Water Quality Monitoring of Candlewood Lake & Squantz Pond 2022

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For the Communities of Brookfield, Danbury, New Fairfield, New Milford, and Sherman

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Introduction

The Candlewood Lake Authority

Candlewood Lake is a pumped storage reservoir built in the late 1920's for the purposes of power generation. It has since become a premier destination for lake recreation in both Connecticut and the New York City tristate area and is a critical economic and environmental asset for local communities. The Candlewood Lake Authority (CLA) is an organization formed from ordinances by the municipal governments of Brookfield, Danbury, New Fairfield, New Milford, and Sherman pursuant Connecticut General Statute §7-151a, to enforce boating law on the water and to provide lake management to protect and conserve the environmental value of Candlewood Lake and Squantz Pond. Those 5 municipalities equally share a substantial amount of the responsibility for much of the CLA's operational budget. FirstLight Power, the owners and operators of Candlewood Lake and its hydropower generation have also historically made a voluntary contribution to the Candlewood Lake Authority's budget. Annual donations, grants, and fundraising projects constitute the final portion of the Lake Authority's budget.

Candlewood Lake Authority Mission Statement

The Candlewood Lake Authority provides lake, shoreline and watershed management to foster the preservation and enhancement of recreational, economic, scenic, public safety and environmental values of the Lake for the City of Danbury and the Towns of Brookfield, New Fairfield, New Milford and Sherman in cooperation with the State of Connecticut and the hydro power owner of the lake.

Lake and Watershed Characteristics

Candlewood Lake is Connecticut's largest, with a surface area of roughly 5,064 acres. The Candlewood Lake & Squantz Pond shared watershed is approximately 25,907 acres and contained almost entirely in the Connecticut municipalities of Brookfield, Danbury, New Fairfield, New Milford, and Sherman. (Jacobs and O'Donnell 2002). New Fairfield and Sherman contain 73% of the watershed, while a small portion crosses the border into New York State (Table 1).

Town	Acres of Watershed	% Of watershed within municipal boundary	% Of municipality within watershed boundary
Brookfield	1,177	4	9
Danbury	2,726	10	10
New Fairfield	12,197	46	72
New Milford	2,629	10	6
Sherman	7,132	27	51
New York State	600	3	
Total	26,461		

Table 1: *Percentages of the Candlewood Lake & Squantz Pond watershed contained within each bordering municipality, and the percentage of each municipality contained within the watershed.*

Squantz Pond has a surface area of roughly 270 acres, with a watershed of 3,662 acres contained entirely within the borders of Sherman and New Fairfield, making it a sub-basin of the Candlewood Lake watershed. A culvert below the Route 39 causeway in New Fairfield connects the two hydrologically, allowing free water flow between Candlewood Lake and Squantz Pond.

The Candlewood Lake watershed has changed dramatically over the course of the lake's life, becoming more urbanized and losing forested and agricultural lands. Since 1970, the percentage of the watershed classified as urban has increased from 11.7% to 28.3% in 2007 (Table 2) (Kohli et al. 2017).

Year	Urban (%)	Agriculture (%)	Wooded (%)	Water (%)
1970	11.7	8.5	57.0	22.0
1977	19.5	2.1	57.0	22.2
1990	28.7	5.6	43.6	21.7
2007	28.3	1.9	47.1	22.7

Table 2: *Candlewood Lake Watershed percent coverage of different land classifications (Table from Kohli et al. 2017).*

The Candlewood Lake Monitoring Program

Long-term management of water resources requires consistent and standardized monitoring to make informed management decisions. By tracking critical water chemistry and biological metrics that are indicators of lake health, we can analyze how management activities are affecting the in-lake ecosystem, and what additional management activities may be necessary. To that end, the CLA began a monitoring program in 1983 to provide a scientifically standardized method of assessing Candlewood Lake & Squantz Ponds health and water quality over time to the surrounding communities.

Initially undertaken by researchers from Western Connecticut State University (WCSU) and later by Connecticut College (CC), the CLA has conducted this monitoring itself since 1998, with the exception of the years 2017-2019, when the monitoring was contracted to Aquatic Ecosystems Research (AER), a freshwater consulting organization specializing in in-lake chemical monitoring. Since 1999, all whole-water sample laboratory analyses have been performed at Hydro Technologies, Inc. at their CT Department of Health certified laboratory in New Milford, CT. In 2022, that laboratory analysis was changed and conducted at York Analytical Laboratories Inc. in Newtown, CT due to an ownership change at Hydro Technologies, Inc.

2022 is the second year where there were two distinct sampling events (one early month, and one late month sampling) from June-September. This was done to give the CLA a more fine-grained view of the chemical monitoring results, allowing us to better understand trends over the course of a season, as well as being able to calculate representative averages of our key metrics more accurately. We hope to continue with this twice-monthly schedule moving forward. For the sake of keeping this report a reasonable size, raw data has not been included as an appendix, but all raw data and lab results are available from the Candlewood Lake Authority upon request: science@candlewoodlakeauthority.org

Materials & Methods

The CLA began its water quality monitoring program in 1983 to provide the community with a scientifically rigorous and standardized method of assessing changes in Candlewood Lake and Squantz Pond over time. The program has continued largely uninterrupted since then, providing us with historical data for 38 years and counting.

More Specifically, The Candlewood Lake Authority has been conducting monthly monitoring from May – October of 4 sites on Candlewood Lake, and one Site on Squantz Pond. From 1985-1987 sites in Lattins Cove, Pocono Point, and the southern end of the New Milford arm of the lake were sampled as well. From 1985-1990 an additional site in New Fairfield Bay was sampled. From 1988-1990 the New Fairfield Bay site was sampled instead of the standard New Fairfield site. In 1990 the New Fairfield site was re-established, and the New Fairfield Bay site was eliminated.

The monitoring has taken some different forms over the years, and different metrics have been added, eliminated, and transferred to new methods of measurement at various times over the course of the monitoring's history. However, the metrics being measured regularly at each monitoring location are:

At each location:

1. Secchi Depth (m)

At 1-meter intervals:

2. Depth (m)
3. Temperature (C°)
4. Dissolved Oxygen (mg/l)
5. pH
6. Standard Conductivity (µmhos/cm)
7. Relative Cyanobacteria (cells/mL)
8. Relative Chlorophyll-a (µg/L) - Started in 2019

At the Epi, Meta, and/or Hypolimnion:

9. Total Phosphorous (ppb)
10. Total Nitrogen (ppm)
11. Chlorophyll-a (µg/m^3)
12. Ca^{++} (mg/l) – Bi-monthly
13. Mg^{++} (mg/l) – Bi-monthly
14. Na^+ (mg/l) – Bi-monthly
15. K^+ (mg/l) – Bi-monthly
16. Cl- (mg/L) –Bi-monthly

Phaeophytin, phytoplankton diversity and cell counts (including Cyanobacteria cell counts), and Chlorophyll b and c have also been included in past years' monitoring, but have been monitored inconsistently, or monitoring has ceased. Phytoplankton diversity and cell counts were monitored from 1985-1998, at which point that monitoring was discontinued until 2017, and has been re-incorporated into the monitoring from 2017 to 2020. Phytoplankton monitoring was not included in the 2022 monitoring and will be re-incorporated on a 3-year rotating basis, which means it will be conducted in 2023. In 2011, a Zebra Mussel Veliger Monitoring program was added in conjunction to the normal monthly monitoring and has continued since.
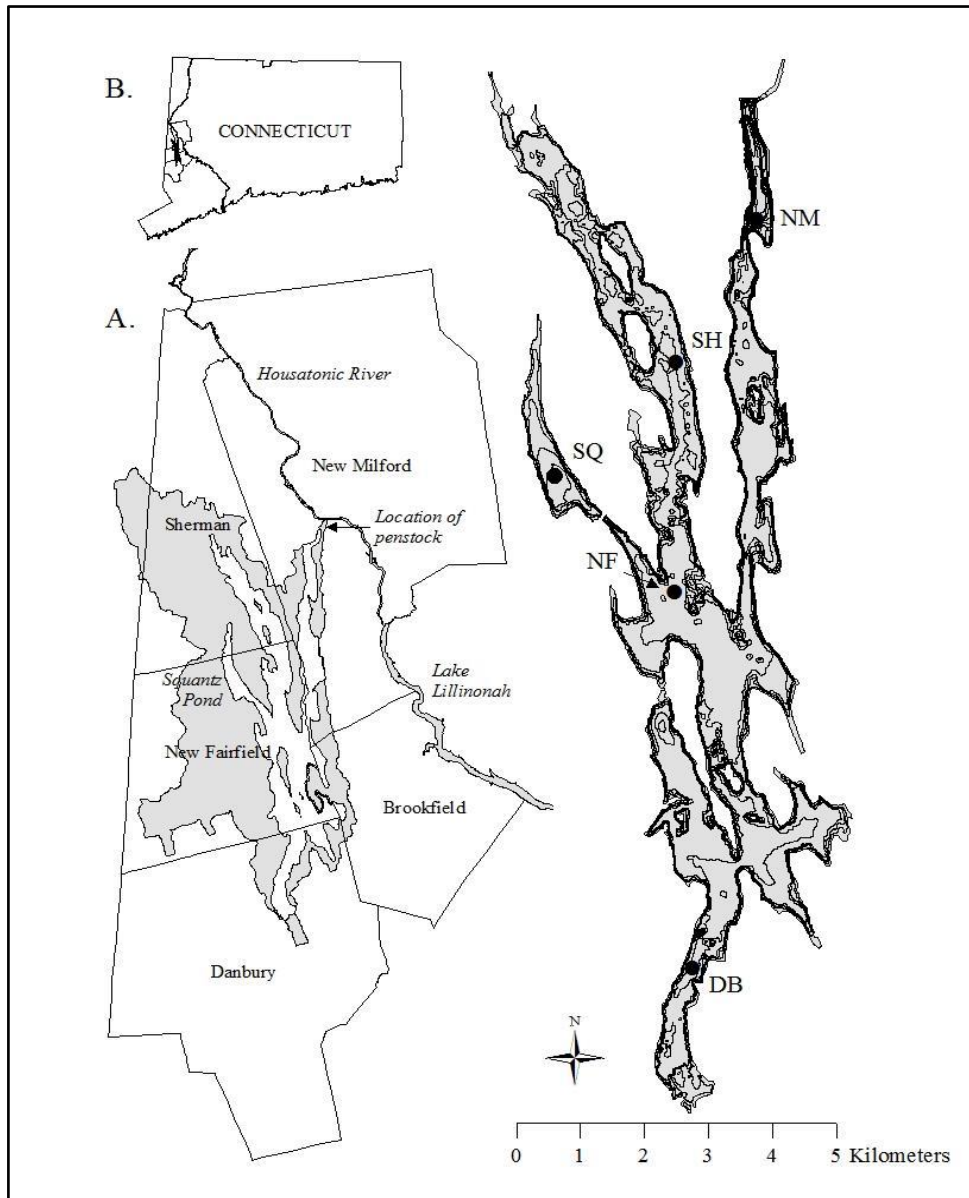

Figure 1: *A) Relation of the Candlewood Lake Watershed to the five bordering municipalities. B) Location of watershed and municipalities in the state of Connecticut. C) Location of the five sampling sites on Candlewood Lake and Squantz Pond.*

Results

Temperature and Dissolved Oxygen Profiles

Candlewood Lake is a dimictic lake, meaning that twice per year, the temperature difference between the surface water and the lake bottom is negligible. That remains true this year, although at the end of May, the thermocline is already beginning to form, but oxygen remains well mixed through the water column.

