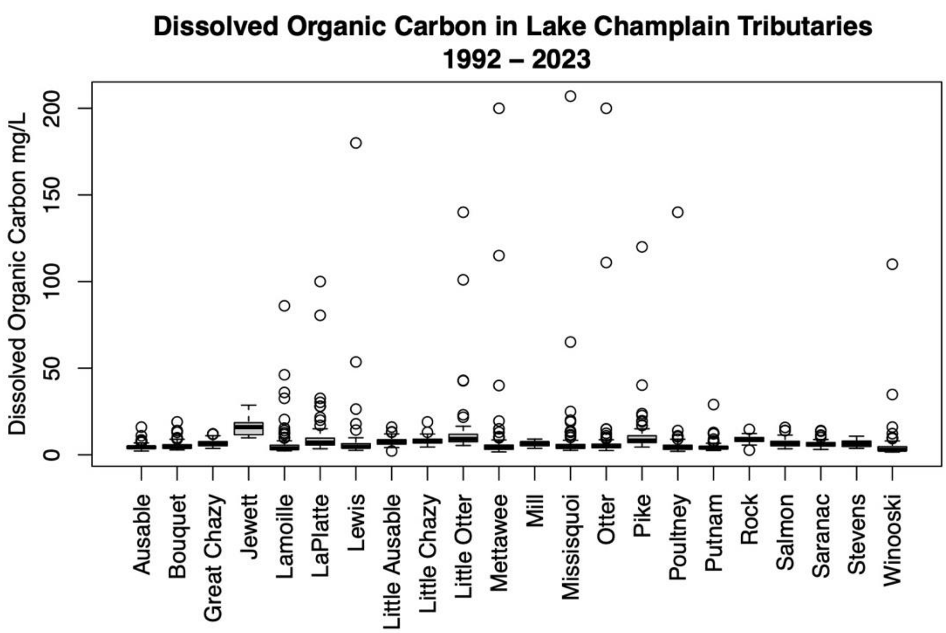


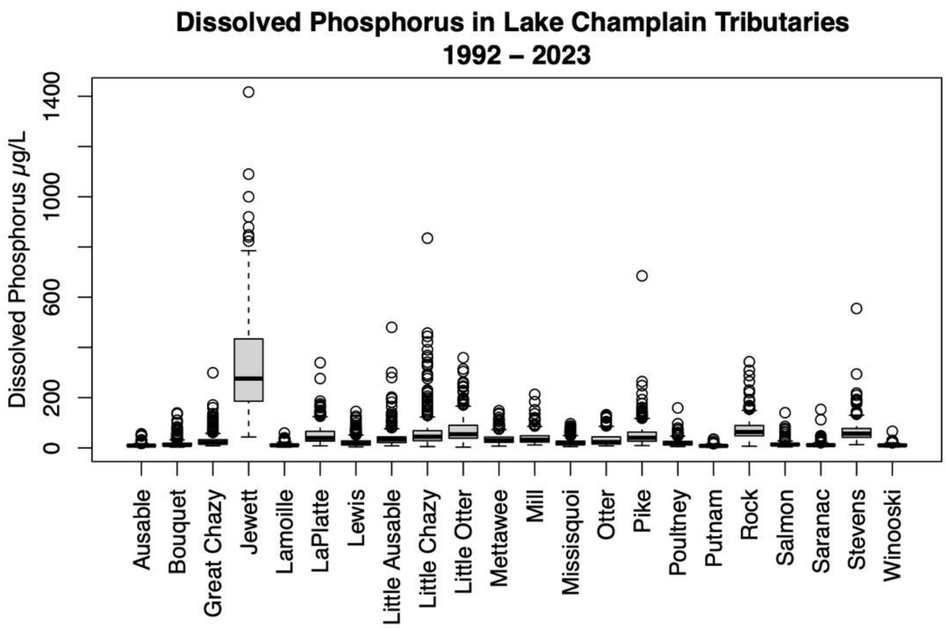
Calcium in Lake Champlain Tributaries
1992 – 2023
Calcium mg/L
20
40
60
80
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

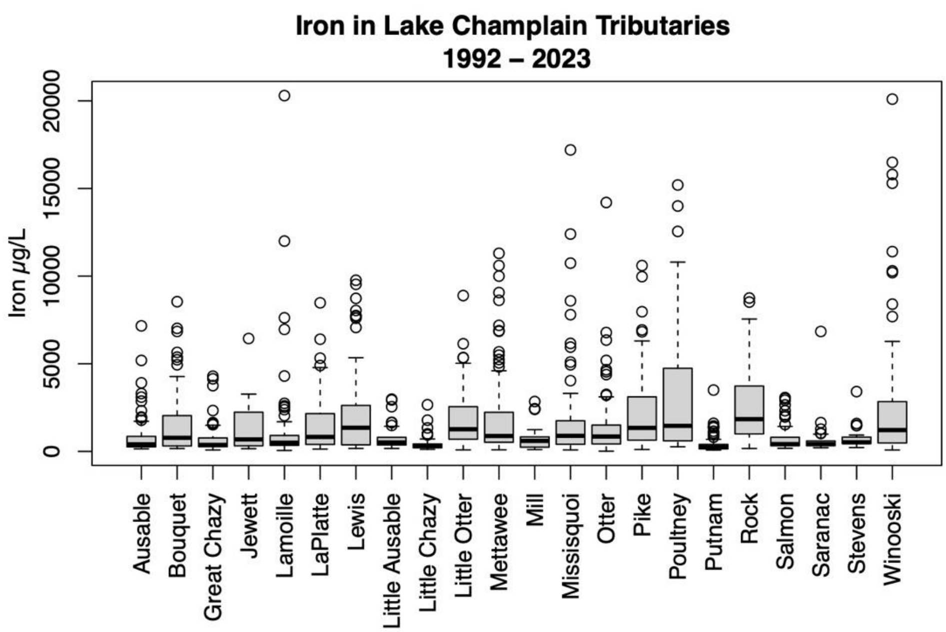


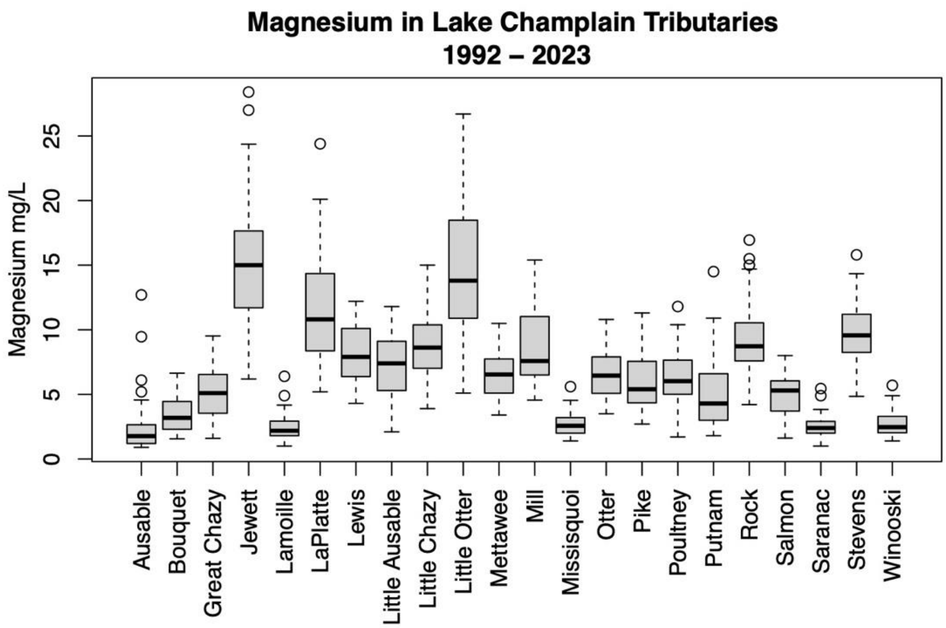
Chloride in Lake Champlain Tributaries
1992 – 2023
Chloride mg/L
0
100
200
300
400
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

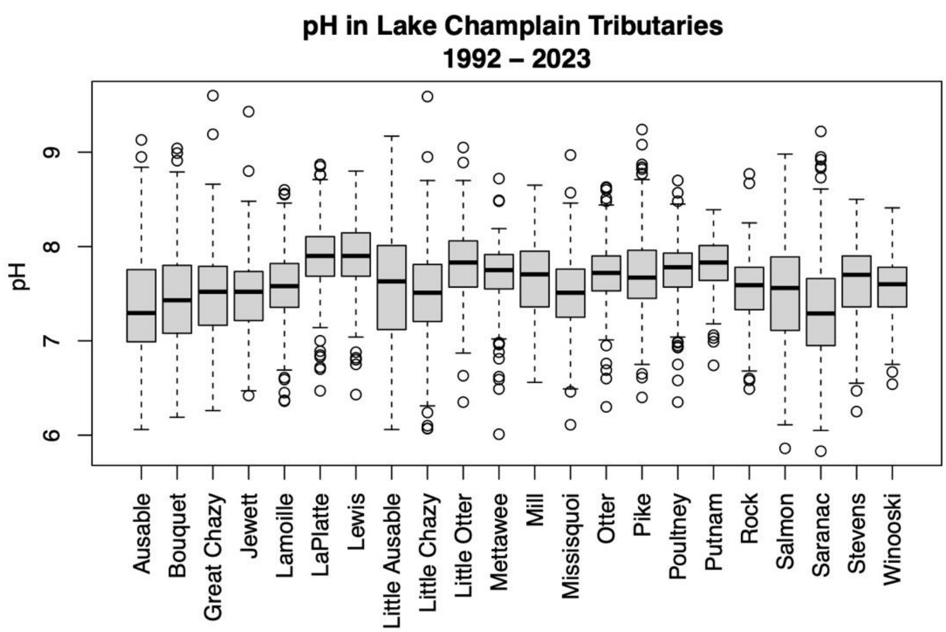

Conductivity in Lake Champlain Tributaries
1992 – 2023
Conductivity μS/cm
0
500
1000
1500
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

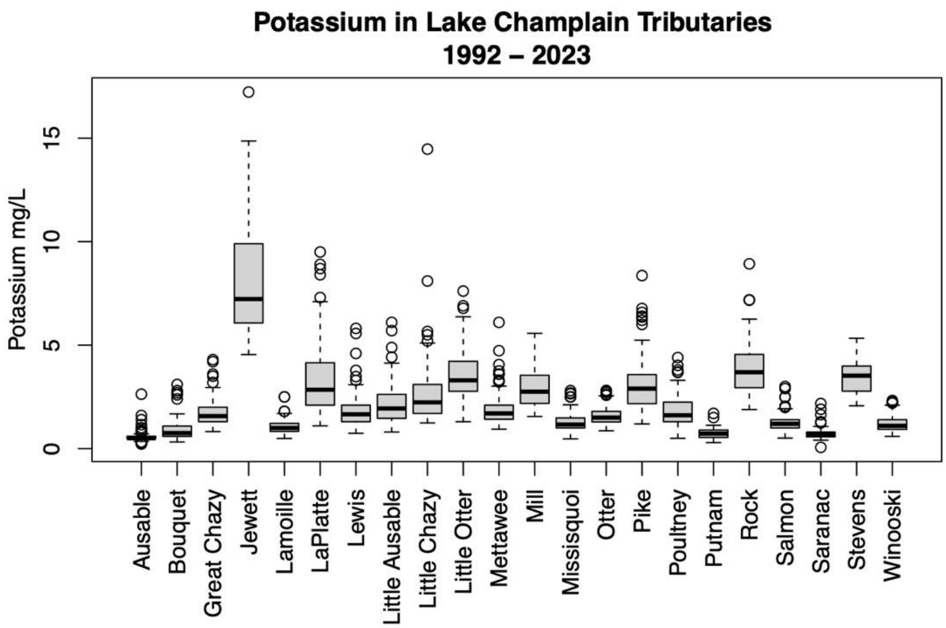

Dissolved Organic Carbon in Lake Champlain Tributaries
1992 – 2023
Dissolved Organic Carbon mg/L
0
50
100
150
200
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

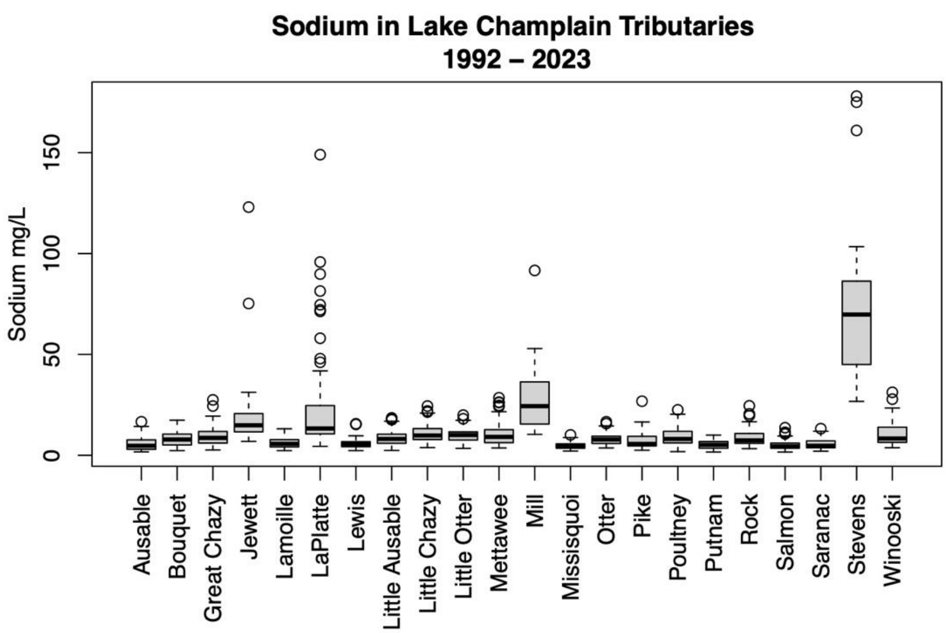

Dissolved Phosphorus in Lake Champlain Tributaries
1992 – 2023
Dissolved Phosphorus μg/L
0
200
600
1000
1400
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

