2018 Long Island Sound Hypoxia Season Review

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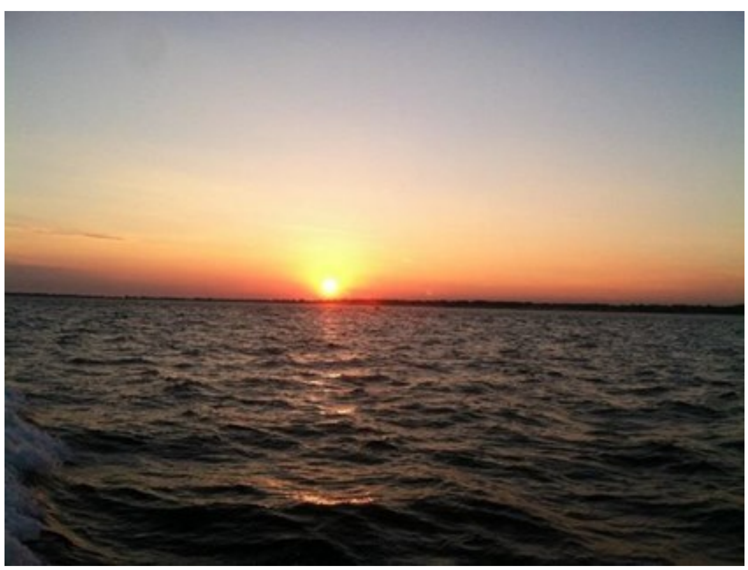
Introduction

Designated as an estuary of national significance by Congress in 1987, Long Island Sound (LIS) is home to a diverse network of flora and fauna, with over 4 million people living in the Sound's coastal communities. It is an estuary of recreational, commercial, and socioeconomic value. The Sound is bordered by the states of Connecticut and New York and has a watershed area extending through Massachusetts, New Hampshire, Vermont, Maine and Quebec that encompasses over 16,000 square miles. Nearly nine (9) million people Live within the watershed. Over time, the Sound has been subject to the effects of increased nutrient loading as a result of urbanization and changes in land use (Latimer *et al.*, 2014).

The term "hypoxia" means low dissolved oxygen (DO) concentrations in the water. Marine organisms need oxygen to live, and low concentrations, depending on the duration and the size of the area affected, can have serious consequences for a marine ecosystem. As defined by the Long Island Sound Study, hypoxia exists when DO drops below a concentration of 3 milligrams per liter (mg/L), although ongoing national research suggests that there may be adverse affects to organisms even above this level. Nutrients, especially nitrogen, fuel the growth of microscopic algae called phytoplankton in the Sound. The phytoplankton die and settle to the bottom. Bacteria break down the organic material from the algae for food and fuel while using up oxygen. Seasonal weather patterns, particularly during the summer months, exacerbate the effects of nutrient loading. Calm weather patterns limit the mixing of the water column and replenishment of oxygen to the bottom waters, resulting in a decrease in bottom water DO over the course of the summer. Hypoxic conditions are mainly confined to the western Sound.

In response to the critical need to document summer hypoxic conditions in Long Island Sound, the Connecticut Department of Energy and Environmental Protection (CT DEEP) and the Interstate Environmental Commission (IEC), have monitored dissolved oxygen, as well as other key water quality parameters relevant to hypoxia, since 1991. This report presents a summary of data collected by CT DEEP and IEC during the 2018 hypoxia season.



Methods Overview

Since 1991, CT DEEP has conducted an intensive year-round water quality monitoring program on Long Island Sound. Physico-chemical parameters (temperature, salinity, DO, pH, and water clarity), nutrient samples, and plankton samples are collected monthly from 17 sites on a year round basis. Beginning in mid-June and extending through mid-September an additional survey is added that samples up to 48 stations every other week for physico-chemical parameters (Figure 1).

IEC has conducted summer season monitoring in the far Western Long Island Sound (WLIS, Figure 1, map inset) and the Upper East River since 1991. Since 2014, IEC's monitoring program has implemented modifications, including the collection of nutrients, to align it with CT DEEP's program. IEC collects physico-chemical data from 22 stations on a weekly basis and biweekly samples for nutrient parameters (Figure 1). Beginning in October 2018, IEC expanded its WLIS monitoring program to sample year-round.