	Danbury		New Fairfield		New Milford		Sherman		Squantz	
	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)
31-May	7-9	N/A	5-8	N/A	5-8	N/A	8-9	N/A	5-7	N/A
14-Jun	6-8	11	6-9	11	5-8	N/A	6-8	9	5-8	11
29-Jun	6-9	9	5-8	11	8-11	N/A	5-8	11	7-9	9
19-Jul	5-8	9	6-9	7	6-8	7-15/20	6-8	7	5-9	9
27-Jul	6-9	7	6-9	7	7-10	8-15/19	5-8	7	5-10	7
10-Aug	6-9	8	6-9	8	5-8	8	5-8	8	6-10	8
25-Aug	7-9	9	6-9	8	7-11	11	7-9	8	6-9	8
15-Sep	9-10	10	8-11	10	8-11	9	8-10	8	8-11	8
28-Sep	9-10	9	10-12	12	11-13	11	N/A	10	9-11	11
27-Oct	N/A	N/A	N/A	N/A	15-17	15	N/A	N/A	8-12	N/A

Table 3: *Stratification, mixing, and oxygen depletion characteristics at 4 locations on Candlewood Lake, and one location on Squantz Pond in 2022. The metalimnetic boundaries are presented as meters below the surface, and the anoxic layer is presented as the upper boundary of the anoxic zone, extending from that level to the bottom.*

The tendencies of Candlewood Lake of top-to-bottom mixing, and strong mid-season stratification followed by a period of mixing are characteristic of deep lakes in the American northeast. The colder, denser, water "sinks" to the bottom of the water column, effectively preventing mixing with the shallower surface water – creating the anoxic layer in the lake bottom. These layers are shown in Figure 1. As surface waters begin to cool at the end of the season, the metalimnion (middle layer) recedes deeper into the water column until such time that the temperature of the column reaches a homogenous state, and the anoxic zone disappears, allowing for a consistent level of dissolved oxygen throughout the water column.
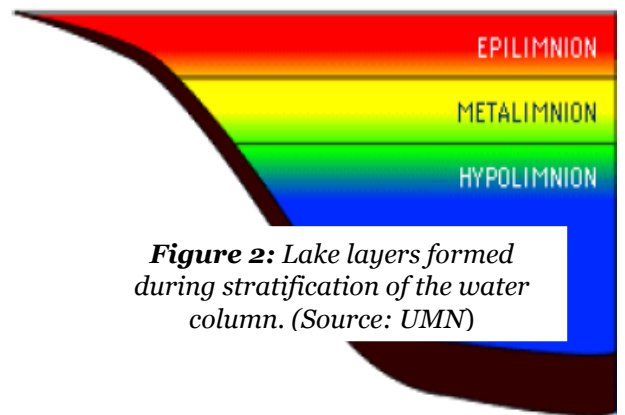

Figure 2: *Lake layers formed during stratification of the water column. (Source: UMN)*

When we began our monitoring in late May all five sites had begun forming a thermocline (the "barrier" of the largest temperature difference between the epilimnion and the hypolimnion, preventing mixing) at roughly the midpoint of the water column as air temperatures warmed the surface water. The hypolimnion below this boundary began to lose dissolved oxygen (DO) concentration, but the water column remained oxygenated throughout. The drop in DO in the deeper water is due to respiring single-celled organisms utilizing that oxygen to digest sinking phytoplankton and other materials for energy. Relatively strong stratification began in early June at all 5 sites, peaking in late July and Early August. Anoxic zones were apparent in early June in all 4 sites except New Milford, which represents a slightly faster move to anoxia than 2021. Temperature and oxygen profiles generally mirror one another due to their strong relationship with thermal resistance to mixing and lake stratification.

The New Milford site shows a unique property of two separate anoxic zones. With low levels of dissolved oxygen between the two zones. This is our deepest site, but the cause of this is somewhat unclear. It could indicate outgassing at a certain point in the deep lake's geology or indicate layers of oxygen utilization by deep water respirating bacteria.
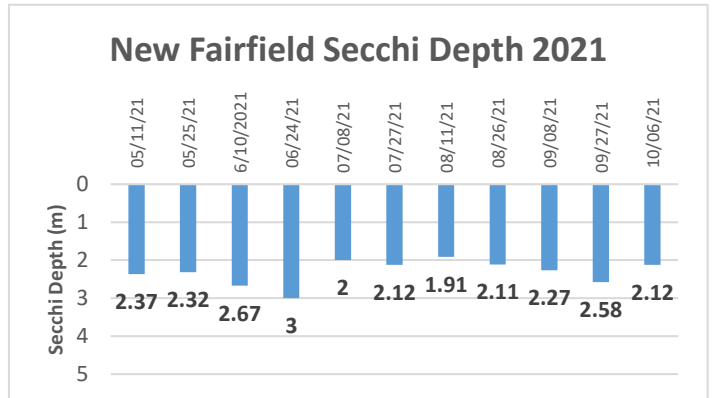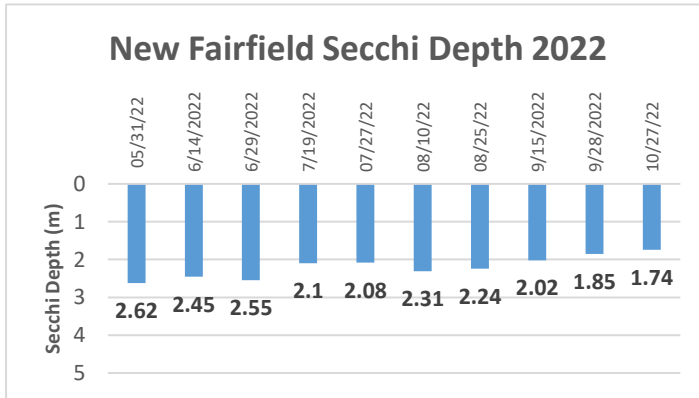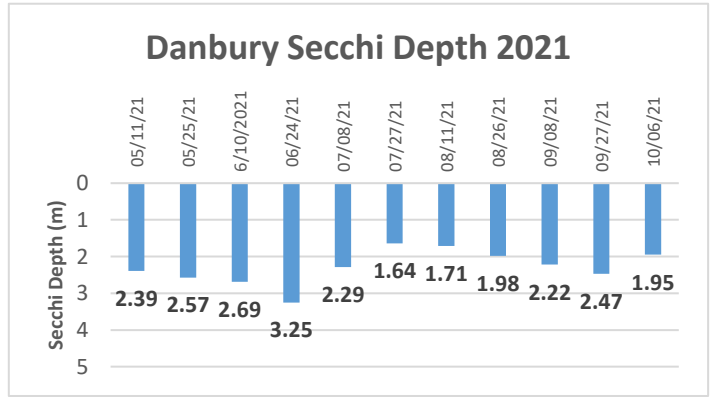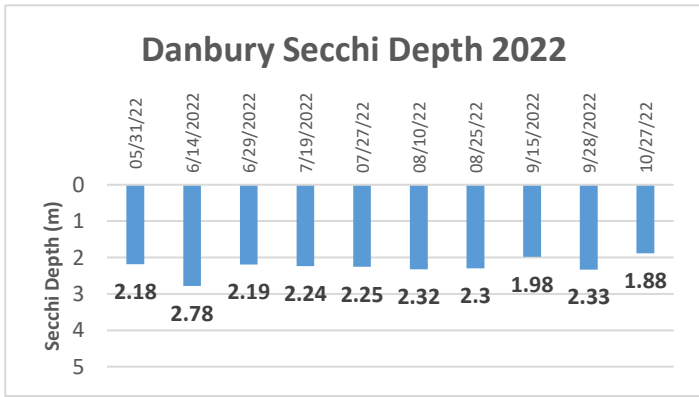
Anoxic zones in the hypolimnion require respirating bacteria to use anaerobic respiration, increasing nutrient release in the hypolimnion as compounds containing both nitrogen and phosphorus are broken down into forms usable by bacteria. This is known as "internal loading" and is a critical component of lake monitoring and management. Mixing allows for the hypolimnion to be refreshed with oxygen, allowing for aerobic respiration and a relative pause in nutrient release while the water column is homogenous. As temperatures continue to increase due to climate change, strong stratification can last for a longer period, increasing the potential for nutrient release in anoxic zones. This can and will accelerate eutrophication (lake "aging") in the long term.

Secchi Transparency

In 2022 secchi transparency (water clarity) in Candlewood Lake ranged from a low of 1.74m in New Fairfield in October to a high of 3.01m in both New Milford in early June. The average reading across the whole of both Candlewood and Squantz was 2.28m, with the highest average being New Milford at 2.44m, and the lowest being Sherman at 2.15m.