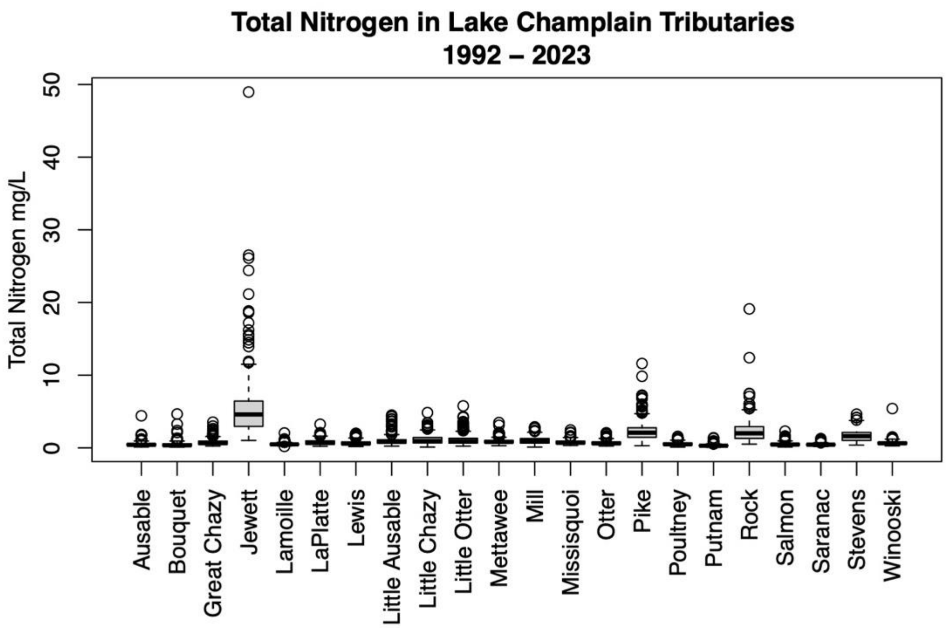

Iron in Lake Champlain Tributaries
1992 – 2023
Iron μg/L
0
5000
10000
15000
20000
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

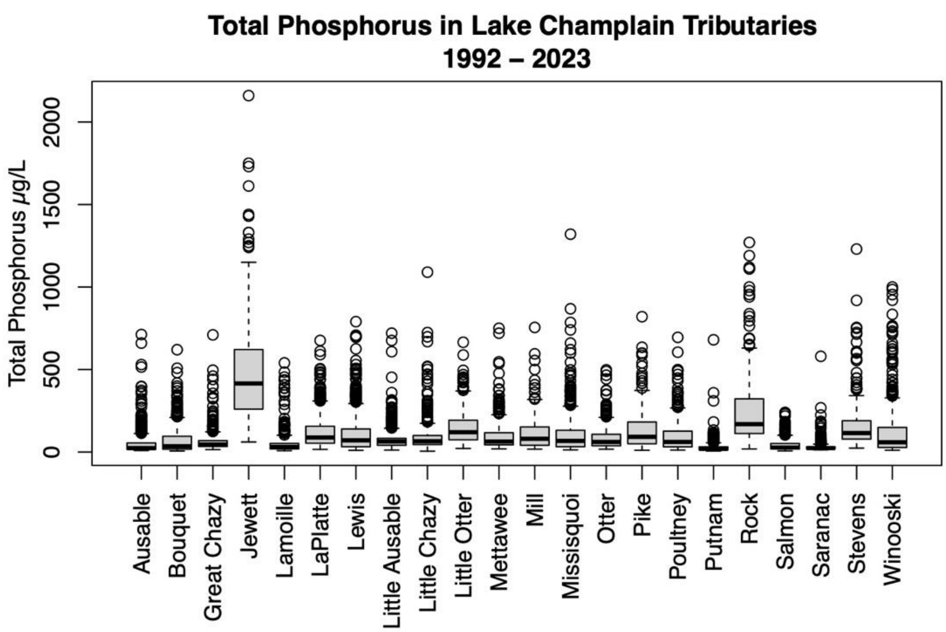

Magnesium in Lake Champlain Tributaries
1992 – 2023
Magnesium mg/L
0
5
10
15
20
25
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

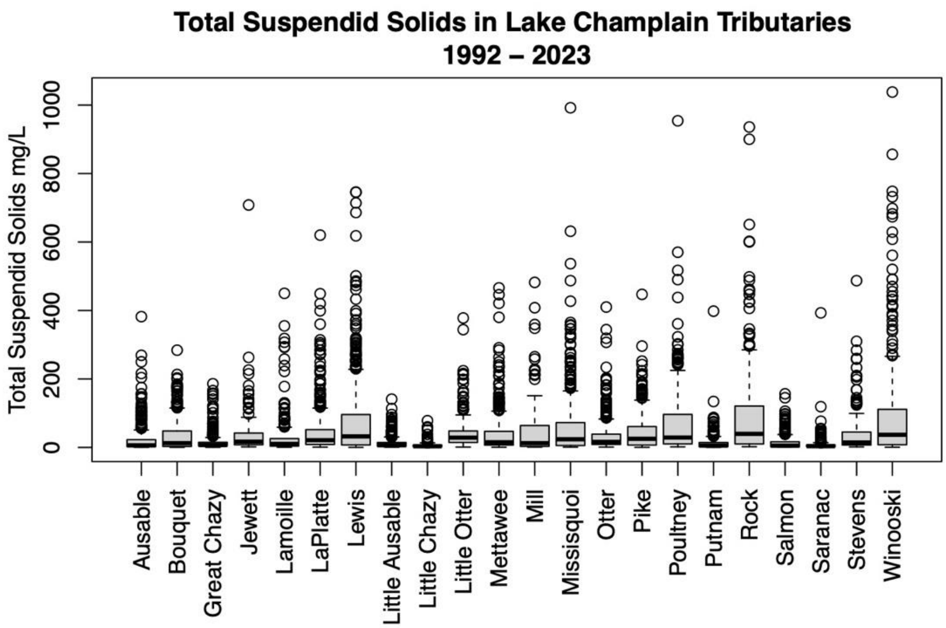

pH in Lake Champlain Tributaries
1992 – 2023
pH
6
7
8
9
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski


Potassium in Lake Champlain Tributaries
1992 – 2023
Potassium mg/L
0
5
10
15
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski


Sodium in Lake Champlain Tributaries
1992 – 2023
Sodium mg/L
0
50
100
150
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski


Total Nitrogen in Lake Champlain Tributaries
1992 – 2023
Total Nitrogen mg/L
0
10
20
30
40
50
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

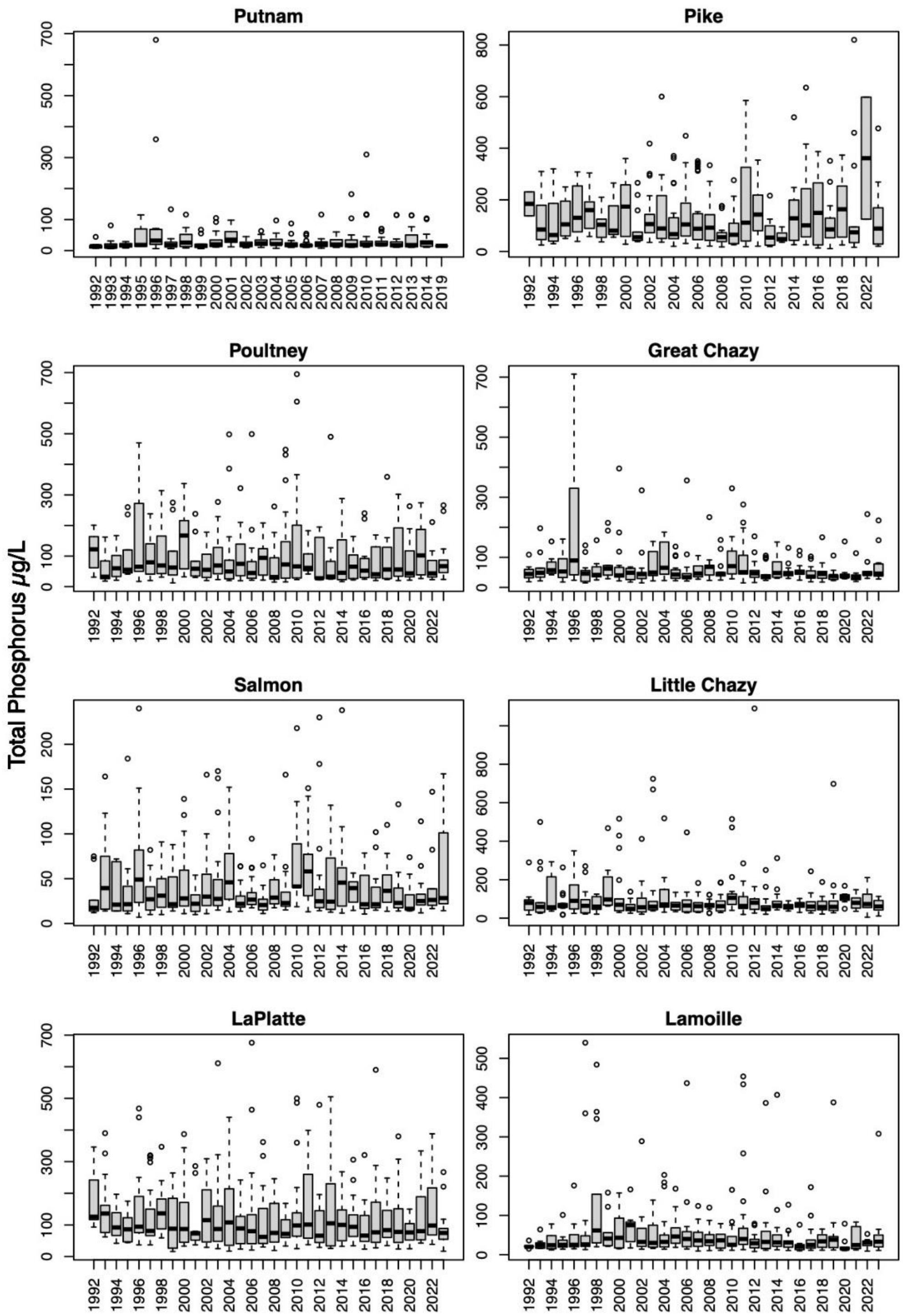

Total Phosphorus in Lake Champlain Tributaries
1992 – 2023
Total Phosphorus μg/L
0
500
1000
1500
2000
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