The Long Island Sound Integrated Coastal Observing System (LISICOS) was established in 2003 as a component of a regional/national ocean observing system. The system was conceptualized as part of a water quality monitoring program that combined the traditional ship-based point sampling surveys with continuous, real-time sampling stations. LISICOS continuously monitors in situ water quality parameters and meteorological parameters at up to eight stations across the Sound. Sensors are attached to a moored buoy at various depths (surface, mid, bottom). Data are transmitted every 15 minutes in real-time via satellite where they are stored in a database and uploaded to the LISICOS website. The system is maintained by the University of Connecticut.

CT DEEP and IEC data provide a snapshot of hypoxic conditions during a specific timeframe while the LISICOS data provide a continuous measurement of hypoxia at specific buoy locations. Together these monitoring programs are better able to characterize the extent and duration of hypoxia across LIS. Both types of data contribute to a better understanding of hypoxia in LIS.

Further information on sampling and analytical methods for water quality parameters can be found in the EPA-approved DEEP, IEC, and LISICOS Quality Assurance Project Plans.

Dissolved oxygen data from 13 of IEC's 22 stations and all of DEEP's stations are incorporated into hypoxia maps and areal estimates that are presented in this report. The 13 IEC stations (A1, A2M, A3, A4, HA-3, HB, A5, HC1, HC, B1S, B2, B3M, B4) represent open water portions of the western Narrows. DO data collected from IEC's embayment stations are not utilized in areal estimates.

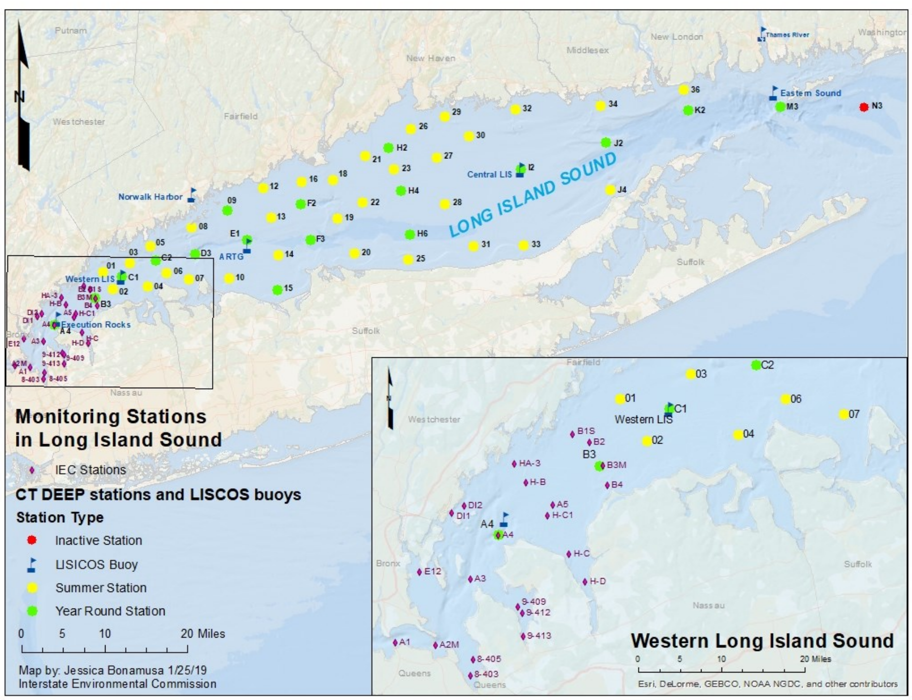
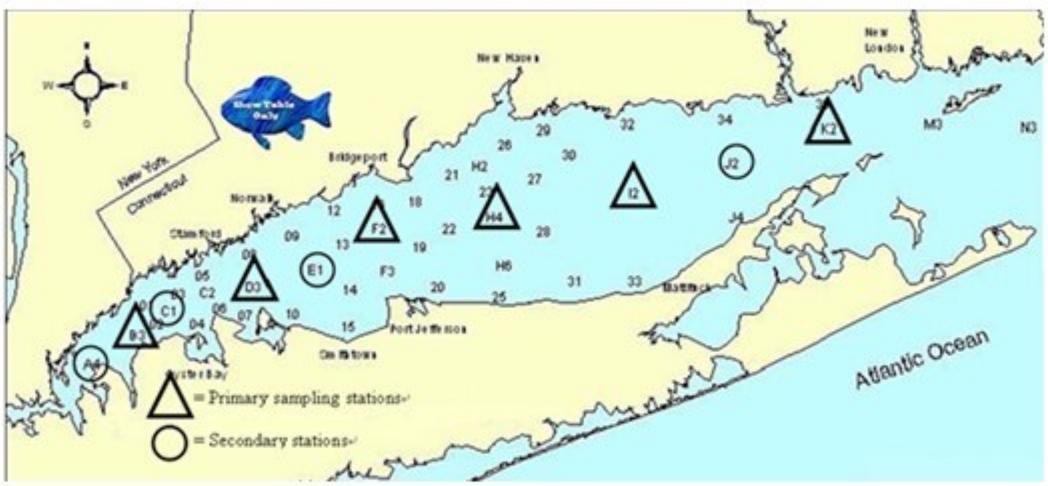