	DB Secchi (m)	NF Secchi (m)	NM Secchi (m)	SH Secchi (m)	SQ Secchi (m)	Average
31-May	2.18	2.62	2.40	2.32	2.72	2.45
14-June	2.78	2.45	3.01	2.54	2.54	2.66
29-June	2.19	2.55	2.62	2.46	2.62	2.49
19-July	2.24	2.10	2.23	1.93	2.91	2.28
27-July	2.25	2.08	1.96	2.02	2.50	2.16
10-August	2.32	2.31	2.65	2.28	2.11	2.33
25-August	2.30	2.24	2.28	2.17	2.38	2.27
15-September	1.98	2.02	2.82	1.98	2.00	2.16
28-September	2.33	1.85	2.45	1.98	1.82	2.09
27-October	1.88	1.74	2.00	1.82	2.04	1.90
Average	**2.25**	**2.20**	**2.44**	**2.15**	**2.36**	**2.28**

Table 4: *Secchi depths measured at each sampling location during the 2022 season.*

Danbury Secchi Depth 2022

2.18, 2.78, 2.19, 2.24, 2.25, 2.32, 2.3, 1.98, 2.33, 1.88

Danbury Secchi Depth 2021

2.39, 2.57, 2.69, 3.25, 2.29, 1.64, 1.71, 1.98, 2.22, 2.47, 1.95

New Fairfield Secchi Depth 2022

2.62, 2.45, 2.55, 2.1, 2.08, 2.31, 2.24, 2.02, 1.85, 1.74

New Fairfield Secchi Depth 2021

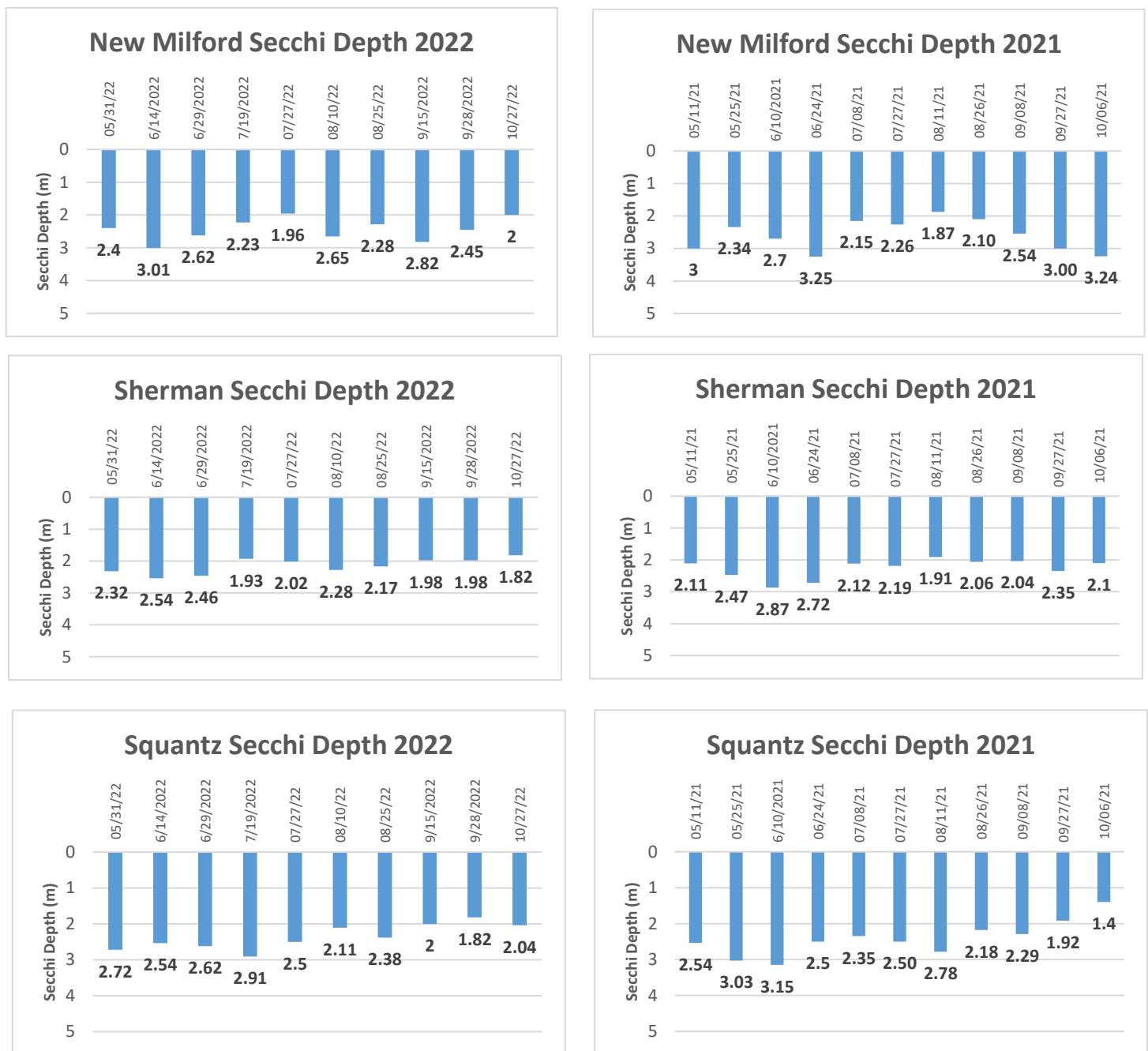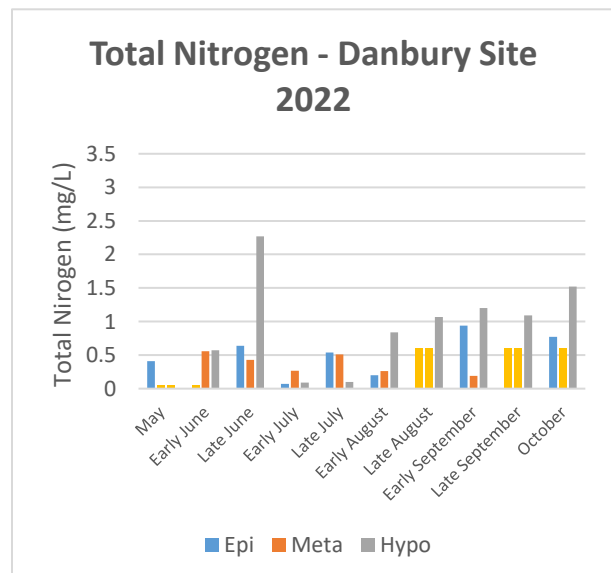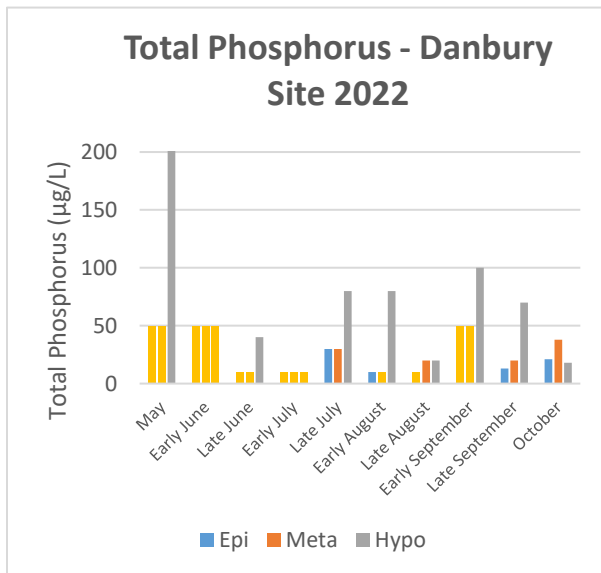2.37, 2.32, 2.67, 3, 2, 2.12, 1.91, 2.11, 2.27, 2.58, 2.12