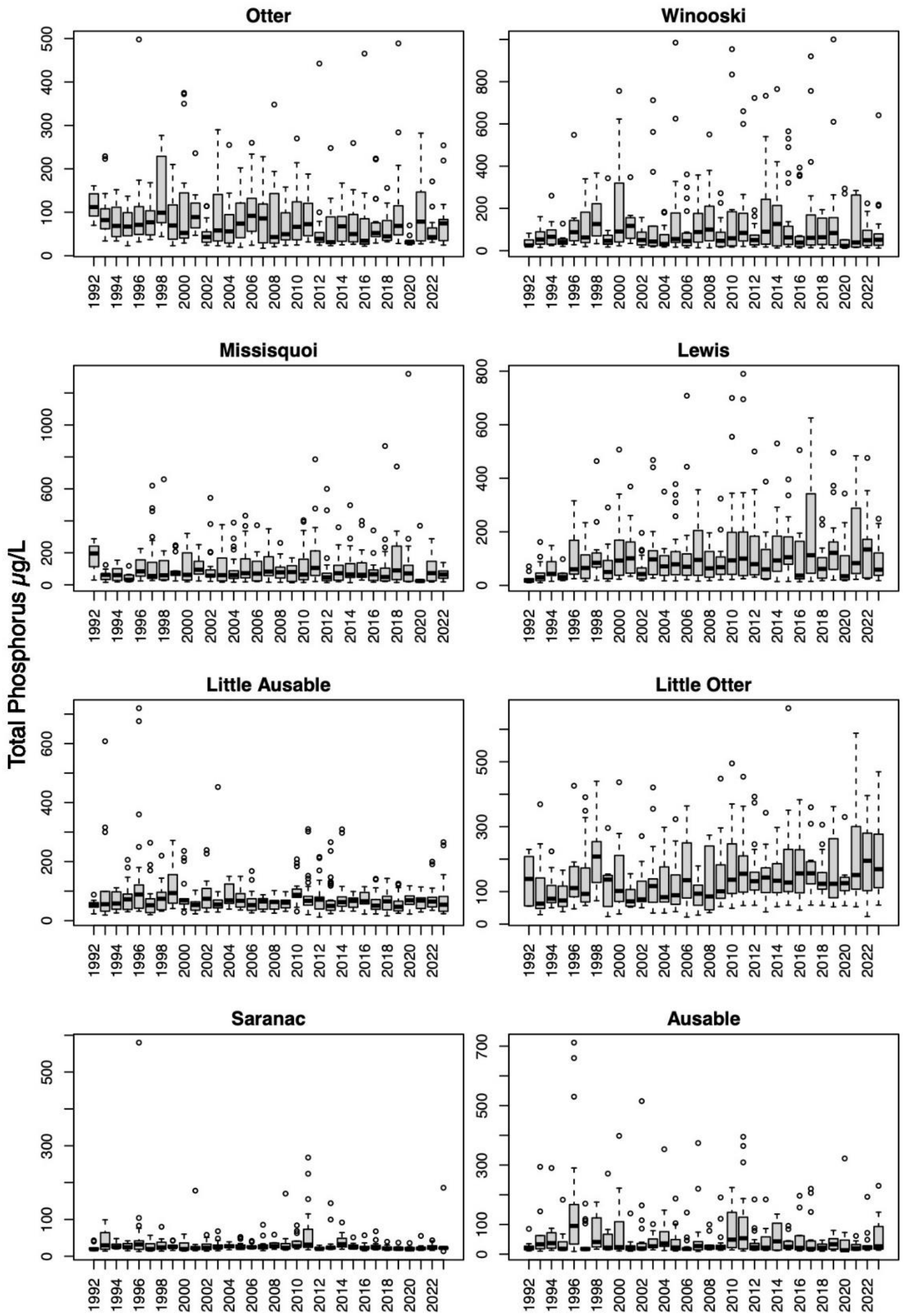


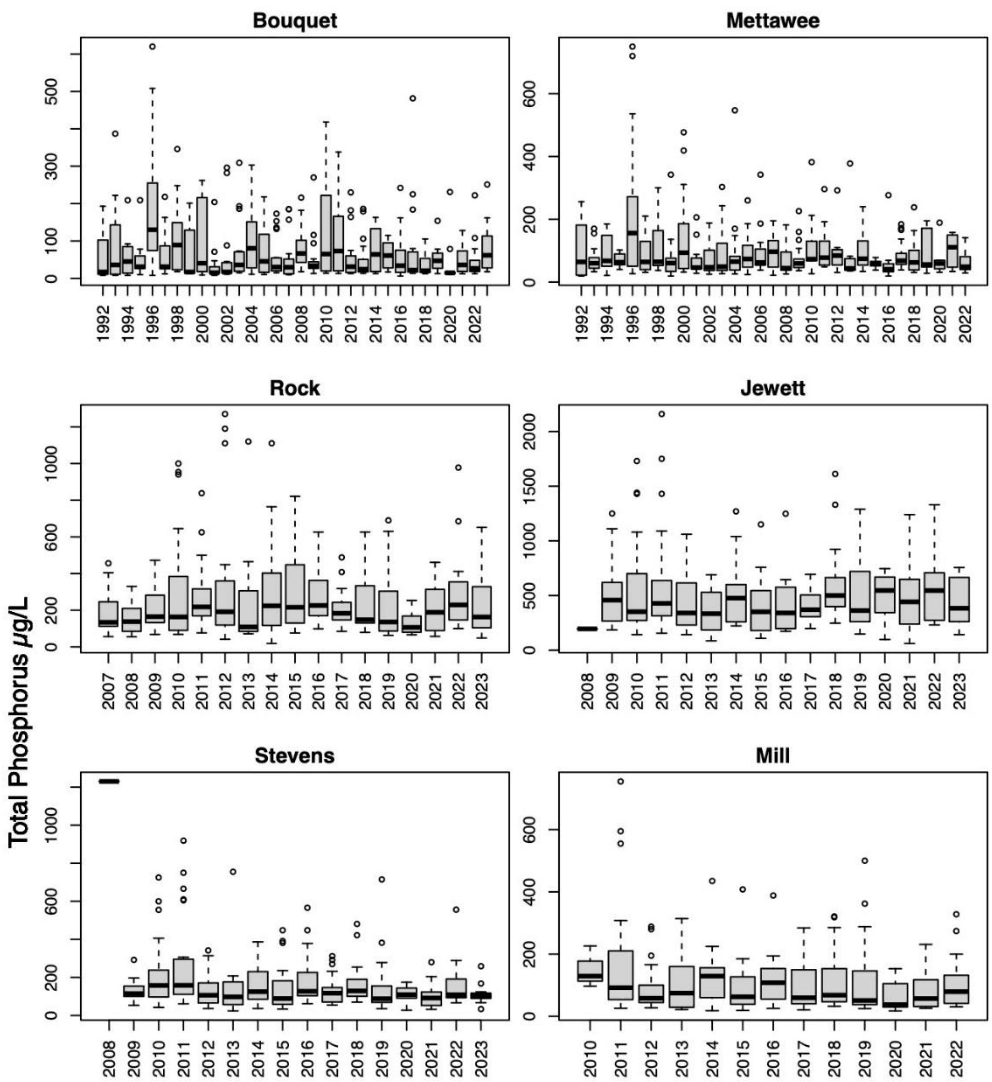
Total Suspendid Solids in Lake Champlain Tributaries
1992 – 2023
Total Suspendid Solids mg/L
0
200
400
600
800
1000
Ausable
Bouquet
Great Chazy
Jewett
Lamoille
LaPlatte
Lewis
Little Ausable
Little Chazy
Little Otter
Mettawee
Mill
Missisquoi
Otter
Pike
Poultney
Putnam
Rock
Salmon
Saranac
Stevens
Winooski

Figure C2: Boxplots of tributary concentrations for individual tributaries by year for selected analytes.

Total Phosphorus

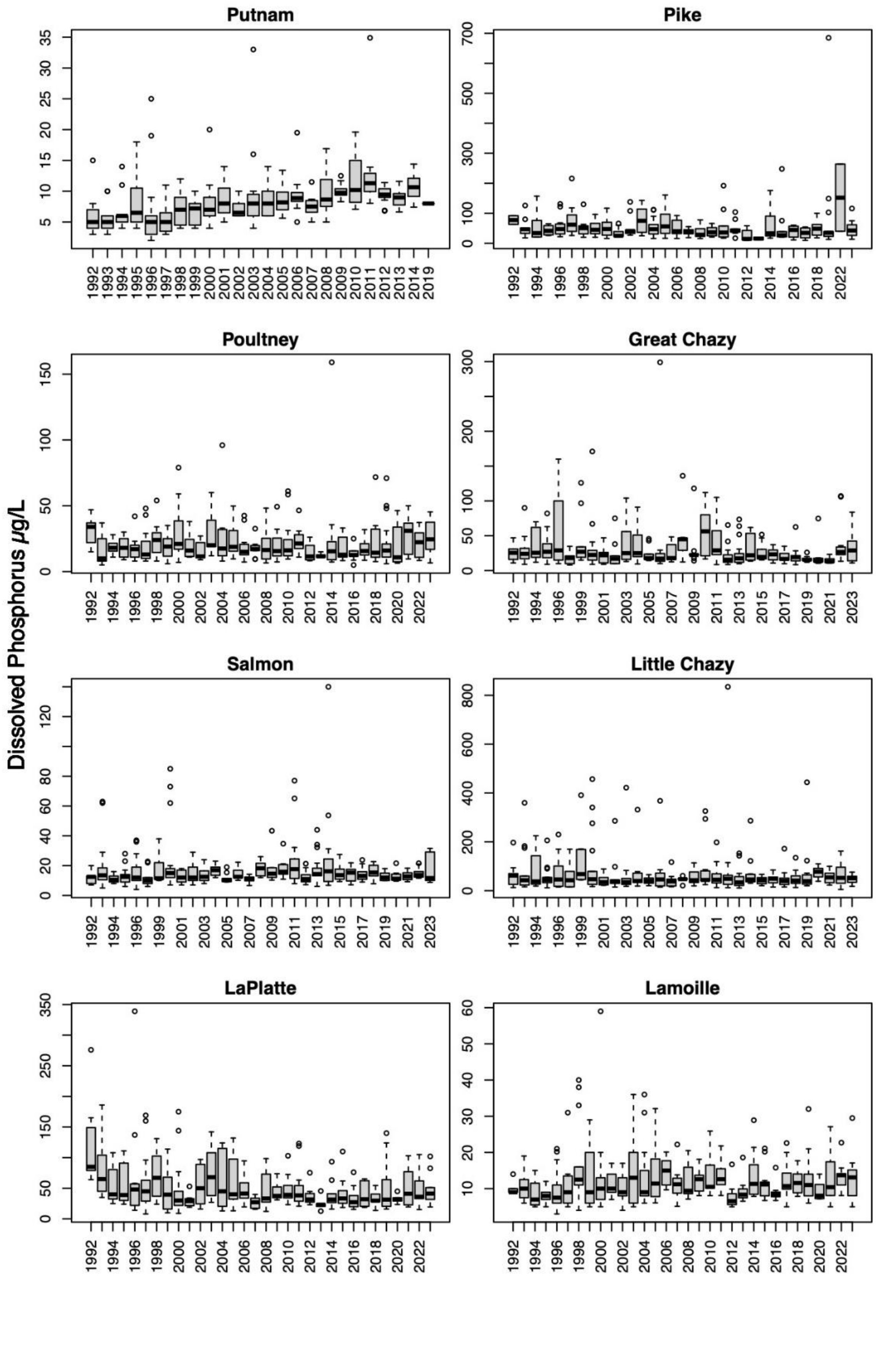


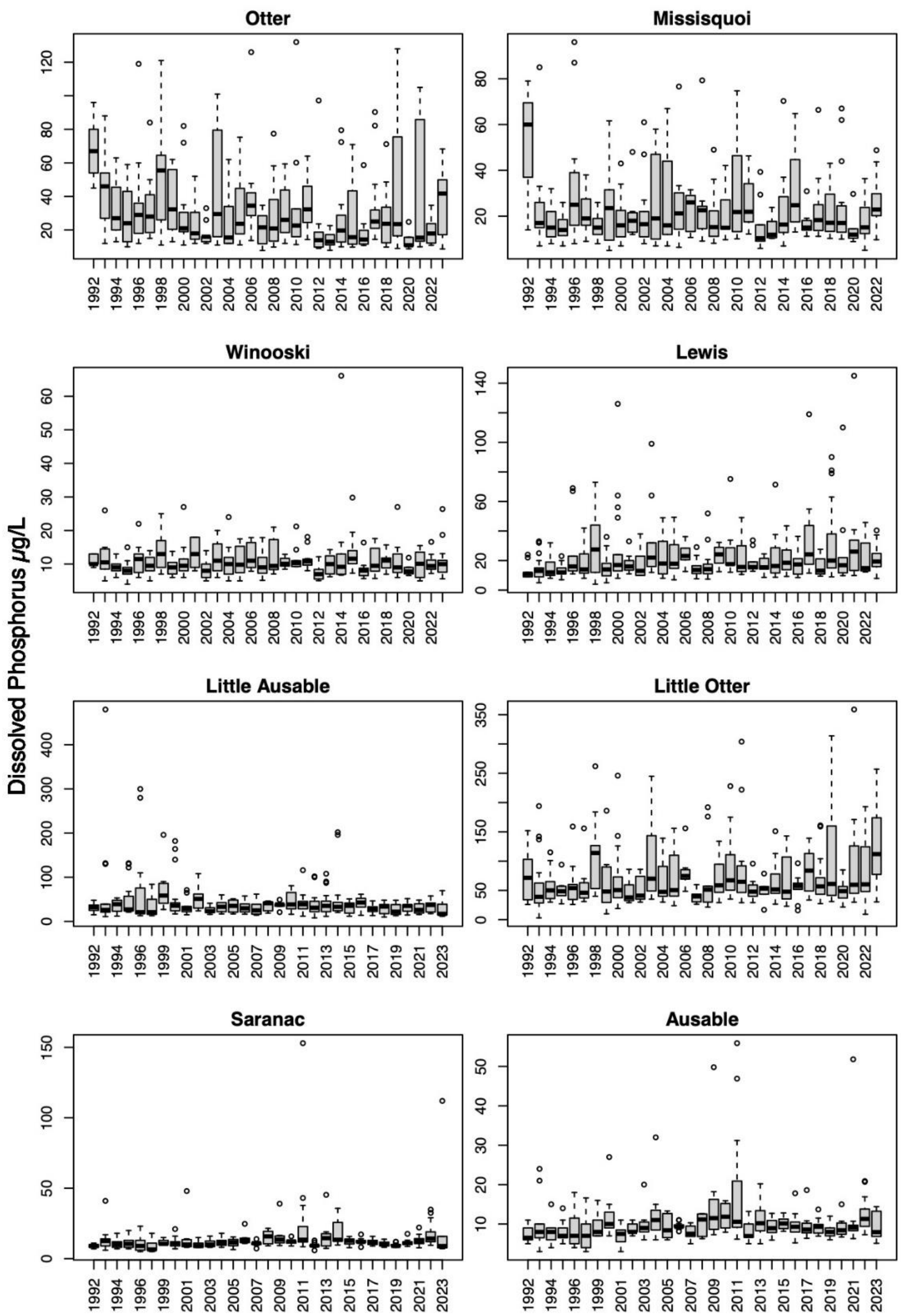

Otter
Winooski
Missisquoi
Lewis
Little Ausable
Little Otter
Saranac
Ausable
Total Phosphorus μg/L