Figure 1. Hypoxia Monitoring Stations in Long Island Sound

CT DEEP collects monthly surface and bottom water samples from ten stations (triangles and circles, Figure 2) distributed across LIS for phytoplankton community analyses. Stations were chosen to examine the "spatial distribution and temporal dynamics of phytoplankton population structure and diversity in LIS" as well as to "investigate the potential contribution of the settlement of the phytoplankton materials from the surface water to hypoxia/ anoxia in the bottom water" (Zhang and Lin 2018). Samples are processed and analyzed by researchers with the Marine Sciences Department at the University of Connecticut. Results are detailed in final project report submitted to CT DEEP. Collection methods and processing methods are available in an EPA approved Quality Assurance Project Plan.

CT DEEP collects monthly composite water samples and conducts oblique plankton tows from six stations (triangles, Figure 2) distributed across LIS for zooplankton community analyses. Samples are processed and analyzed by researchers with the Marine Sciences Department at the University of Connecticut. Results are detailed in final project report submitted to CT DEEP (Dam and McManus 2018). Collection methods and processing methods are available in an EPA approved Quality Assurance Project Plan.

Figure 2. Location of Plankton Sampling Stations across Long Island Sound



Quality Assurance

The IEC and CTDEEP have been collecting data from the Sound since 1991. Both IEC and CTDEEP programs are designed to collect high quality data. IEC and CTDEEP sample collection and handling procedures are outlined in EPA-approved Quality Assurance Project Plans (QAPPs) and method-specific standard operating procedures (SOPs, see Methods section for hyperlinks to program quality assurance documents). Shared program goals include maintaining a long-term database of collected information and monitoring the extent of hypoxia within the Sound throughout the summertime (late June through mid-September) to assess achievement of the Comprehensive Conservation and Management Plan (CCMP) for restoring LIS.

Measures of data quality include completeness, representativeness, and comparability.

In 2018, IEC achieved an overall completeness rate of 95.8%; one run was terminated early due to unsafe weather conditions, resulting in 11 missed station visits. CT DEEP completed 401 station visits in 2018. The mid-March chlorophyll survey was not conducted due to weather, resulting in 6 missed stations visits and a 98.5% completeness rate for 2018.

IEC and CT DEEP met their data quality objectives for representativeness and comparability as specified in their respective QAPPs. Station locations for both programs were chosen to be representative of ambient conditions Soundwide. With the expansion of IEC's program to year round monitoring beginning in the fall of 2018, both programs will sample representative temporal conditions. Most sampling and analytical procedures have remained unchanged over the course of the monitoring program. Consistent field and laboratory procedures, well documented by the appropriate SOPs, help ensure consistent and reproducible data. QC checks performed by the programs' analytical laboratories including continuing calibration verifications (CCV), blanks, duplicates and spike samples are used to flag suspect data and to ensure accuracy and precision of the results. Additionally, CT DEEPs analytical lab participates in a multi-lab comparison program that provides data specifically to assess the analytical laboratory's ability to produce data comparable to several other laboratories located in the Northeast and Mid-Atlantic regions of the United States. IEC hopes to begin participating in this multi-lab comparison program in 2019.