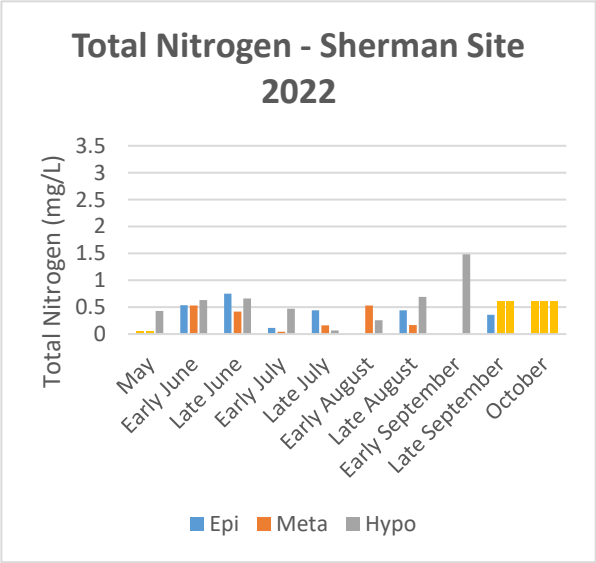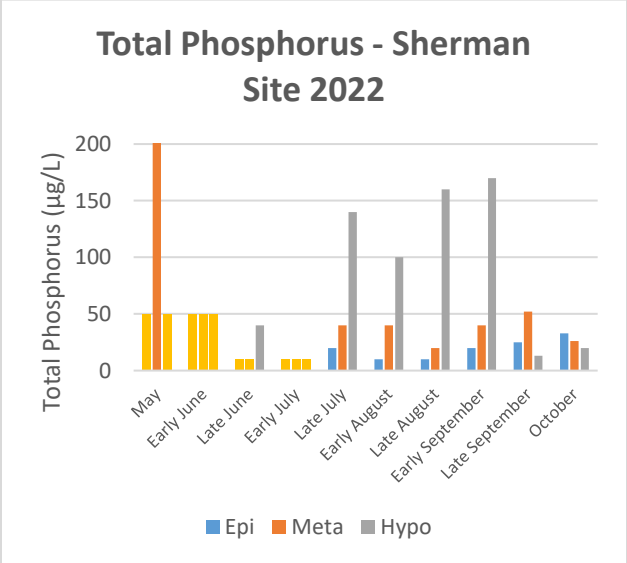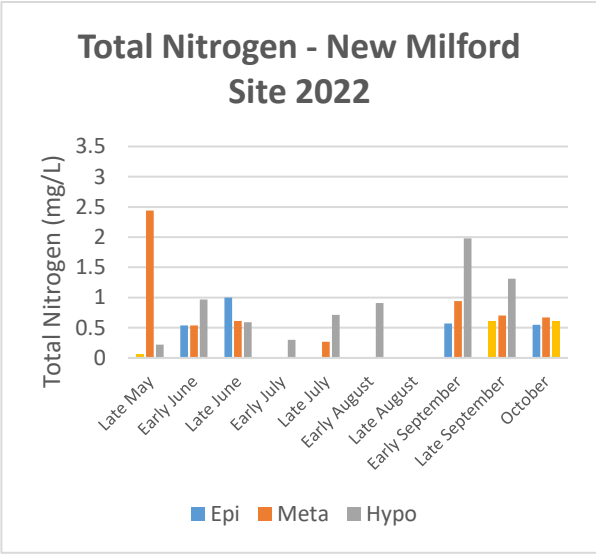**Figure 3:** *Measured Secchi Transparency in Candlewood and Squantz in 2022 & 2021.*
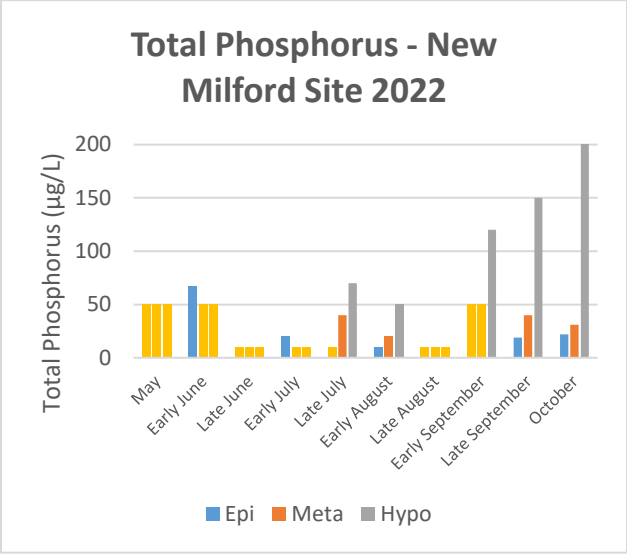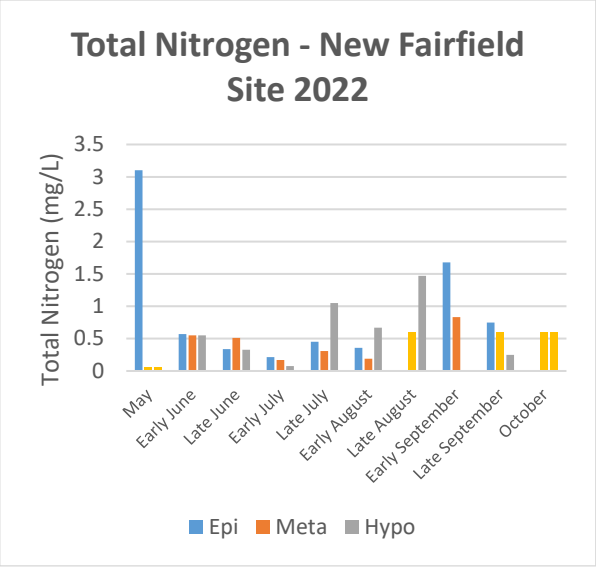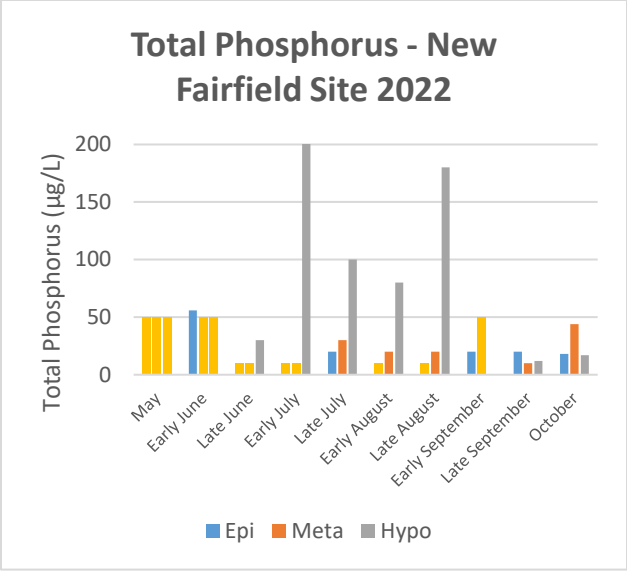
Compared to 2021, secchi transparency has decreased on average for the second consecutive year. The average in 2020 was 3.23, which was the second highest average in the history of monitoring (only 1989 was higher at 3.38). In 2021, that average dropped to 2.38, and now in 2022, the average dropped again to 2.28 due mostly to higher average chl-a values, which could be attributed to several factors, including strong stratification, and higher nutrient availability due to the lack of vegetation in Candlewood in the 2022 season.

Nutrient Levels

In 2022, nutrient measurements were taken 30 times at each site. This includes 3 samples at each location (Epilimnion, Metalimnion, and Hypolimnion samples) twice per month except for May and October, when they were taken once per month. The hope with the twice-monthly sampling throughout the season is that it will give us a better impression of nutrient dynamics in the water, and how that might impact blue-green and green algae growth in the water. This will also allow for a closer look at how nutrients are "locked" into the hypolimnion due to stratification and subsequent internal loading, and when those nutrients begin to mix with the rest of the water column. We sample total phosphorus, as well as four different forms of Nitrogen, but to visualize the nitrogen levels, we will use total nitrogen levels.

One important caveat for the 2022 monitoring year is that when we switched labs due to the changes at our old lab, our new lab was not able to get us the results at a level of detection we needed for much of the season. Unfortunately, for both Nitrogen and Phosphorus, a detection limit was established that, while it improved over the course of the season, prevents us from the finer-grained nutrient level results we've had in the past. That means throughout the year, many readings are reported as simply being lower than these detection thresholds. We will work with our lab or pursue different analytical solutions to remedy this for the 2023 season. **Note that in the below graphs, all results that are reported as below a detection limit are colored in yellow to show the bar is not representative of the true value.**

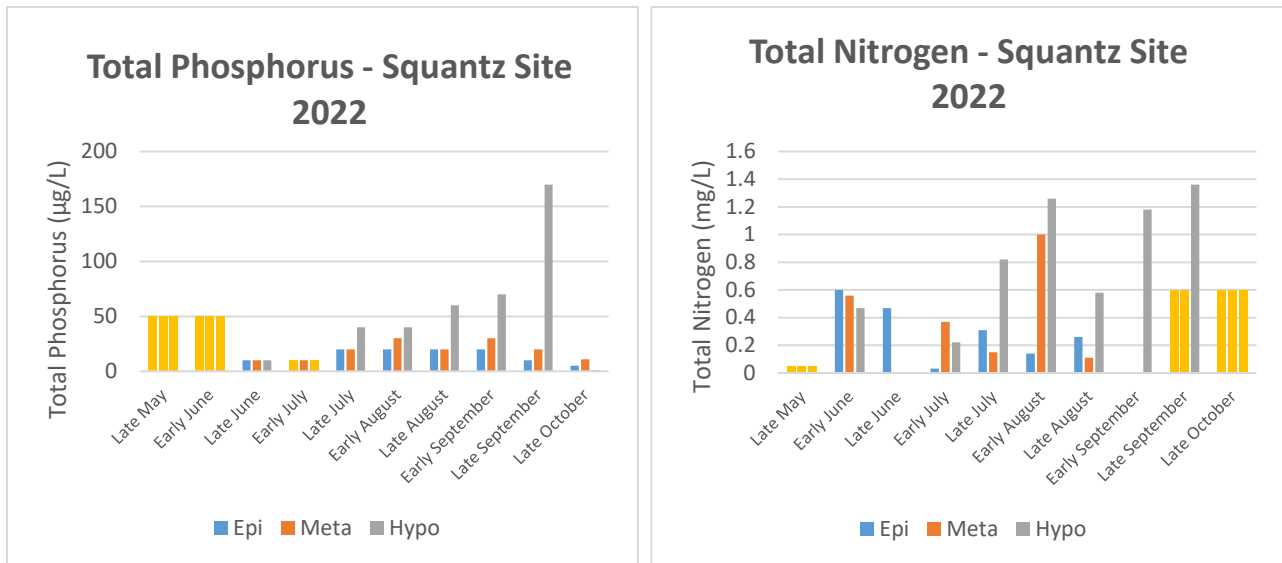Total Phosphorus - New Fairfield Site 2022

Total Nitrogen - New Fairfield Site 2022

Total Phosphorus - New Milford Site 2022

Total Nitrogen - New Milford Site 2022

Total Phosphorus - Sherman Site 2022

Total Nitrogen - Sherman Site 2022

Figure 4: *Measured Total Phosphorus and Nitrogen at 3 depths in 2022. Note that yellow bars indicate that the actual value is somewhere below the shown top threshold. Some values are reported as zero if reported as "Non-Detect."*

While there are different schools of thought about which of these two nutrients are more important in algae dynamics and eutrophication in freshwater systems, both are critical raw materials for algae blooms. Historically, Candlewood Lake has been considered phosphorus limited, and the blue-green algae community has been largely dominated by Microcystis cyanobacteria. To examine how the nutrient profile in Candlewood has changed over the course of the CLA's monitoring, it is useful to visualize epilimnion phosphorus levels, as those are the most relevant to algae growth, and thus the most likely to impact recreation during the boating season.

In 2022, the largest measurements for both nitrogen and phosphorus were found in the hypolimnion from late July through September, and even through October at the deeper New Milford site. This is indicative of internal loading in hypoxic conditions, a well-documented phenomenon in Candlewood Lake. Sediments at the lake bottom contribute nutrients to the system during the midsummer months, and those nutrients are incorporated into the rest of the water column after mixing.