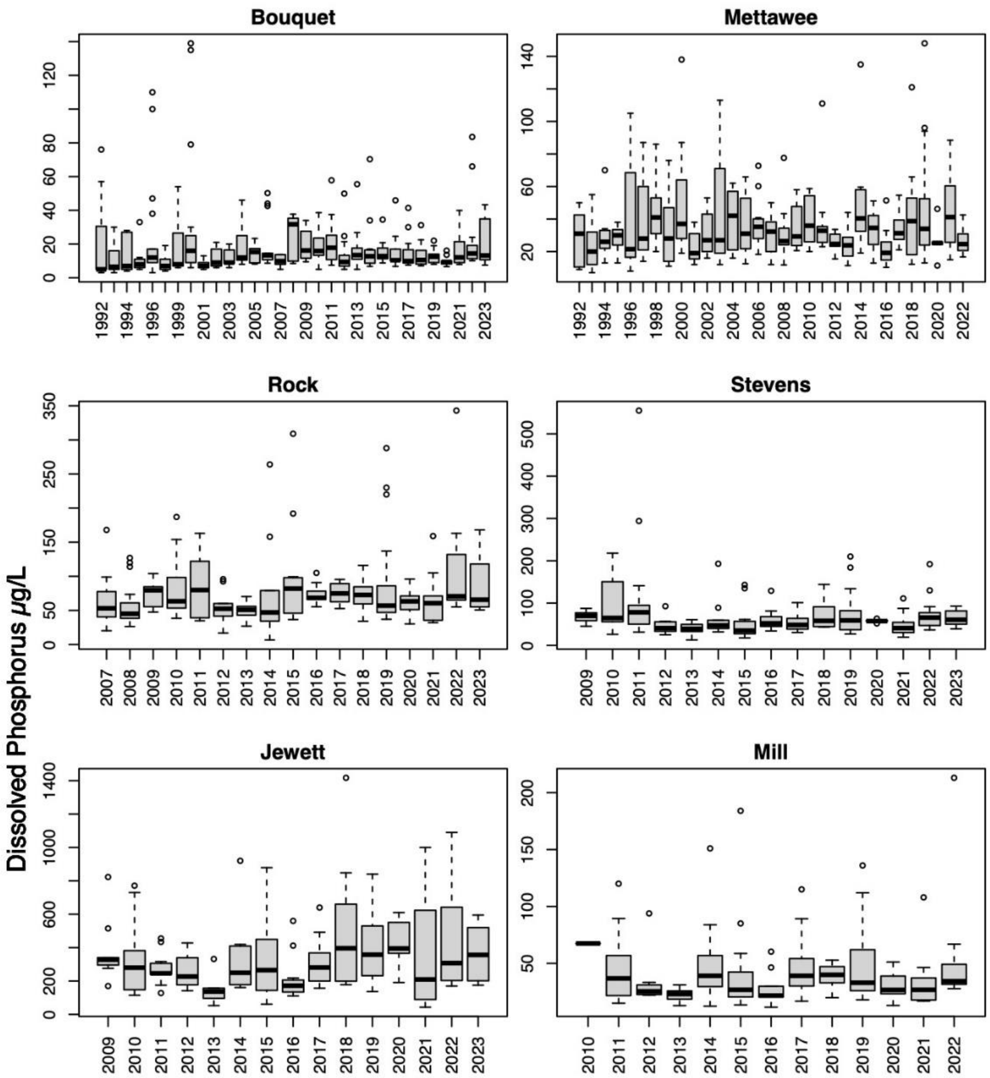


Bouquet
Mettawee
Rock
Jewett
Stevens
Mill
Total Phosphorus µg/L

Dissolved Phosphorus

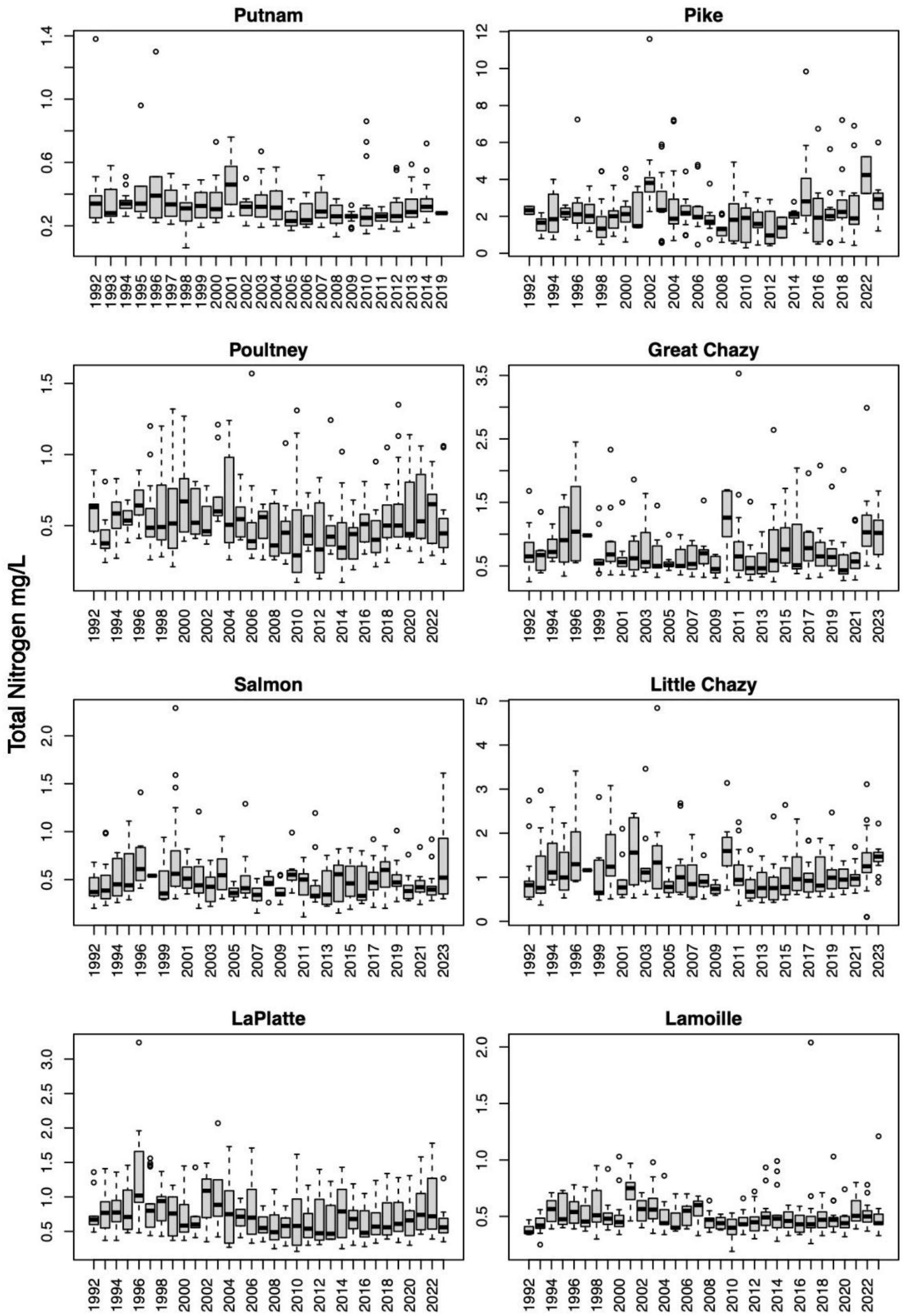


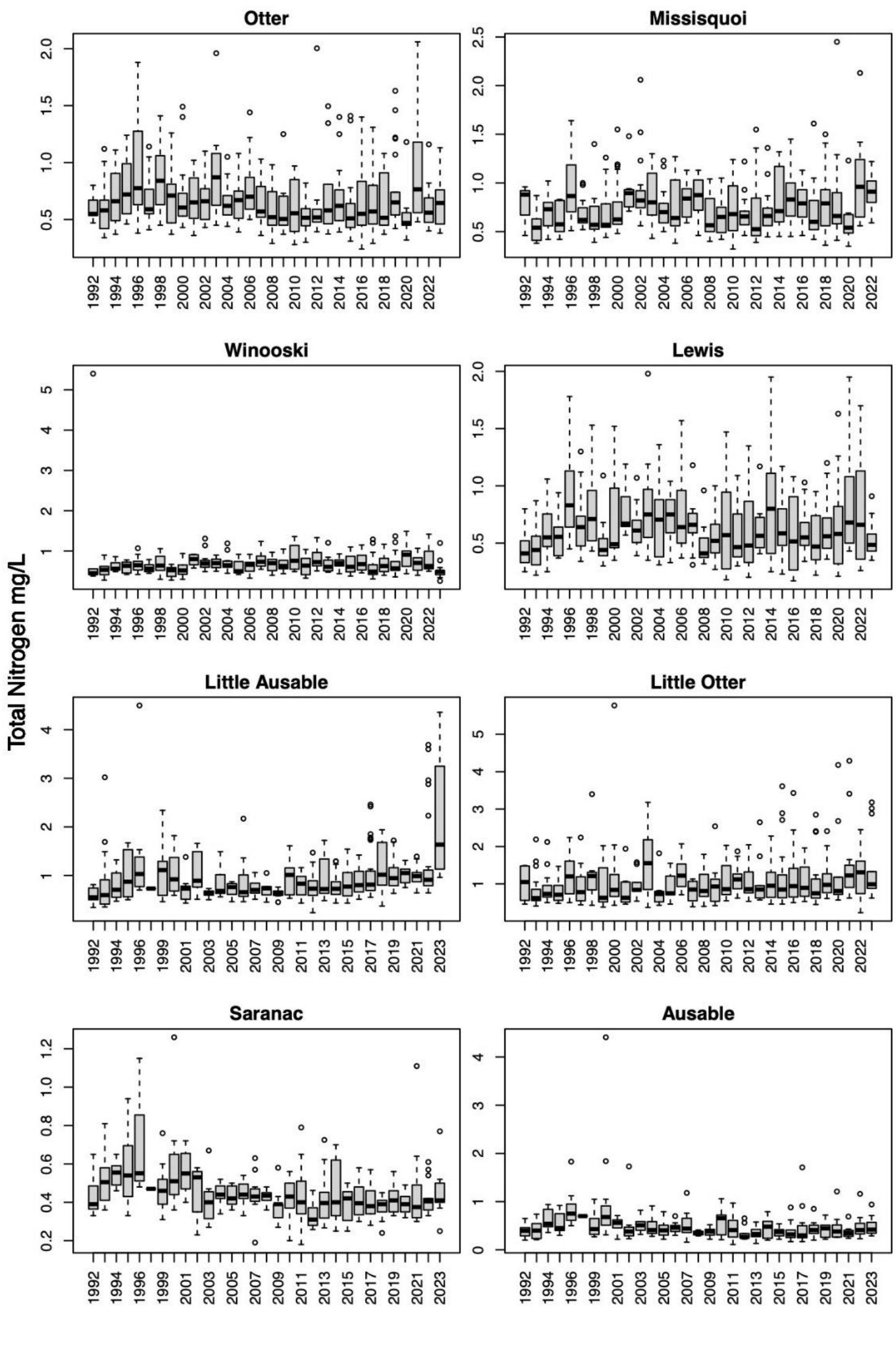

Otter
Missisquoi
Winooski
Lewis
Little Ausable
Little Otter
Saranac
Ausable
Dissolved Phosphorus μg/L