RESULTS

Dissolved Oxygen

For Long Island Sound, DO levels below 3 mg/L are considered hypoxic, causing mobile animals to leave and sessile animals to die or be physically or behaviorally impaired. However, early studies in LIS by CT DEEP Marine Fisheries biologists found that DO can become limiting below 4.8 mg/L for sensitive fish species, while more tolerant species are not affected until DO falls below 2 mg/L (Simpson et al, 1995, 1996). This study documented a 4% reduction in finfish biomass when DO levels are between 3.0-3.9 mg/L, a 41% reduction occurs at 2.0-2.9 mg/L DO, and an 82% reduction in waters with concentrations between 1.0 and 1.9 mg/L. Finfish biomass is reduced by 100% (total avoidance) in waters with DO less than 1.0 mg/L (Simpson et al, 1995, 1996).

CT DEEP conducted eight surveys during the summer of 2018 between May 30th^th and September 12th (Table 1). At some point during the course of the season, stations 03, C2, A4, 12, 13, 21, B3, and D3 exhibited hypoxia. Hypoxic conditions were found during three surveys (Table 1). Summaries of CT DEEP bi-weekly sampling are available on the Department's website.

IEC conducted twelve surveys during the summer of 2018 between June 28th and September 12th (Table 1). Hypoxic conditions were found during five surveys (excluding embayment stations). All 13 of IEC's open-water stations exhibited hypoxic conditions at some point over the course of the season. Summaries of IEC weekly sampling are available on the Commission's website.

Dissolved oxygen plots from stations in WLIS are available in Appendix A. All data are available upon request.

Timing and Duration

The 2018 hypoxic event lasted an estimated **35 days** and began on July 30th. Between August 15th and August 22nd there was a clear period when DO concentrations rose and remained above 3.0 mg/L for 8 days. DO concentrations dropped below 3.0 mg/L again and remained below 3.0 mg/L until September 8th. This is also evident in the continuous data collected by the LISICOS Execution Rocks Buoy. Compared to the previous 31 years, 2018 was well below the average of 55 days (Figure 3).

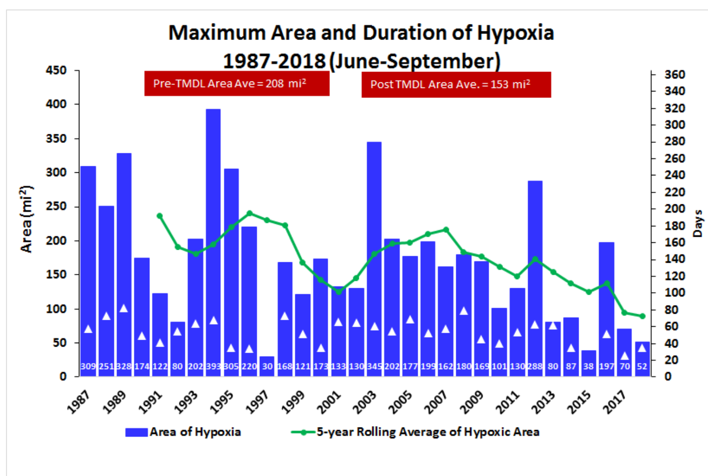


Figure 3. Maximum Area and Duration of Hypoxia. Blue bars represent area, white triangles represent duration, green line is the five-year rolling average of hypoxic area. The total area of Long Island Sound is 1,320 mi^2.

Table 1. CT DEEP and IEC Cruise Summary Information. See Figure 1 for station locations.

Cruise	Start Date	End Date	Number of stations sampled	Number of hypoxic stations	Hypoxic Area (mi^2)	Minimum DO	Station where minimum DO occurred
WQJUN18	5/30/18	6/5/18	17	0	0	6.69	A4
HYJUN18	6/12/18	6/12/18	21	0	0	5.84	02
IEC Run #1	6/28/18	6/28/18	22	0	0	5.14	8-403*
WQJUL18	7/2/18	7/5/18	41	0	0	3.38	A4
IEC Run #2	7/5/18	7/5/18	22	1	0	1.70	9-413*
IEC Run #3	7/12/18	7/12/18	22	0	NC	3.46	H-D
HYJUL18	7/16/18	7/18/18	36	0	0	3.7	A4
IEC Run #4	7/19/18	7/19/18	22	1	NC	2.64	8-403*
IEC Run #5	7/26/18	7/26/18	22	0	NC	3.93	A5
WQAUG18	7/30/18	8/2/18	40	1	20.7	2.58	A4
IEC Run #6	8/2/18	8/3/18	22	6	NC	2.41	H-C *
IEC Run #7	8/9/18	8/9/18	22	18	NC	1.01	H-D *
IEC Run #8	8/18/18	8/18/18	22	7	NC	1.47	H-D *
HYAUG18	8/13/18	8/15/18	38	2	7.6	2.81	03
IEC Run #9	8/23/18	8/23/18	22	1	NC	2.42	9-413*
WQSEP18	**8/27/18**	**8/29/18**	**42**	**5**	**51.6**	**2.34**	**A4**
IEC Run #10	**8/30/18**	**8/30/18**	**22**	**11**	**NC**	**1.86**	**A4**
IEC Run #11	9/9/18	9/9/18	22	11	NC	1.80	A5
HYSEP18	9/12/18	9/12/18	23	0	0	4.78	A4
IEC Run #12	9/13/18	9/13/18	22	1	NC	1.47	9-413*