There are a few unusually high readings found in May at multiple locations and depths (some so high, in fact, that they are cut off by the upper axis of the graph). In each of these cases the likelihood that these are the true values is very low. It is far more likely that these high numbers are due to sampling or lab error. Unfortunately, an IQR calculation for May to determine outliers is impossible because most other readings are below the detection threshold, so we cannot calculate based on those true values.
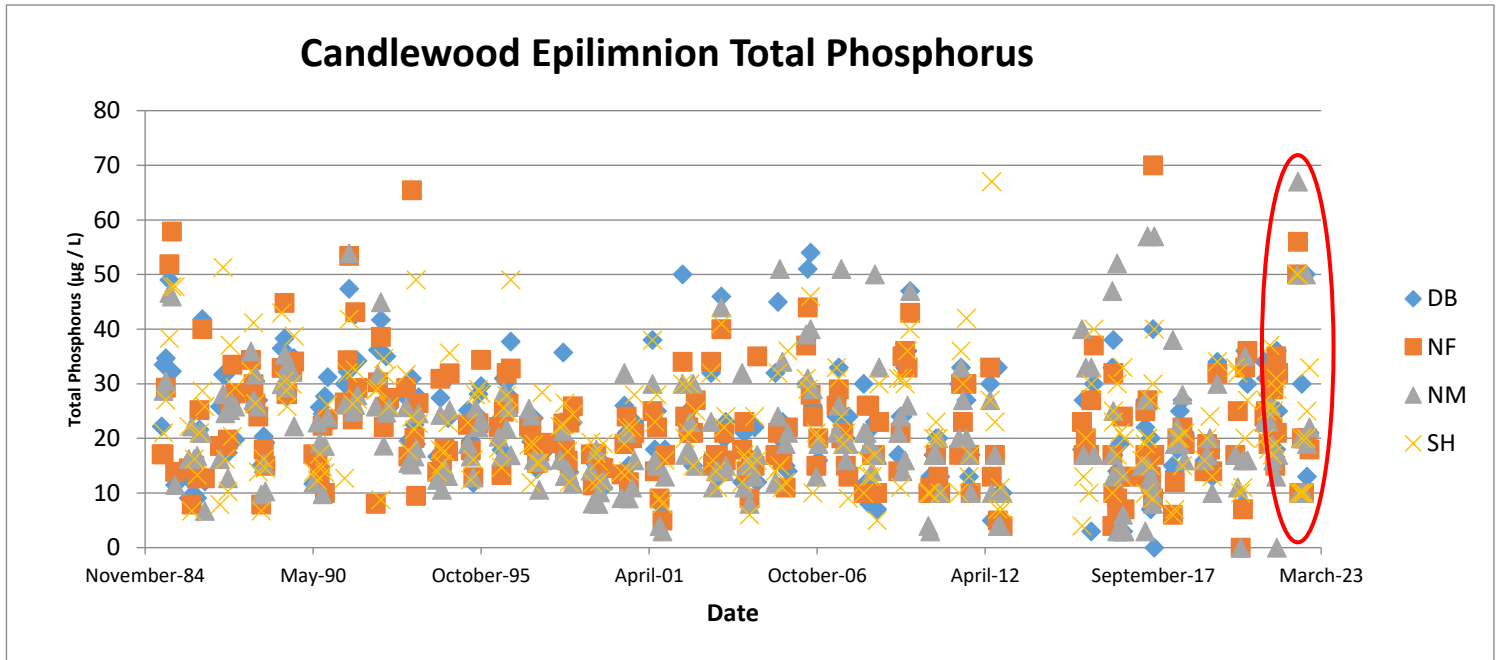
Figure 5: *Epilimnion phosphorus measurements at all 4 Candlewood monitoring sites taken from 1985 to 2022. The 2022 measurements have been highlighted.*

To help illustrate the trend over time of these measurements, we can look specifically at one sampling location, in this case we will look at Danbury:
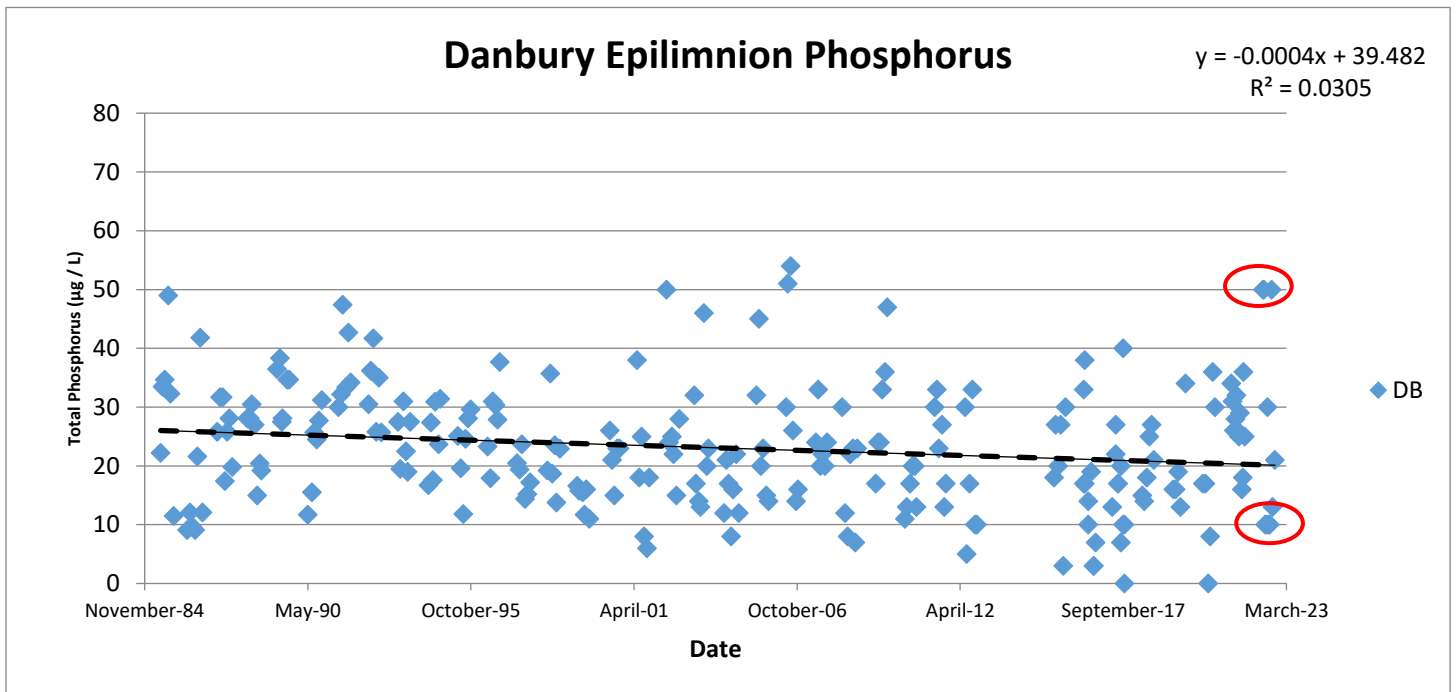

Figure 6: *Danbury Epilimnion Phosphorus from 1985-2022. Data clusters due to detection thresholds highlighted.*

While there is substantial variation in the data, (R^2 value of 0.0305) the negative slope of the line is encouraging. Based on all the above data from danbury, a 95% confidence interval of the population mean of epilimnion of phosphorus was found to be 21.4-22.9 µg/L. Hopefully continued expanded sampling can can help us determine a more accurate mean measurement in the coming years. The R^2 value decreased, from last year (.0459) in part due to the unfortunate detection levels from this year's lab results. The clusters at the detection levels of 10 and 50 µg/L are adding substantial noise to the graph where the true values would be more representative of the actual conditions in the lake. We plan to fix this issue for the 2023 season with the lab doing the analysis.

In 2021, New Milford was the only site with a positive trend for epilimnion phosphporus over time, but after 2022, that slope turned negative, to -0.000006. Obviously this is a slope that is effectively 0, which is still positive news, as many lakes in the country battle quickly increasing nutrient levels. The slope for New Fairfield is -0.0004, and in Sherman it is -0.0003, all three other sites with substantially stronger negative slopes than New Milford's very slightly negative slope. This year's results and the impact on the trend shouldn't necessarily be highlighted too strongly though, as the detection levels could be impacting the slope of the trends in either direction.

Chlorophyll Concentrations

Chl-a	May	Early June	Late June	Early July	Late July	Early August	Late August	Early September	Late September	October	Average
DB	5.02	6.15	14.34	16.34	5.16	9.76	7	9	5.09	10.69	**8.86**
NF	2.45	6.92	4.45	9.59	4.49	13.56	6.07	11.96	6.31	10.99	**7.68**
NM	4.41	4.8	10.54	13.6	4.41	8.71	3.96	2	2.08	9.84	**6.44**
SH	5.04	5.58	9.2	12.33	70.4	13.28	4.21	11.28	6.6	11.3	**14.92**
SQ	5.05	3.86	4.91	11.09	63.19	8.44	5.88	13.93	10.03	5.11	**13.15**
Average	4.40	5.46	8.69	12.59	29.53	10.75	5.42	9.63	6.02	9.58	<u>10.21</u>

Table 4: *Chorophyll-a as measured in the lab during the 2022 season (μg/L). Note that there was no chl-a sample for late october in Sherman.*

  One of the best ways to measure both eutrophication and potential recreational impact on a freshwater lake system is by measuring Chlorophyll-a. This measurement is effectively a measurement of the algal material in the lake by measuring the green pigment present in green algae and cyanobacteria. The largest measurement taken in 2022 was in Sherman in late July at 70.4 μg/L, which is unusually high, as was the measurement of 63.19 μg/L in Squantz Pond the same month. These outliers could be due to sampling a very small bloom event, or lab error, as they are clear outliers not only from this year, but would be the two highest recorded samples on record since 1985. If we run Grubb's Outlier test on the data just from Candlewood, the 70.4 μg/L result is a clear outlier with a P value of <0.01. Similarly, when we run Rosner's Extreme Studentized Deviate test for multiple outliers on the whole set, both measures are found to be outliers with a P value of <0.01. Because these measurements are likely due to sampling error or lab error, we will not include it in the overall discussion and analysis, but we wanted to include them here for reference. Following removal, the remaining data passes the Kolmogorov-Smirnov Goodness of Fit test with a P value of <0.05.