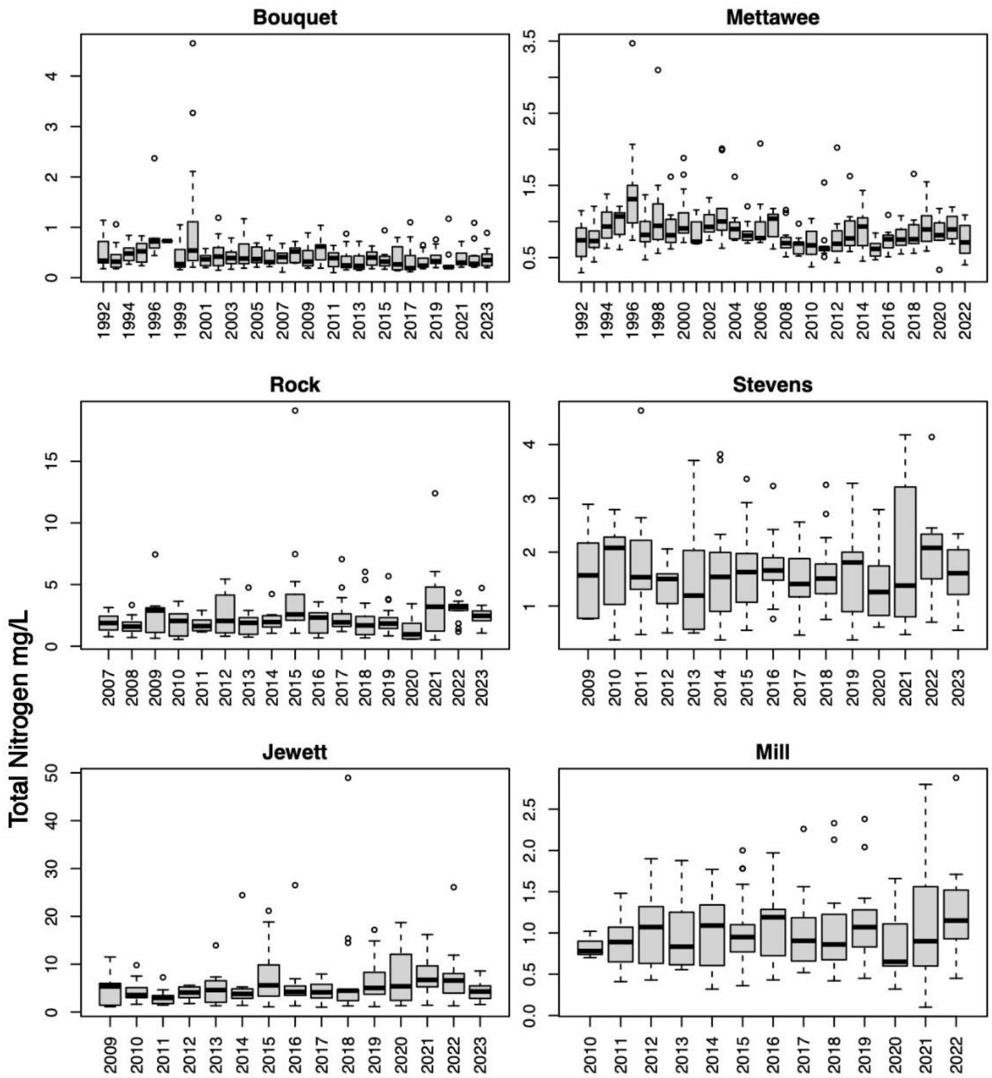


Dissolved Phosphorus µg/L
Bouquet
Mettawee
Rock
Stevens
Jewett
Mill

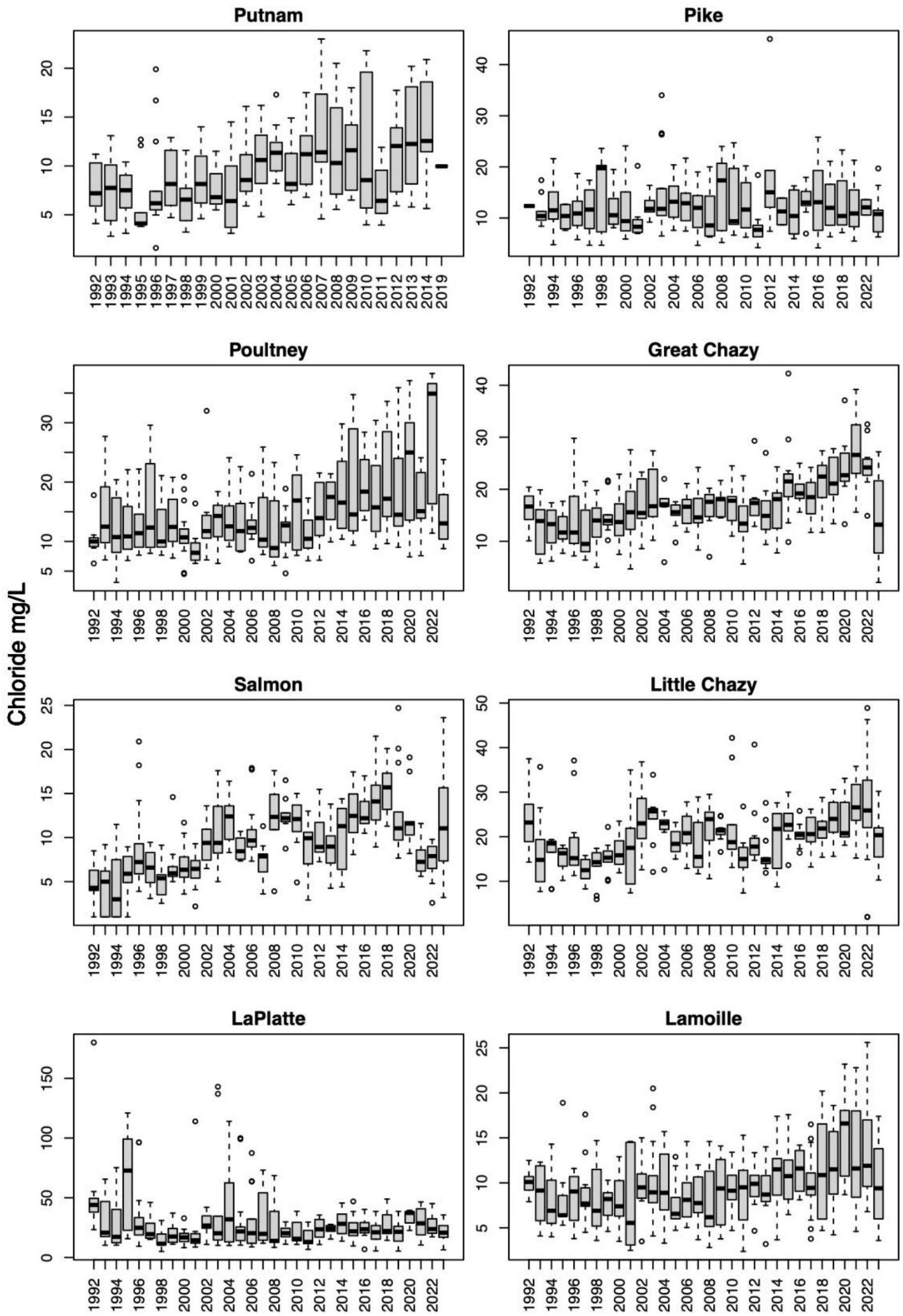
Total Nitrogen



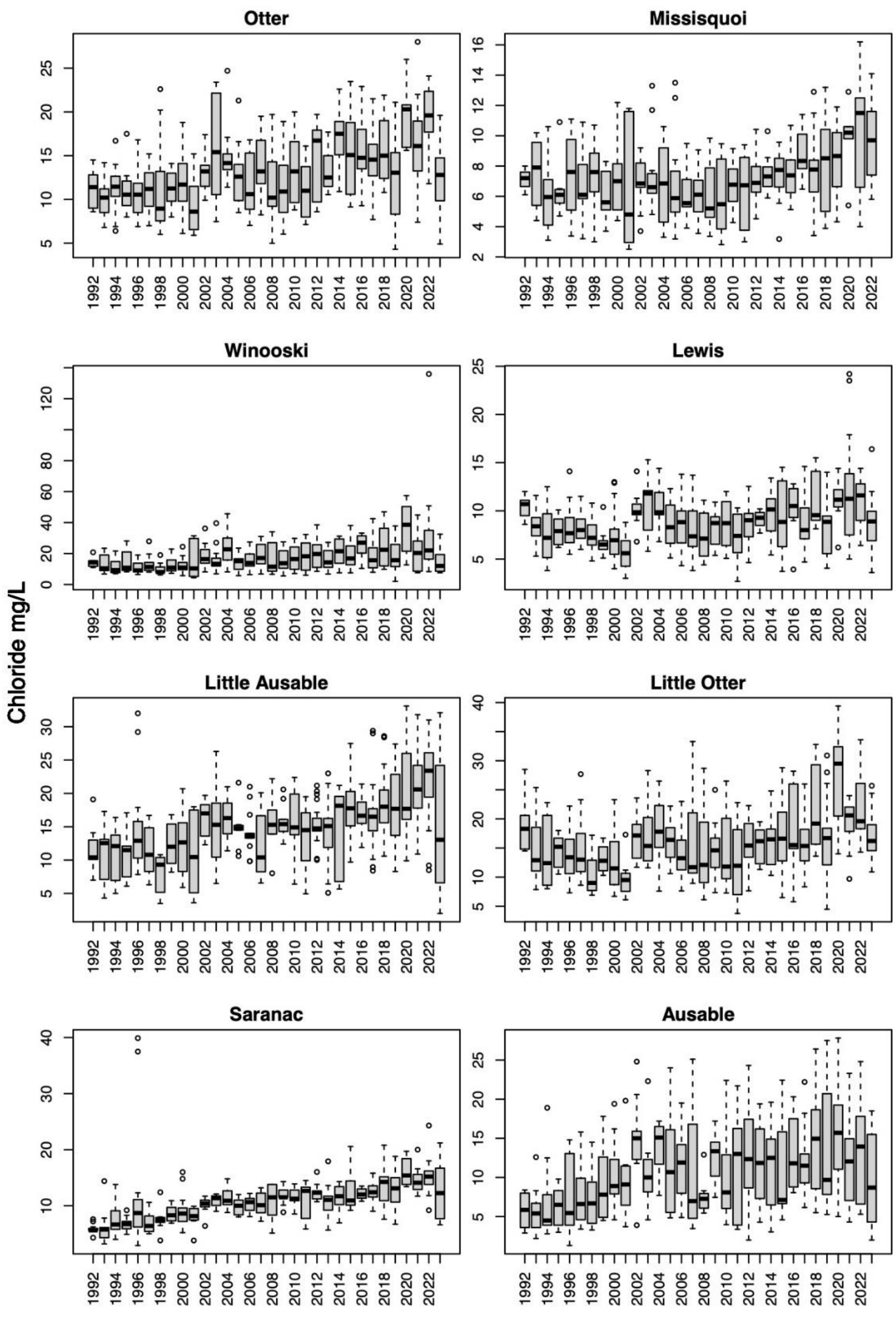

Otter
Missisquoi
Winooski
Lewis
Little Ausable
Little Otter
Saranac
Ausable
Total Nitrogen mg/L

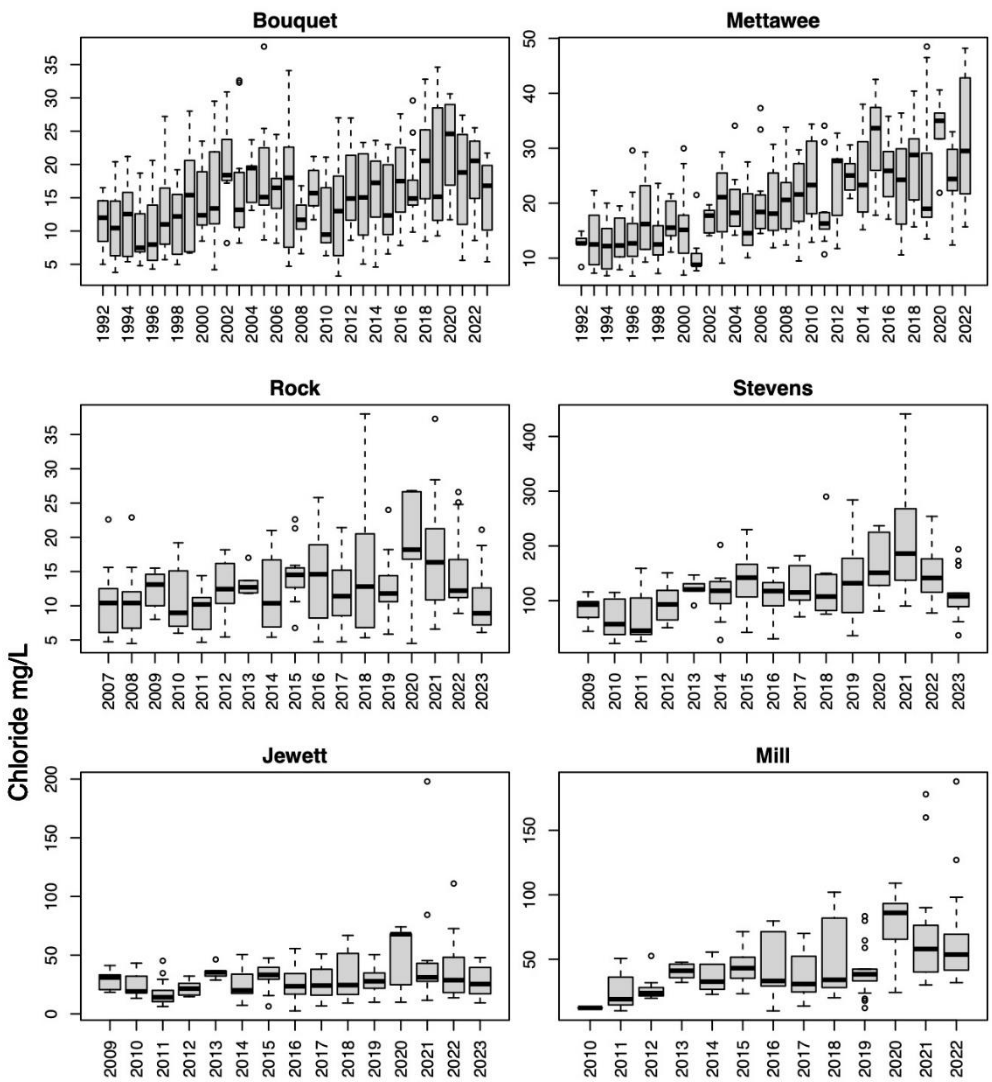

Total Nitrogen mg/L
Bouquet
Mettawee
Rock
Stevens
Jewett
Mill

Chloride:

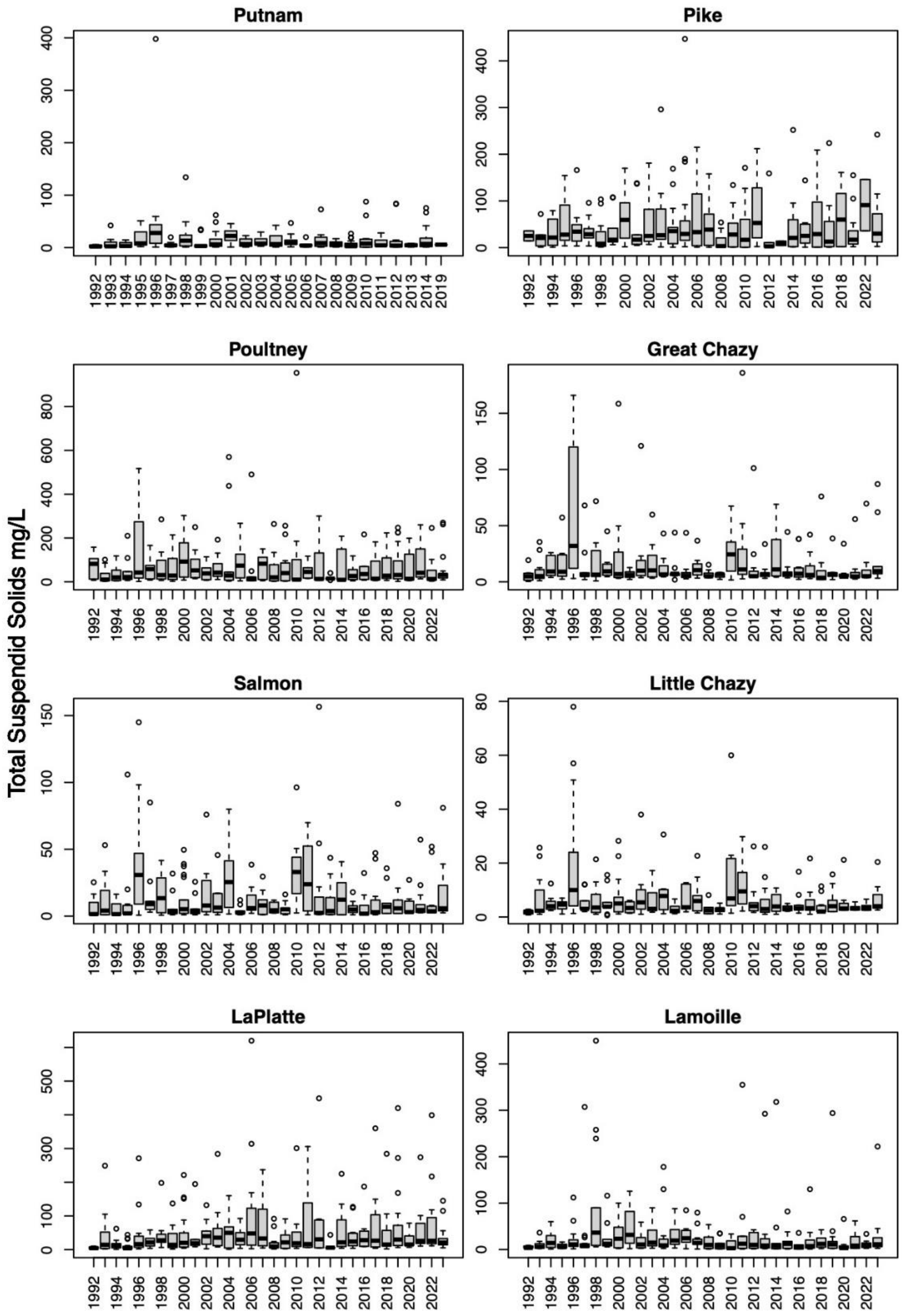


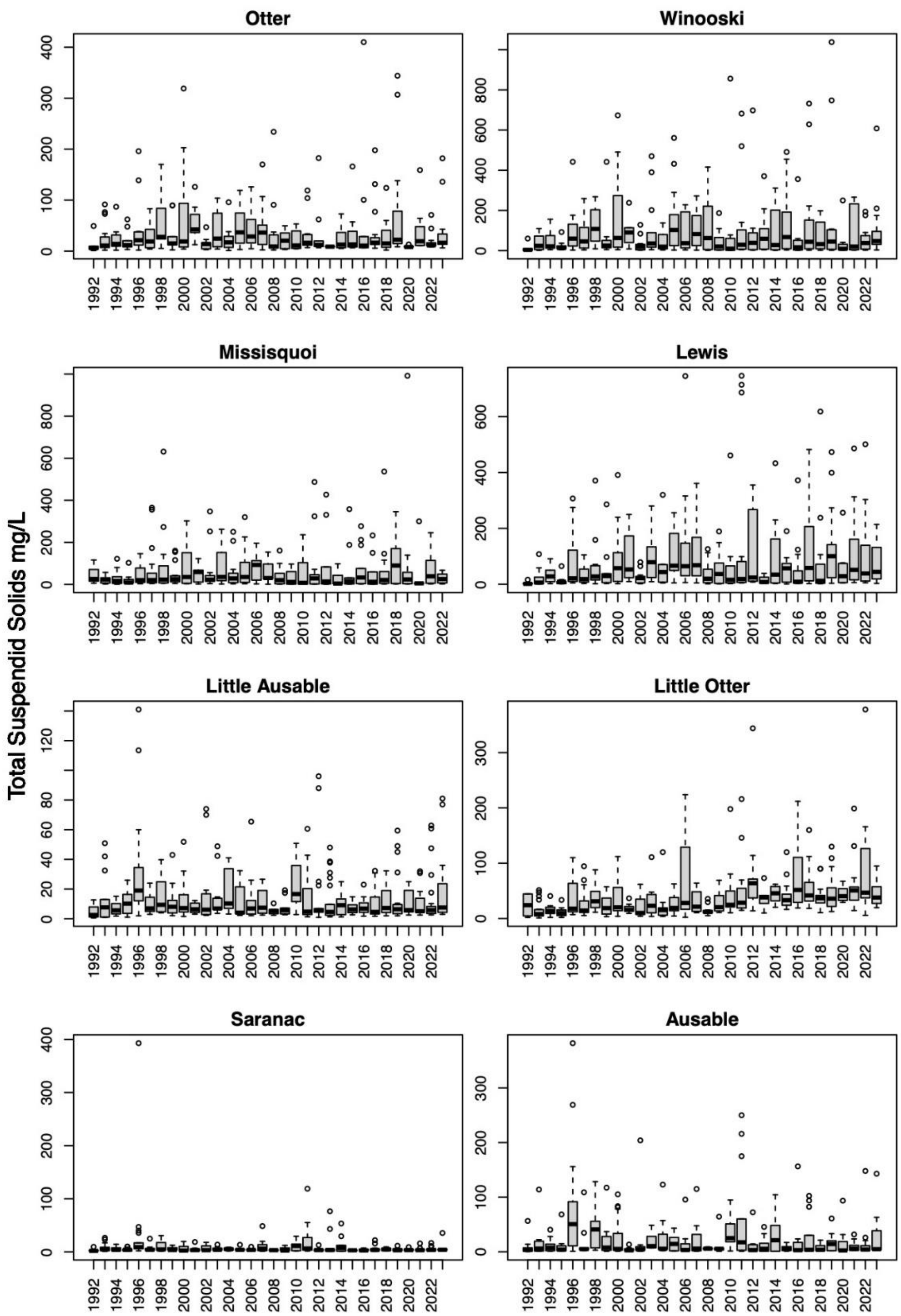
Putnam
Pike
Poultney
Great Chazy
Salmon
Little Chazy
LaPlatte
Lamoille
Chloride mg/L

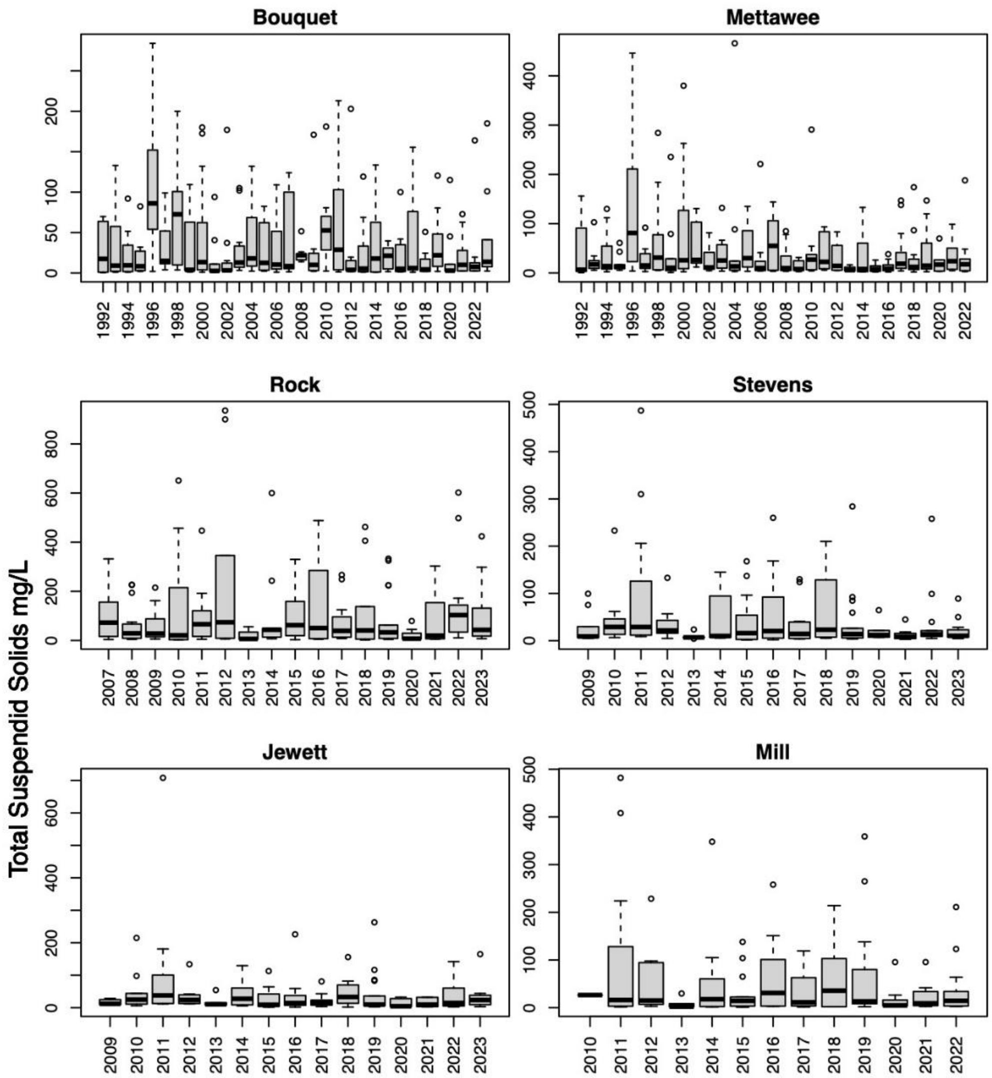

Otter
Missisquoi
Winooski
Lewis
Little Ausable
Little Otter
Saranac
Ausable
Chloride mg/L