Bold= Maximum Extent of Hypoxia

NC= Not Calculated

*   Embayment Station

Area estimates

In order to maintain the continuity and comparability of the long-term data set, areal estimates are based on CT DEEP data only. It is expected that data from 1991-2018 will be re-interpolated using both the CT DEEP and IEC stations at some point in the future. CT DEEP and IEC data are synoptic and provide a snapshot of hypoxic conditions during a specific timeframe over a broad area, while the LISICOS data provide a continuous measurement of hypoxia at specific buoy locations over a more detailed span of time. This often results in disparity between the datasets.

Estimated Maximum Area Between 3.0 and 4.8 mg/L

In 2018, the maximum area of LIS bottom waters between 3.0 and 4.8 mg/L occurred during the WQSEP18 survey and was estimated at 545 mi^2. From 1991-2018, the area affected by concentrations between 3.0 and 4.8 mg/L averaged 587 mi^2 and varied slightly from 398 to 601 mi^2.

Estimated Maximum Area Below 3.0 mg/L

The 2018 peak hypoxic event occurred during IEC Run #10 and the WQSEP18 cruises between 27 and 29 August. The maximum area was **51.6 square miles**. Compared to the previous 31-year average, 2018 was below average in area (Figure 2). The lowest dissolved oxygen concentration (2.34 mg/L) documented by CT DEEP during 2018 occurred on 8/27/18 at Station A4 (Appendix A, pg. A3). The lowest dissolved oxygen concentration documented by IEC during 2018 at an open water station was 1.53 mg/L and occurred on 8/7/18 at Station H-C (Appendix A, pg. A1). The Execution Rocks Buoy recorded its lowest reading, 0.30 mg/L, on 9/5/18, while the Western Sound Buoy recorded its' lowest reading, 1.65 mg/L, on 8/24/18.

Estimated Maximum Area Below 2.0 mg/L

Based on CT DEEP data, in 2018, bottom water dissolved oxygen concentrations were not less than 2.0 mg/L. The average area with concentrations less than 2.0 mg/L, calculated from 1991-2018 , is 49.12 mi^2. In 2018, based on CT DEEP estimates, there were 0 days with DO <2.0 mg/L. IEC documented concentrations below 2.0 mg/L at six of their open-water stations on 7 August and two of their open-water stations on 28 August. At the LISICOS Execution Rocks buoy, there were 25.11 cumulative days below 2.0 mg/L.

Estimated Maximum Area Below 1.0 mg/L

CT DEEP and IEC did not document DO concentrations less than 1 mg/L in 2018, However, this year the LISICOS Execution Rocks buoy (Station A4) documented a minimum DO of 0.30 mg/L and 9.22 cumulative days with DO concentrations less than 1.0 mg/L. The overall average area affected from 1991-2018 is 11.06 mi^2. The greatest area with DO below 1 mg/L (62 square miles) was during the summer of 2003.