  The highest measurement in Candlewood (apart from the outliers) was in the early July in Danbury at 16.34μg/L, with the second highest at the previous sampling in Danbury in late June. This is supported by the low secchi readings from June-July this year, indicating a productive algae year, particularly in the early summer. Strong stratification and high temperatures likely helped algae growth, along with the possibility of available nutrients due to the lack of plant growth in the lake. Danbury and Sherman are generally the two most productive sampling locations, and that is again supported with this year's data, as they have the two highest averages (without outliers).

  By plotting chlorophyll-against secchi depth, we can get a good idea of how the lake generally compares to other years. This is a useful way to track two critical measures of eutrophication, while also displaying important aspects of the recreational value of the lake compared to past years.
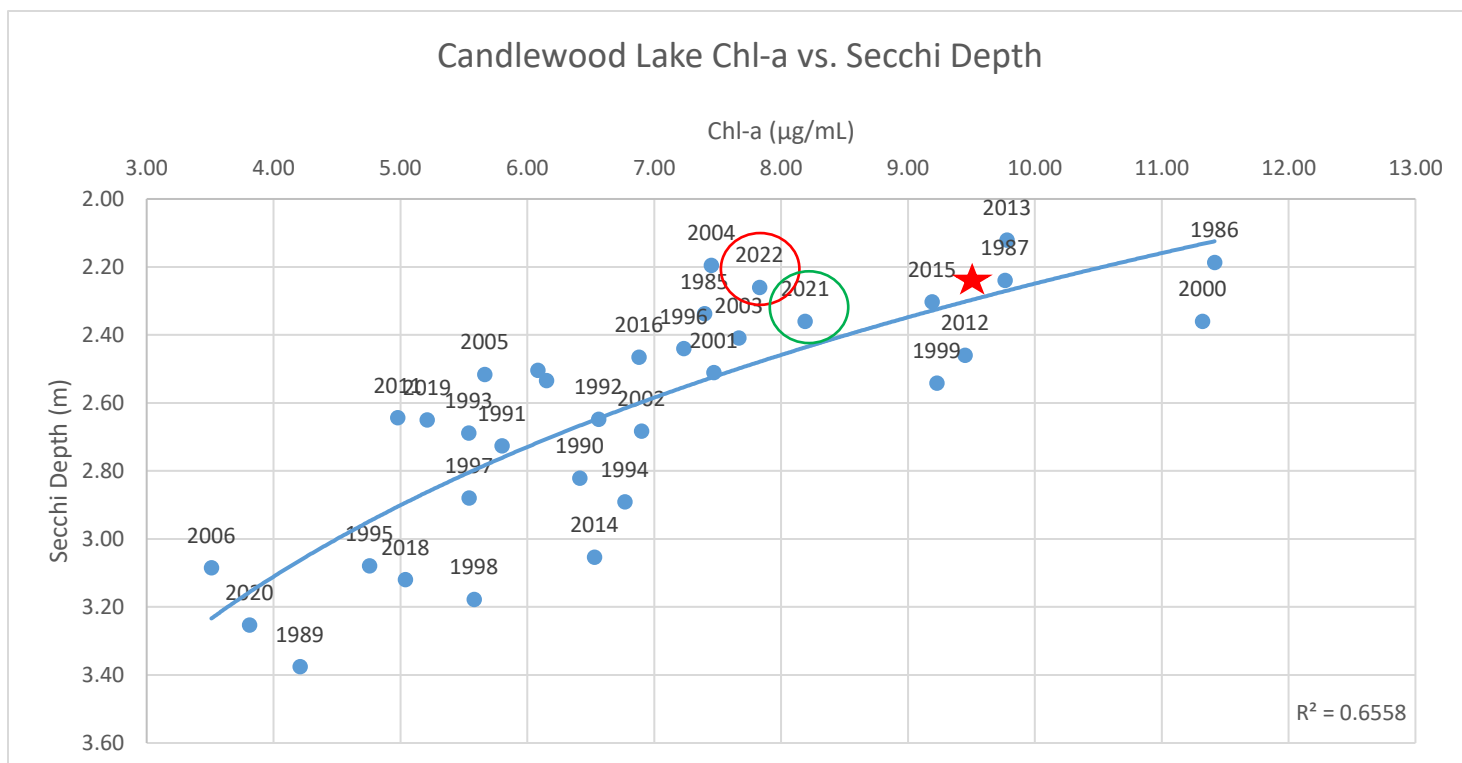
Figure 7: *Chlorophyll-a plotted against Secchi Depth in Candlewood from 1985-2022. The years 2022 and 2021 have been highlighted, as well as the location of 2022 if we include the one outlier measurement (red star). (Note that this graph does not include Squantz Measurements).*

The above figure is really useful in displaying the general productivity (that is, algae growth) of the lake, and comparing different years. The line shows the general (logarithmic) relationship between the two metrics. 2022 is again a year where we saw higher than average chl-a measurements, and lower than average clarity measurements. While there are clearly years where chl-a has been higher (greener water) and secchi depth has been lower (lower clarity), 2022 and 2021 are both on the high end of the lower spectrum when it comes to these measurements. 2020 on the other hand, was a near record setting year, with the second highest average clarity, and the second lowest average chl-a. This banner year was likely due to a host of factors, including very low precipitation and low mixing, denuding the epilimnion of most of its usable nutrients for algae early in the season. 2022 is a year that, while in drought conditions, was marked by high temperatures, and possible high nutrient availability. While there is no clear trend to the relationship between chl-a and secchi clarityover time, the graph presents a useful method to comparing the "recreational usability" of the lake between years.

In 2019 we added a new sensor to our probe to measure chlorophyll-a using spectrophotometry. This uses a specific wavelength of light that bounces off of chlorophyll-a pigment to measure the concentration in the water and returning a relative value based on that measurement and the water volume in the sensor, rather

than taking an entire water sample, filtering it, and measuring the pigment in the lab. We purchased this sensor in the hopes that a relationship could be established between the two methods that would allow us to rely on the new sensor rather than having to take whole water samples to the lab for analysis. To help establish that relationship, we have to compare the results from the two methods and see what their linear relationship looks like. We can then run an F-test to see if that relationship is indeed significant, and we can look at the R^2 value to see how strong that relationshisp is (how much the difference in the two measurements can be explained by only those two measurements).
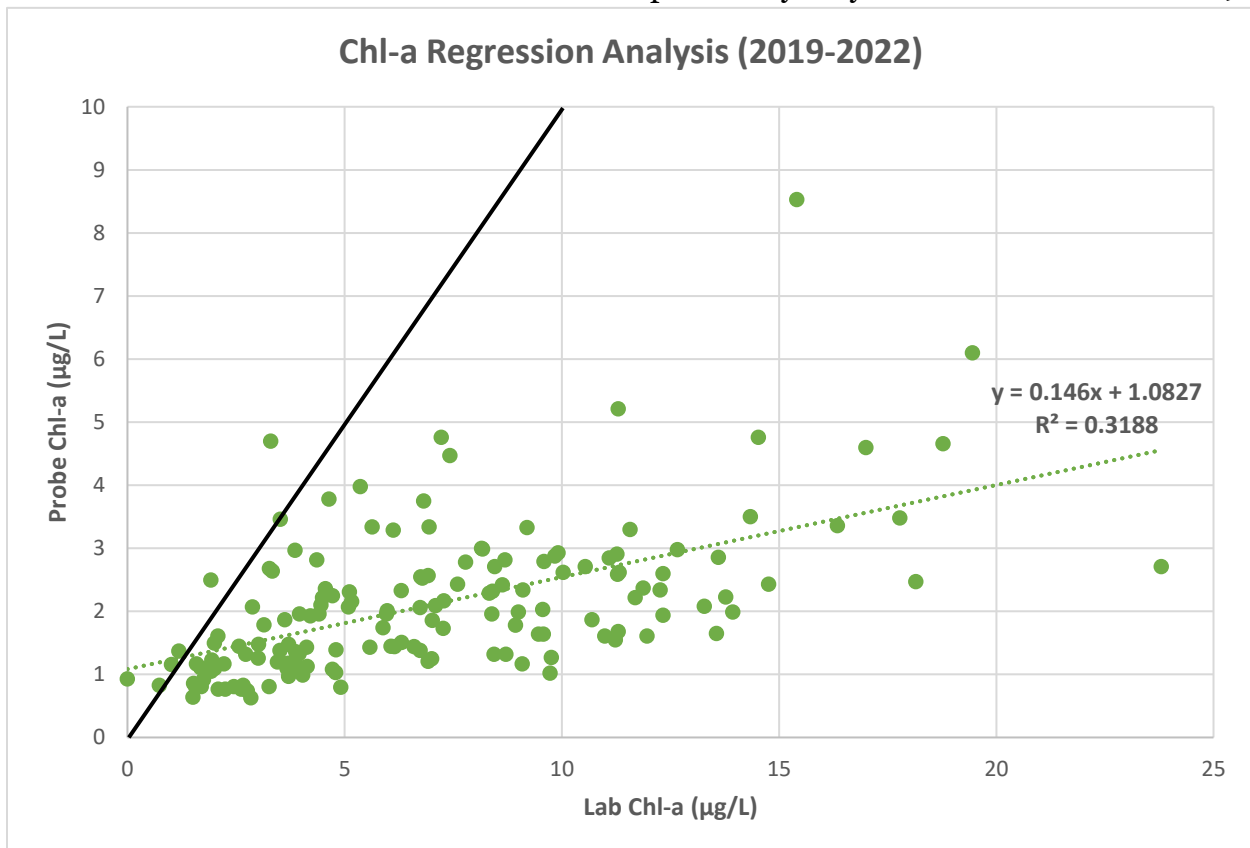

Figure 8: *Regression model for Probe and Lab measurements of Chl-a at 1m depth, including the equation for the relationship and the adjusted R² value. The black line illustrates what a 1:1 relationship would look like for the measurements.*

This green line shows the relationship between the probe measurements (the dependent variable, in this case) and the lab measurements (the independent variable). The black line shows the ideal 1:1 relationship that would occur if the probe was measuring exactly the same amount of chl-a as the lab was. Instead, we see that generally the probe measures the amount of chl-a as less than what we find in the lab (the only exceptions are those measurements above the black line). This makes sense logically, as the sensor on our probe is more limited to chance, if a high level of algae or cyanobacteria happens to be passing through the sensor at the time of meaurement or not, while the lab measurements take a much larger volume of water and measure the

entire concentration in that sample. This makes the lab samples more representative of the "population" of 1m depth where the samples are taken than the sensor samples. This is why we also see that the goodness of fit of the trendline gets worse as the concentration increases, as the likelihood that the sensor might be missing areas of high algae concentration increases as the total amount of algal material in the 1m band increases.