Bouquet
Mettawee
Rock
Stevens
Jewett
Mill
Chloride mg/L

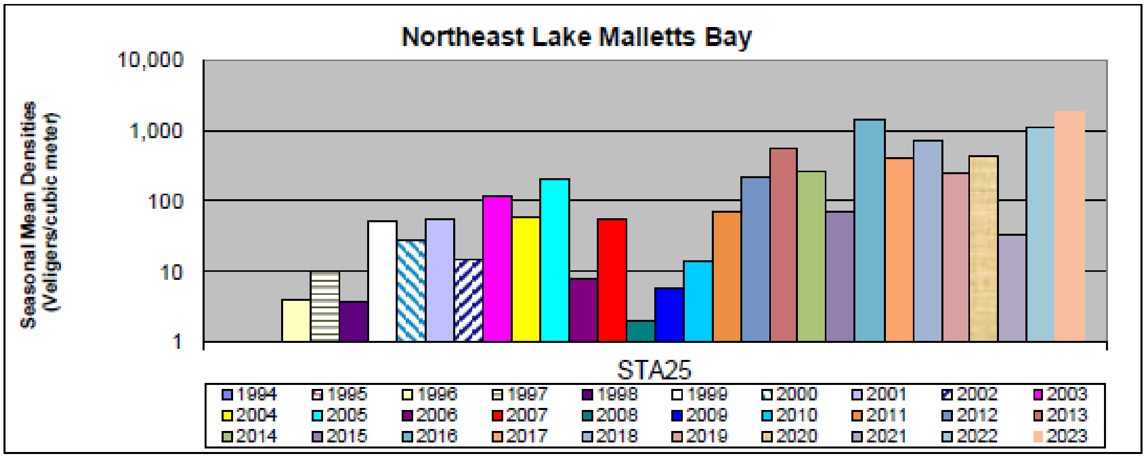
Total Suspended Solids

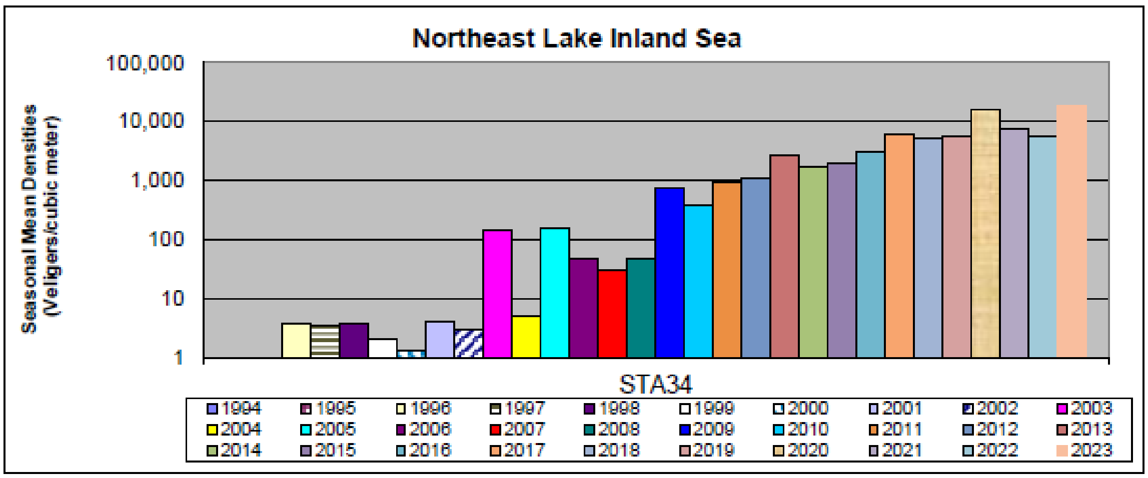


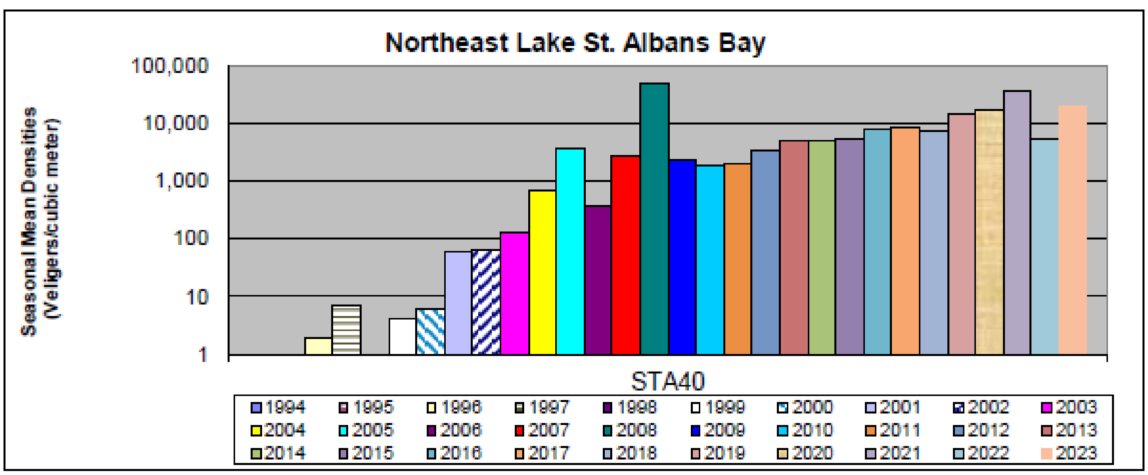

Otter
Winooski
Missisquoi
Lewis
Little Ausable
Little Otter
Saranac
Ausable
Total Suspendid Solids mg/L

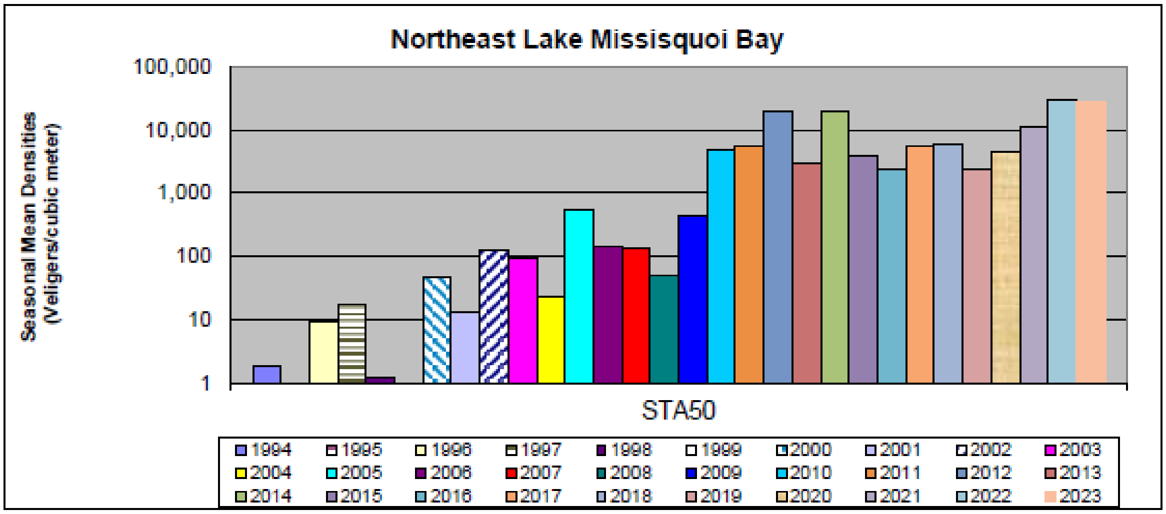

Bouquet
Mettawee
Rock
Stevens
Jewett
Mill
Total Suspendid Solids mg/L

Appendix D. Lake Champlain Zebra Mussel Veliger Densities

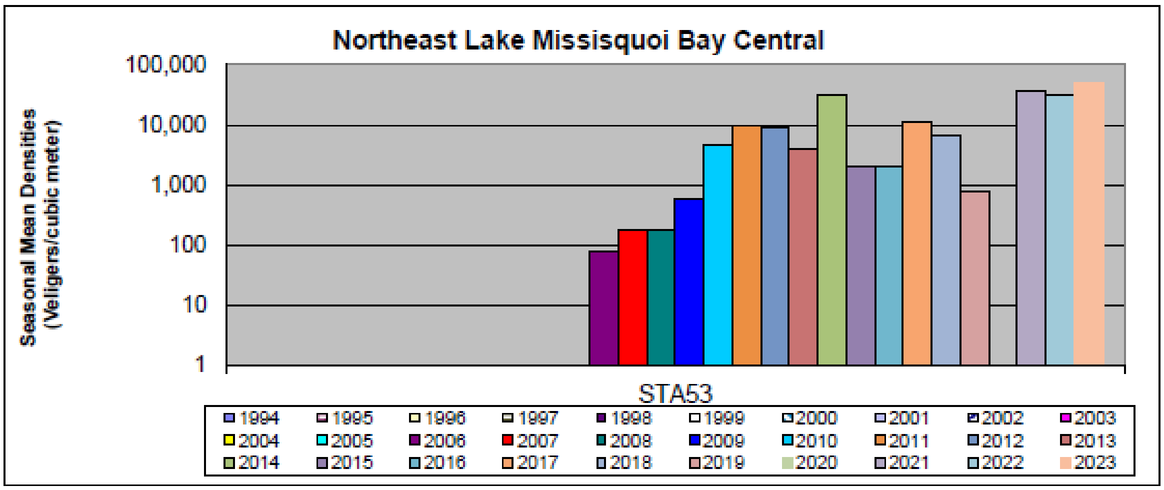




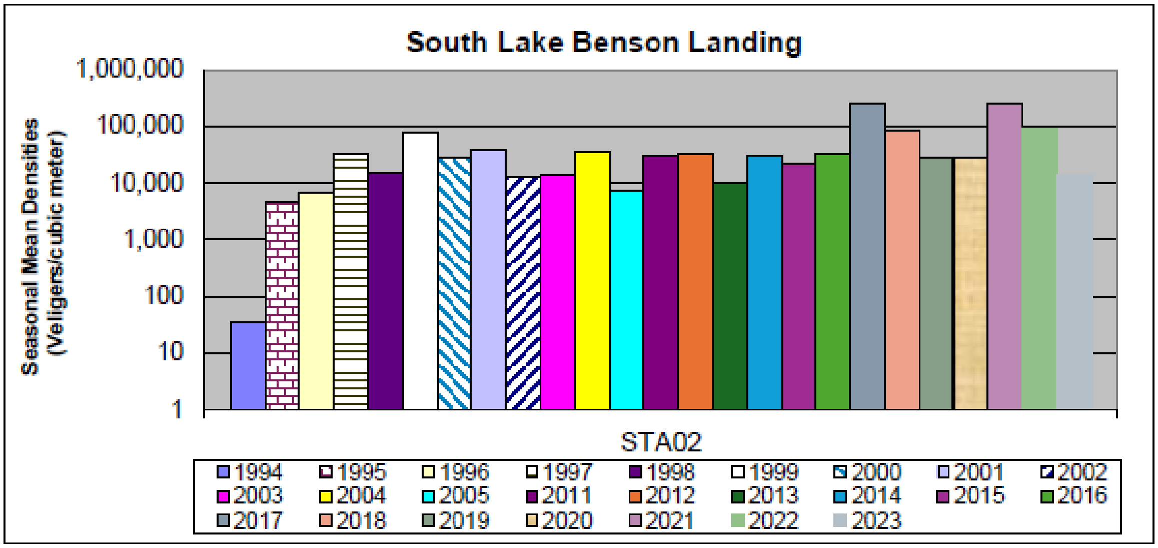


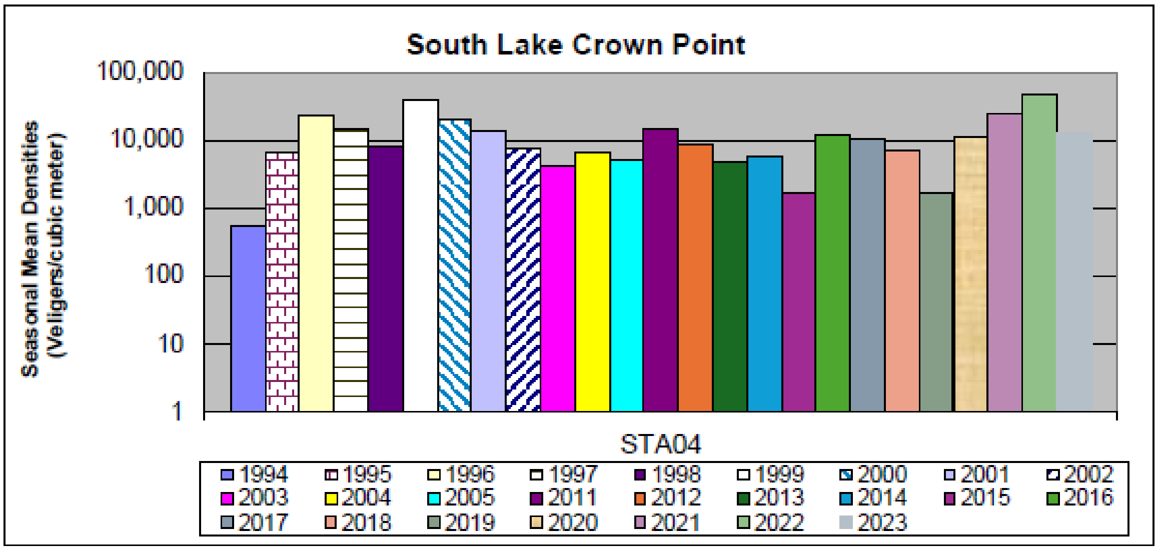


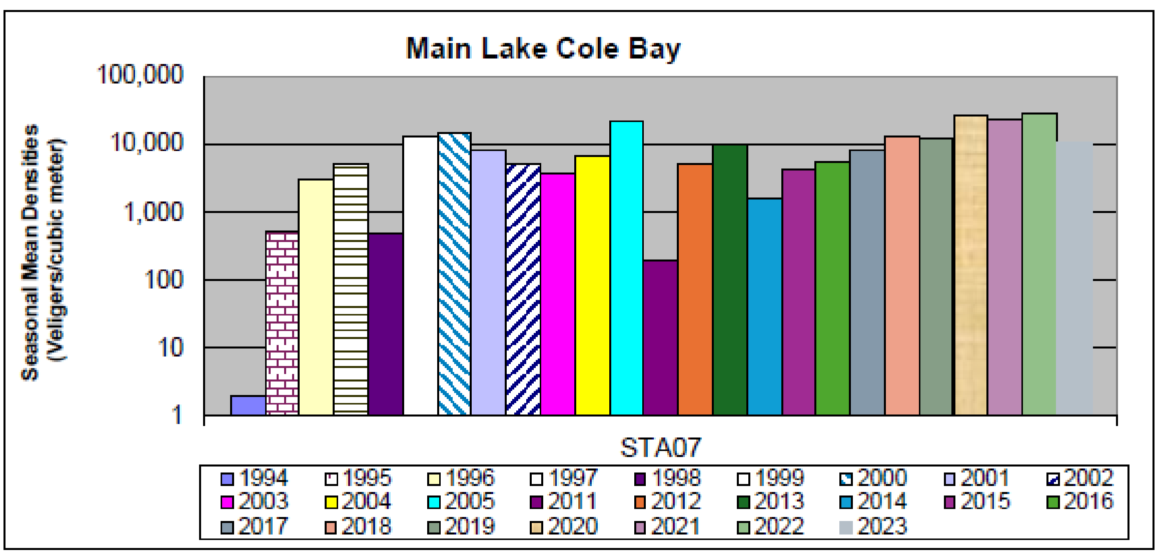
Northeast Lake Missisquoi Bay
100,000
10,000
1,000
100
10
1
Seasonal Mean Densities (Veligers/cubic meter)
STA50
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