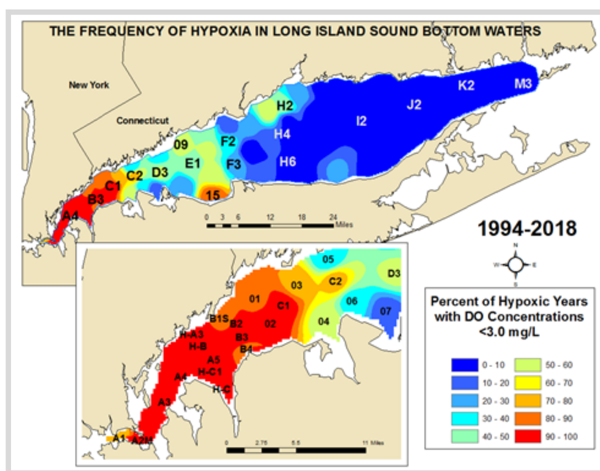


Figure 4. Frequency of Hypoxia in Long Island Sound Bottom Waters

Frequency

The percent of WLIS stations that experience hypoxic conditions continues to be between 90 and 100% (Figure 4). However, stations C2, D3, E1, 09, and 15 seem to be showing improvement; in the 1990's these stations were hypoxic about 60-80% of the time, while over the past four years they were hypoxic only about 10-30% of the time.

WATER TEMPERATURE

Water temperature plays a major role in the timing and severity of the summer hypoxia events. Water temperature differences in the Western Sound during the summer months are particularly influential in contributing to the difference in dissolved oxygen content between surface and bottom waters. The density stratification of the water column creates a barrier between the surface and bottom waters, and it is this barrier, the pycnocline (where the change in density with depth is at its greatest), that prevents mixing between the layers.

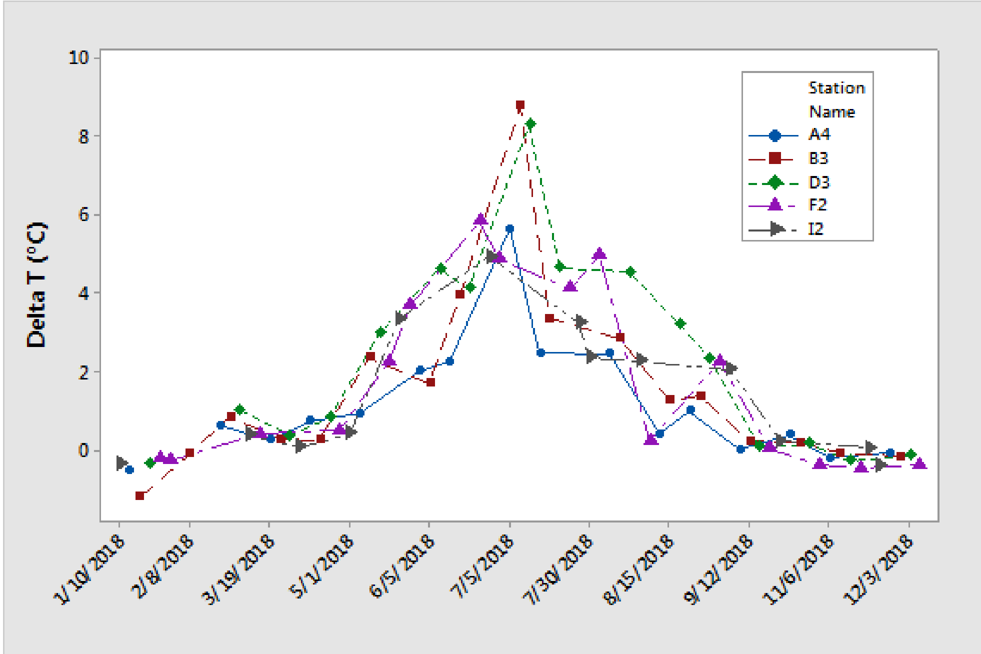


Figure 5. Progression of Stratification across Long Island Sound in 2018. Delta T= surface water temperature minus bottom water temperature

In 2018, stratification began to set up in May (Figure 5) . Delta T's (the difference between surface and bottom water temperature) peaked in the Western Narrows in early July. Destratification (fall turnover) began around mid–September. The 2018 maximum surface temperature was 26.18ºC recorded on July 31 at Station H4. The minimum surface temperature was 0.16ºC at Station A4 recorded on January 11.

Both surface and bottom water temperatures in LIS appear to be increasing. The surface and bottom temperatures from CT DEEPs 17 year round monitoring stations are averaged and then plotted in Figure 6.

Additional information is available on the LISS website.

Temperature data are available in Appendix B.