With all that said, the F-test of significance returns a p-value (that is, the test of whether the relationship between the variables is significant at all) of 1.28 x 10⁻¹⁴. The closer this number is to 0, the more certain we can be that we can reject the null hypothesis that there is effectively no relationship between the two measurements. What this means is that while the entire relationship between these measurements its confounded by other things (like the concentration issue mentioned above), that there is very strong evidence to say that these two variables are related in at least some capacity. The R^2 value can tell us, in general, how much of that relationship can be attributed to these two variables, and in this case, 31.8% of the relationship can be explained through comparison of these two variables alone, which unfortunately is down from last year where it was 36.5%. Effectively, this means that 2022 added more data that supported a weaker relationship between these variables than last year. Ultimately, the trend does not fit the data well enough to confidently say we can switch to using the new sensor entirely (by correcting the values with the equation $y=0.146x+1.0827$). So we will continue using both methods, and analyzing the differences in the hopes that we can strengthen the relationship with more data in the future.

Conductivity

Conductivity is a measurement of how well the water can conduct an electric charge. This is a good analog for measuring the level of dissolved salts in the water, as these salts dissolve into charged ions, which increase the water's ability to conduct an electric charge. This means that the higher the conductivity is, the higher the "saltiness" of the water. Over time, Candlewood has been accumulating more and more of these ions mostly through stormwater runoff and stormwater discharges that empty into the lake, precipitating a pretty clear increase in the water's conductivity.
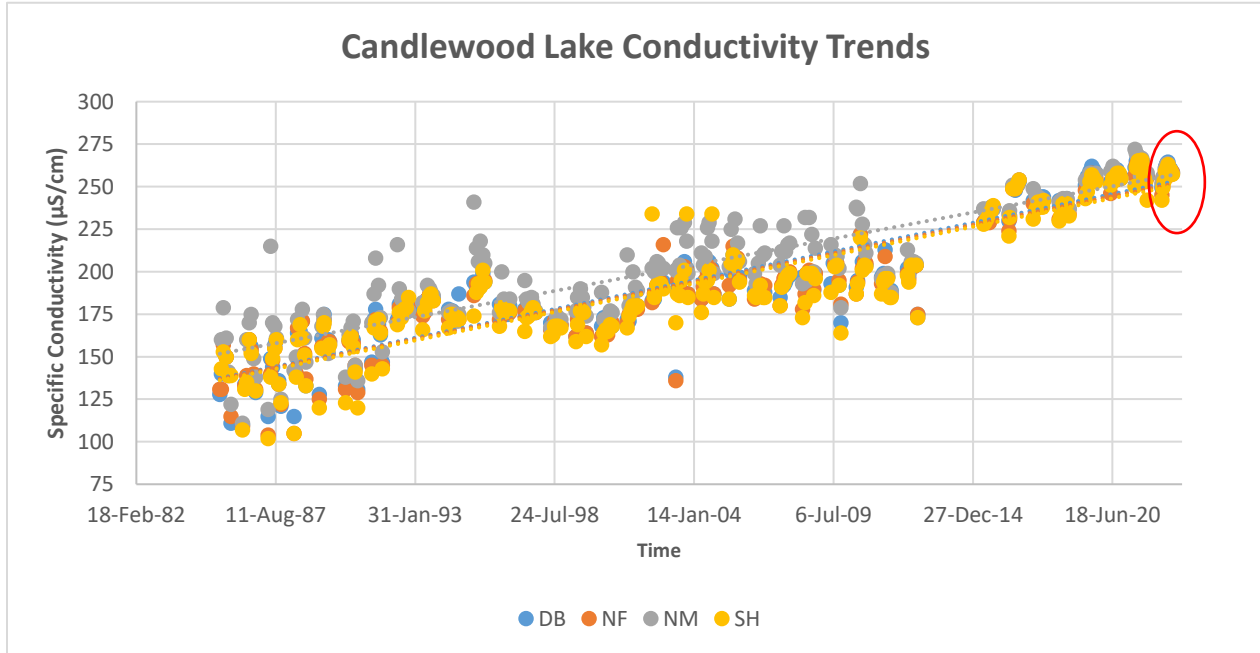

Figure 9: *Candlewood Lake Conductivity from 1985-2022 measured at 1m depth. 2022 has been highlighted, and trend lines have been included to illustrate the clear increase over time.*

This concerning trend thankfully slowed in 2022 compared to 2021, decreasing from an average of 261 in 2021 to an average of 258 in 2022. To put these numbers in context, seawater has a conductivity of 50,000 µS/cm, and the limit of drinkable freshwater is around 3000 µS/cm, so while the lake is not in immenent danger of becoming a salt lake, there are species of fish and plankton that are more sensitive to these measurements, and eventually, should the trend of salt accumulation in the lake continue, we might begin to have impacts on the lake's fishery and ecosystem.

Cations and Anions

As part of the measurement of salts in Candlewood Lake, bi-monthly we test the water for key positive and negatively charged ions that are key parts of certiain biological or ecological pathways. Those ions are calcium, magnesium, sodium, potassium, and chlorine. The measurement of these ions began in 1992 and has continued since

	Sodium (Na+)		Calcium (Ca++)		Chloride (Cl-)		Magnesium (Mg++)	
Danbury	17.59	(18.3)	19.80	(21.0)	33.19	(31.3)	7.07	(7.5)
New Fairfield	17.16	(17.0)	20.18	(21.3)	32.15	(30.7)	7.14	(7.5)
New Milford	16.77	(17.7)	20.02	(21.7)	32.06	(30.7)	7.15	(7.7)
Sherman	17.93	(17.0)	21.01	(21.0)	32.33	(30.3)	7.48	(7.5)
Squantz	13.98	(13.0)	12.81	(12.7)	25.20	(23.3)	4.75	(4.8)

Table 5: *2021 (in parantheses) and 2022 average cation and anion concentrations measured at 1m depth (in mg/L).*

Of particular interest are the calcium ion levels, as these are a critical raw material for zebra mussel shell formation, and there are well documented thresholds for effective zebra mussel infestation of waterbodies based on calcium levels.

Risk	pH	Calcium (mg/L)
Low	<7.4	<12.0
Medium	7.4 − 8.0	12.0 − 20.0
High	>8.0	>20.0

Table 6: *Risk thresholds for Zebra Mussel Colonization (via: Murray et al. 1993, Biodrawversity 2013). Note: O'Neill 1996 classifies the range from 20-25mg/L as moderate risk.*

In Candlewood, most readings are at or above the high threshold of 20 mg/L. What is interesting is that this year, the average concentration decreased slightly at every location except in Squantz. This could either be a good sign that inputs into the lake have sowed to a rate lower than export, or a sign that the zebra mussels found so far in the lake are using the available calcium and lowering the measurement. If that is the case, the concentration is so close to the boundary that it could mean the population of mussels is effectively competing with itself, and lowering the available concentraion to a less efficient level for their growth and reproduction. We will continue to pay careful attention to this measure, as well as changes in the mussel population dynamics.
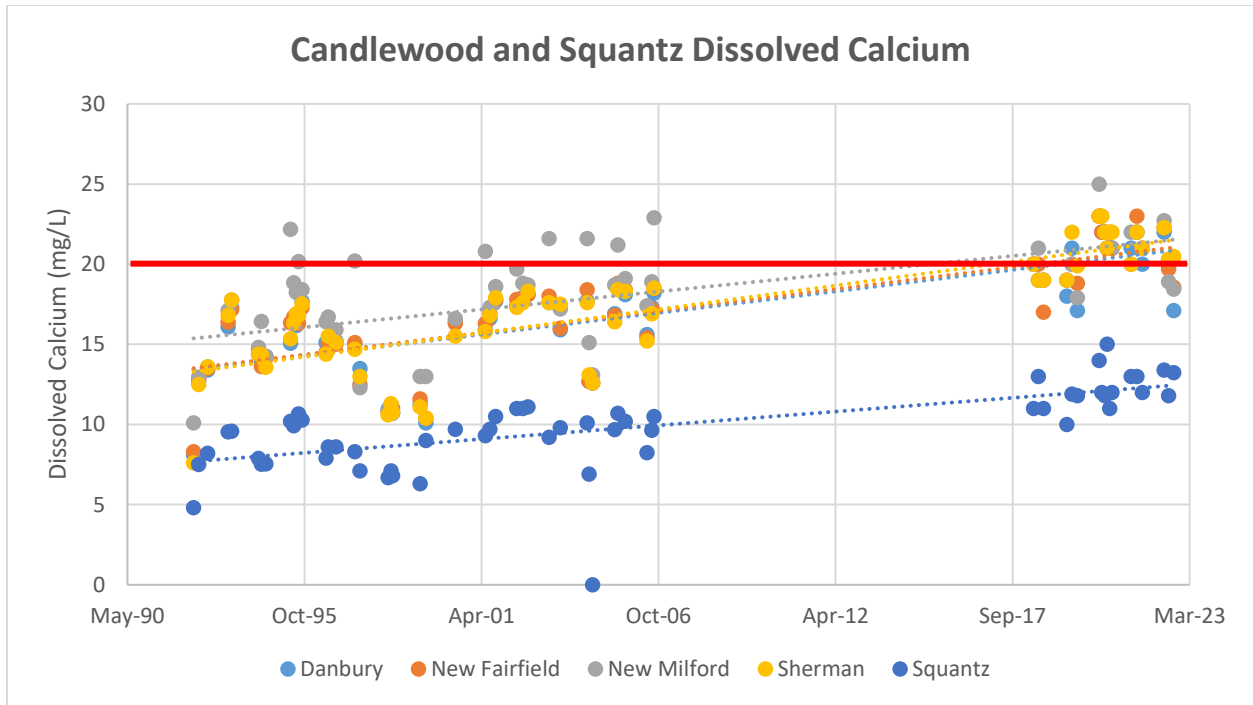
Figure 10: *Calcium concentrations in Candlewood and Squantz since 1992. Note that missing data between 2006 and 2018 is still being re-organized and undergoing quality assurance, and will be included in future reports. The red line shows the "high" risk threshold for zebra mussel colonization.*

This trend is concerning, but unsurprising, as calcium shows a strong correlation to conductivity in freshwater systems, meaning that as conductivity increases much of that increase is likely due to increases in dissolved calcium concentrations. We'd also like to work to keep Squantz Pond below high risk thresholds for zebra mussel colonization. Should zebra mussels colonize Candlewood, it will be interesting to see how efficiently they are able to spread into Squantz Pond where risk is low to moderate.