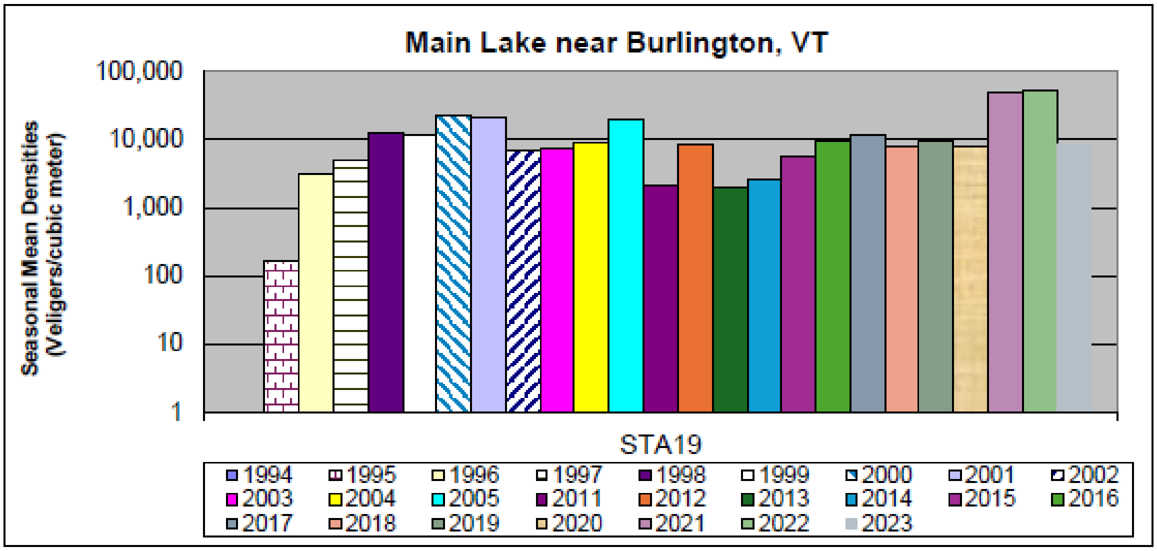


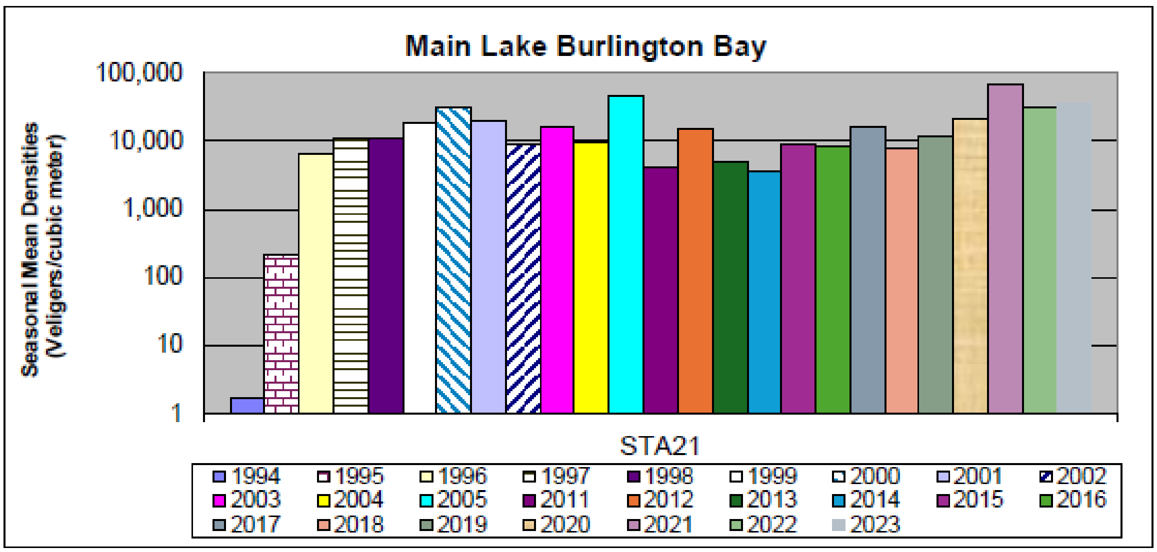
Northeast Lake Missisquoi Bay Central
100,000
10,000
1,000
100
10
1
Seasonal Mean Densities (Veligers/cubic meter)
STA53
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

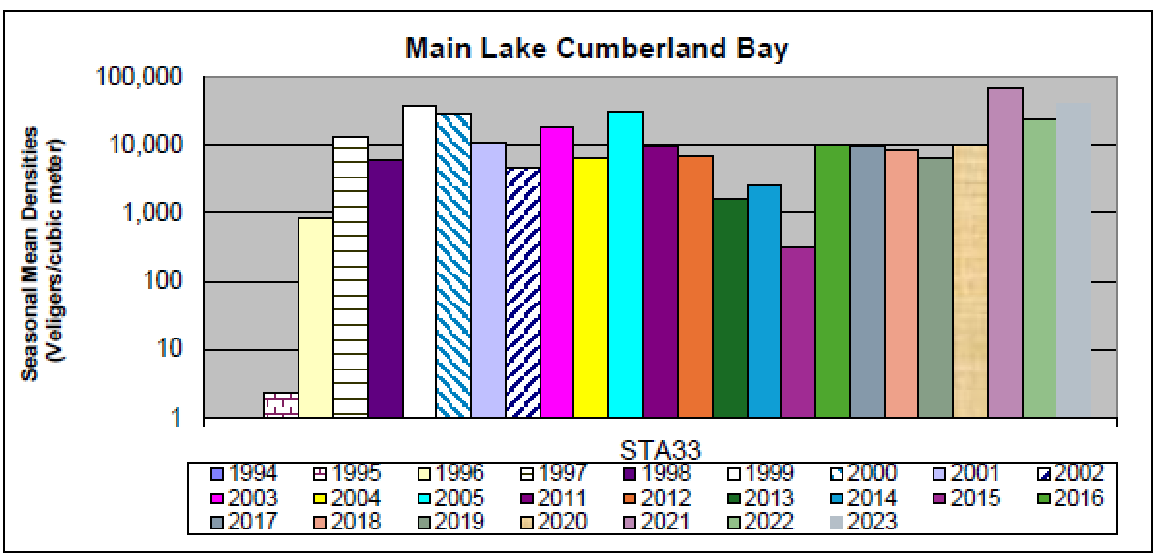

South Lake Benson Landing
Seasonal Mean Densities (Veligers/cubic meter)
1,000,000
100,000
10,000
1,000
100
10
1
STA02
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023

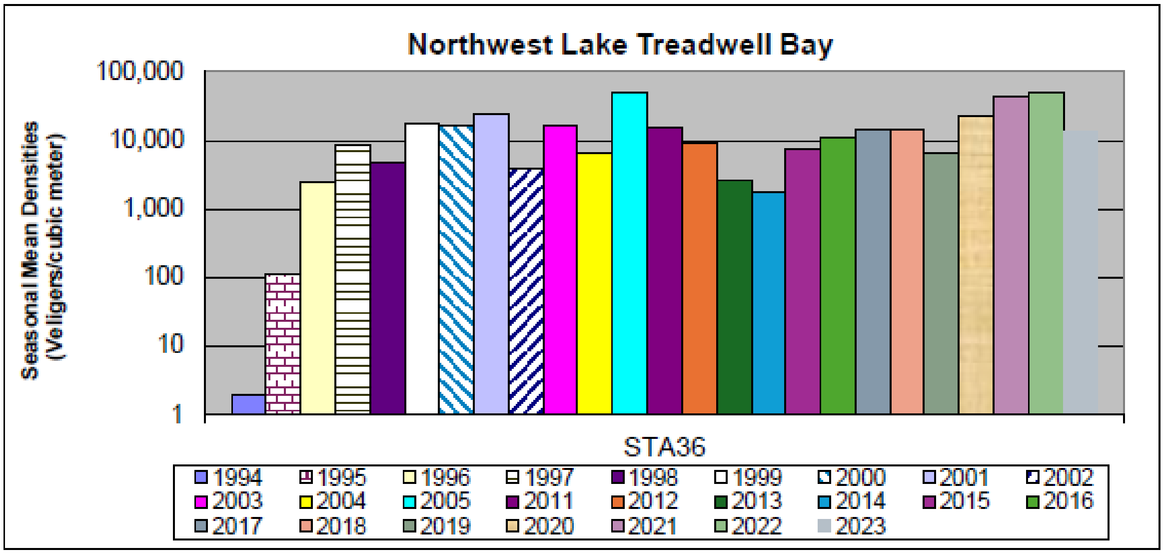

South Lake Crown Point
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA04
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023

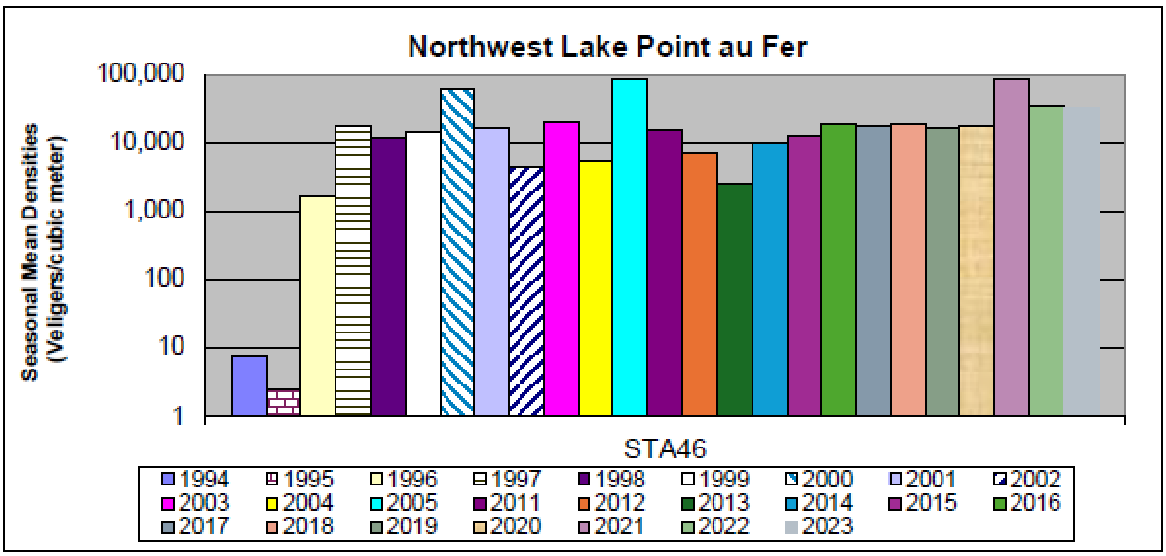

Main Lake Cole Bay
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA07
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023


Main Lake near Burlington, VT
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA19
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023


Main Lake Burlington Bay
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA21
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023


Main Lake Cumberland Bay
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA33
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023


Northwest Lake Treadwell Bay
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA36
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023


Northwest Lake Point au Fer
Seasonal Mean Densities (Veligers/cubic meter)
100,000
10,000
1,000
100
10
1
STA46
1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2011 2012 2013 2014 2015 2016
2017 2018 2019 2020 2021 2022 2023