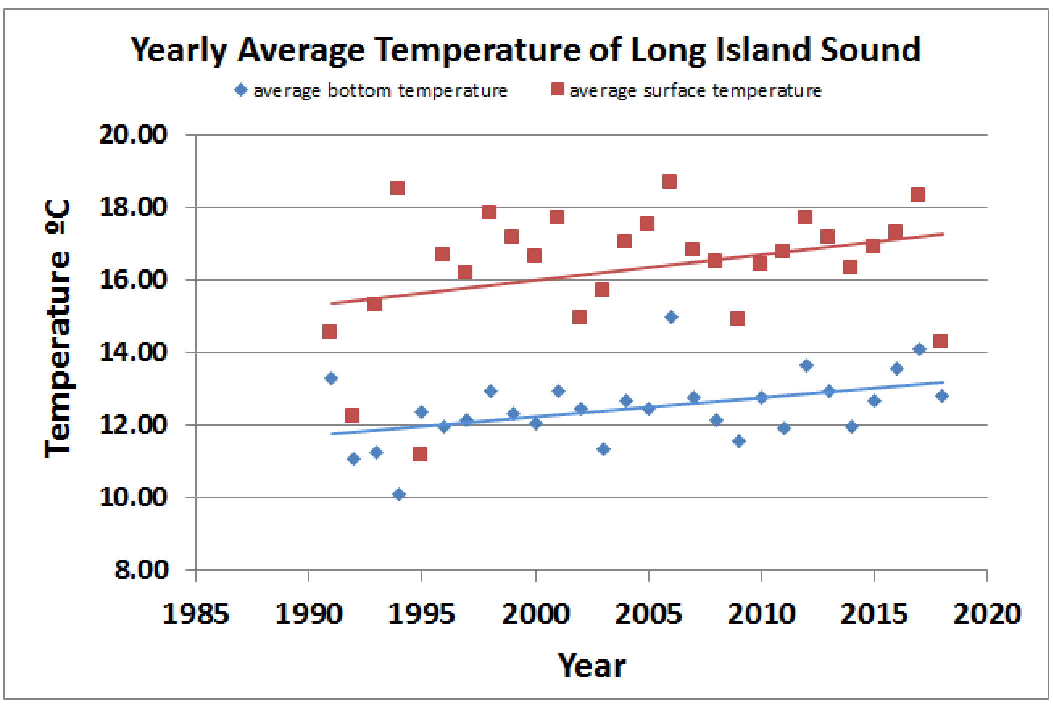


Figure 6. Yearly Average Water Temperatures of Long Island Sound

Water Clarity

Water clarity in Long Island Sound follows a west to east gradient, with clarity improving as you move eastward (Figure 7). The graph below highlights this gradient present in Long Island Sound. In 2018, the Western-most axial station (A1 near the Whitestone Bridge) had an average summer Secchi disk depth of 1.5 meters, whereas the eastern-most axial station (M3 near Fishers Island) had an average summer Secchi disk depth of 4.2 meters. The eastern portion of Long Island Sound is a wide and deep channel with considerable influx from the Atlantic Ocean. This exchange of waters increases water clarity in the Eastern Sound. The Western Sound is more narrow and shallow compared to the Eastern Sound and its surrounding land is densely populated and developed. This results in less of an exchange of waters and also increases the concentrations of pollutants in the water that may affect water clarity.

Individual station data from 2014-2018 are available in [Appendix C](#).