Zebra Mussel Monitoring

In May 2020, the first zebra mussel was found in Candlewood Lake by a diver off the tip of Vaughn's Neck in New Fairfield. This is in the main basin of Candlewood Lake, which is relatively surprising, as it is not near a usual vector for invasion (boat launch, natural stream, or housatonic river penstock). This spurred a more in depth search over the course of the next three summer and winter seasons. This search included:

1. Additional samplings for zebra mussel veligers using vertical net tows and cross-polar microscopy.
2. Shoreline searches during the drawdown by CLA employees, volunteers, and other organizations.
3. Zebra mussel "hotels" deployed by CLA employees and volunteers off of residential docks.
4. eDNA analysis of water samples by Dr. Wong's lab at Western Connecticut State University.
5. Dive searches from CLA volunteers and Biodrawversity.

Since that first discovery in May of 2020, a total of 600 zebra mussels have been discovered in the lake over the course of those three years. With 153 found in 2020 and 2021, and an additional 77 found on the shoreline in 2022, and 370 found via Biodrawversity's 2022 dive. The mussels discovered cover a wide range of age classes, and include both juvenile and adult mussels, and their distribution in the lake is low density but widespread. This map
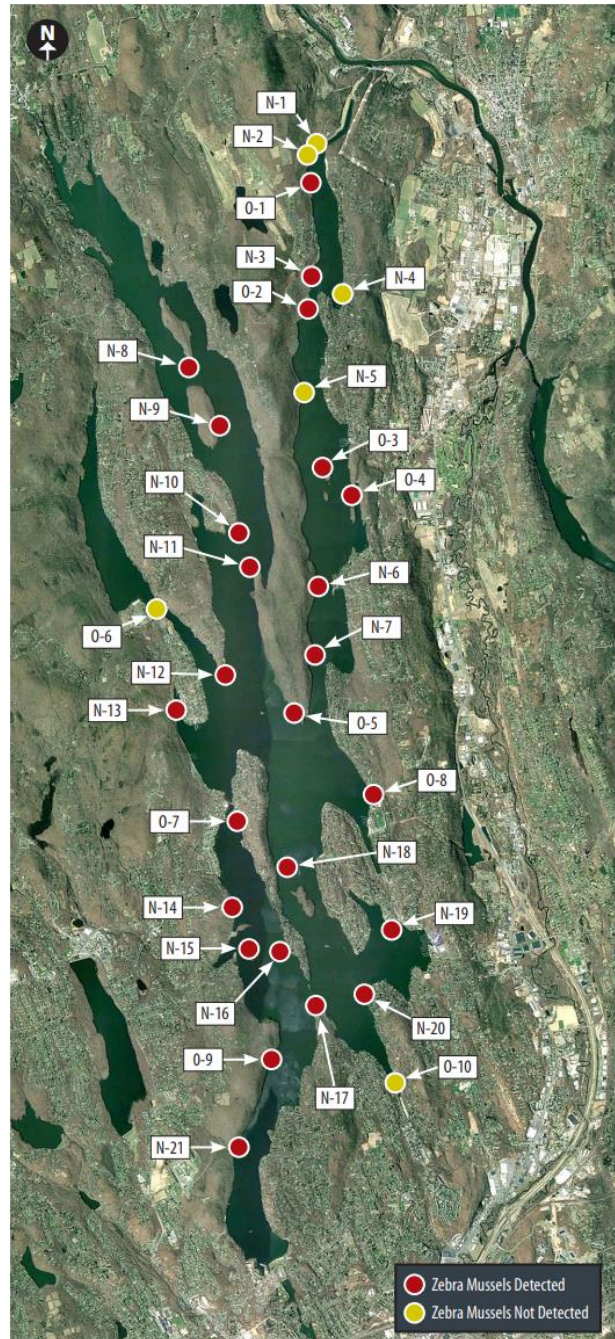
Figure 11: *Map of Zebra Mussel dive locations from Biodrawversity in May of 2022 with locations of found zebra mussels highlighted in red.*

illustrates the locations of this 2022 dive from Biodrawversity, and the locations where mussels were discovered. It's important to note also that this dive focused on depths below the deep drawdown level, meaning that these depths could not be managed by the annual dewatering of the lakeshore.

All veliger cross-polar microscopy came back negative, but one result of the eDNA analysis, taken from 3m depth at the mouth of Lattins Cove came back positive, at low concentration. This is the first chemical indication of possible reproduction, but it could have simply picked up free floating DNA from adult mussel cell loss, rather than reproductive cells. We will continue this analysis to both see if concnetrations and incidince of positive results increase. These negative and low concentration results could mean that the population is simply too small for these methods to pick up the low levels of reproduction occuring in the lake, or that the population of zebra mussels is not reproducing successfully in the lake due to either a lack of upstream recruitment (no pumping from the Housatonic River during spawning season) or the moderately insufficient chemical measurements of dissolved calcium. It is still unclear whether or not the population in Candlewood lake is enough to fully establish and become a nuisance species that would impact recreational and environemental health of the lake, or if it will survive at low levels thanks to management via the drawdown and lack of upstream recruitment. We will continue the increased vigilence over the next 2 years at least to assess the trajectory of the population to get a better idea of the ultimate fate of the zebra mussel population in Candlewood Lake.

Discussion

2022 was another year marked by change for both the CLA's monitoring, and for Candlewood Lake. This marks the second year where the CLA was able to do two separate monitoring events per month for all of our key metrics. By increasing our samples per month and year, we can get a more accurate idea of the actual state of Candlewood Lake. We plan to continue this moving forward so that all of our measurements more closely approximate the true values in the whole lake, while also allowing us to see changes in the chemistry over time more accurately.

The lake itself also saw changes compared to last year. While the chemical results are actually very similar to last year in nearly every metric, the lake went through some major ecological changes this year. In particular, the increased population of zebra mussels, and the widespread rapid loss of macrophyte plants. The loss of plants is still being researched and is likely due to a variety of factors working together to push the ecosystem to a stable state devoid of plant life. We will work to research this change in more depth during the 2022 season. We are also encouraged that nutrient concentrations in the epilimnion continue their meager decrease over time – a trend likely attributable to public education efforts and better community engagement. However, this trend might be slowing in recent years, so careful watch of nutrient level average change will be critical. The lake still shows strong internal loading tendencies during stratification, which can lead to strong algae blooms at the end of the season when the water column mixes, and those nutrients become available for use by the algal community. Salts and ions continue their concerning trend of growth, once again conductivity levels increased in the lake, and ions like calcium also continue their ascent.

Trophic Category	Total Phosphorus (µg / L)	Total Nitrogen (µg / L)	Summer Chlorophyll-*a* (µg / L)	Summer Secchi Disk Transparency (m)
Oligotrophic	0 - 10	0 - 200	0 - 2	>6
Early Mesotrophic	10 - 15	200 - 300	2 - 5	4 - 6
Mesotrophic	15 - 25	300 - 500	5 - 10	3 - 4
Late Mesotrophic	25 - 30	500 - 600	10 - 15	2 - 3
Eutrophic	30 - 50	600 - 1000	15 - 30	1 - 2
Highly Eutrophic	> 50	>1000	> 30	0 - 1

Table 7: *Eutrophication "report card" with 2022 average levels highlighted to illustrate the general eutrophic identity of the lake.*

Candlewood generally remains a mid to late mesotrophic lake, meaning that most metrics point to the lake being "middle-aged" in the general lifespan of lakes. While

Candlewood Lake is not an old lake, it is substantially impacted by the surrounding human development, precipitating higher nutrient measurements, lower clarity, and greener water. By working to lower nutrient levels in the lake, ideally we might begin to see improvements in chlorophyll-a and secchi disk measurements as well.

One of the most substantial changes in the lake's ecosystem in the past 2 years is the introduction of Zebra Mussels. While the population remains at relatively low levels, keeping tabs on any changes in their population growth is paramount. While they are distributed on a large enough scale that eradication is not an option, the viability of the population's long-term expansion remains unclear. Year-to-year growth is increasing, but not at a level indicating exponential growth at this point. By continuing and expanding efforts to monitor this population, we can more accurately evaluate whether the population is on course to become a nuisance species, or if it will continue to persist at low and more manageable levels. This will inform public education and community engagement projects, invasive species awareness for boaters, as well as future discussions with stakeholders about Housatonic River water pumping.

The general recommendations for the coming years based on these results are as follows:

1. Continue developing long-term monitoring strategies and remediation goals in a dedicated Candlewood Lake Management Plan (LMP).

2. Continue community education efforts surrounding phosphorus and nitrogen pollution to continue and strengthen downward trend.

3. Engage town public works and departments of transportation with a focus on efficient road salting to minimize lake impacts of road salt runoff.

4. Expand zebra mussel population monitoring efforts to decipher possible trajectories of the population and verify reproductive capacity.

5. Ensure lab is able to lower detection thresholds necessary for proper nutrient analysis.

6. Continue twice monthly sampling and consider adding April to monitoring to catch early season information before stratification begins.

7. Increase macrophyte research to decipher causes and impacts of the substantial loss of plants during the 2022 season.