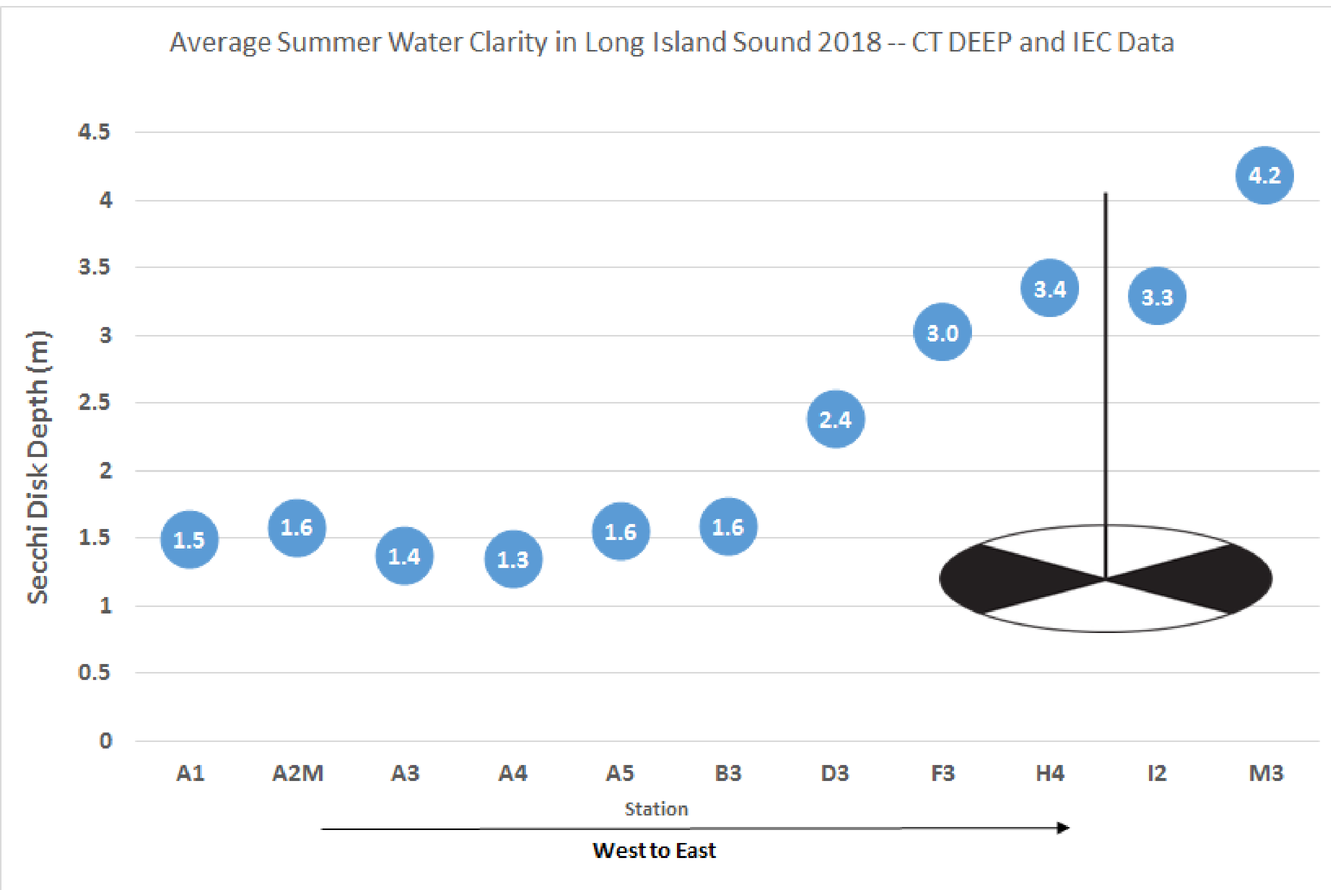


Figure 7. 2018 Average Summer Water Clarity across Long Island Sound

pH

In Long Island Sound eutrophication can contribute to coastal acidification (Wallace et. al., 2014). Excess nutrients fuel algae and phytoplankton growth. As the phytoplankton die and decay, carbon dioxide (CO2) is released. This release has the same effect on pH as carbon dioxide from atmospheric deposition (NECAN undated; Appendix D, pg. D4). EPA released guidelines for measuring changes in pH and carbonate chemistry in eastern coastal waters in 2018 (Pimenta and Grear, 2018). Two of four parameters are needed to describe the seawater carbonate system- pCO2, DIC (dissolved inorganic carbon), alkalinity, and pH, along with temperature and salinity measurements. As of 2018, CT DEEP and IEC only collect one of the four needed parameters - pH. In 2019, the LISICOS Western Sound buoy will be equipped with a pCO2 sensor.

Data from the 2014-2018 monitoring seasons, are available in Appendix D.

Chlorophyll-a

The spring phytoplankton bloom occurs in Long Island Sound between February and April. Historically high levels of chlorophyll a in the Western Sound during this time have been linked to summertime hypoxia conditions. Chlorophyll-a samples are collected year- round by CT DEEP while IEC currently only samples during the summer months. Beginning in October 2018, IEC sampling will expand to year-round.

In 2018, the spring bloom occurred during March, April, and May. The maximum chlorophyll a concentration (26 ug/L) measured in LIS in 2018 occurred at Station A4 on July 5. A minor fall bloom occurred in September and October.

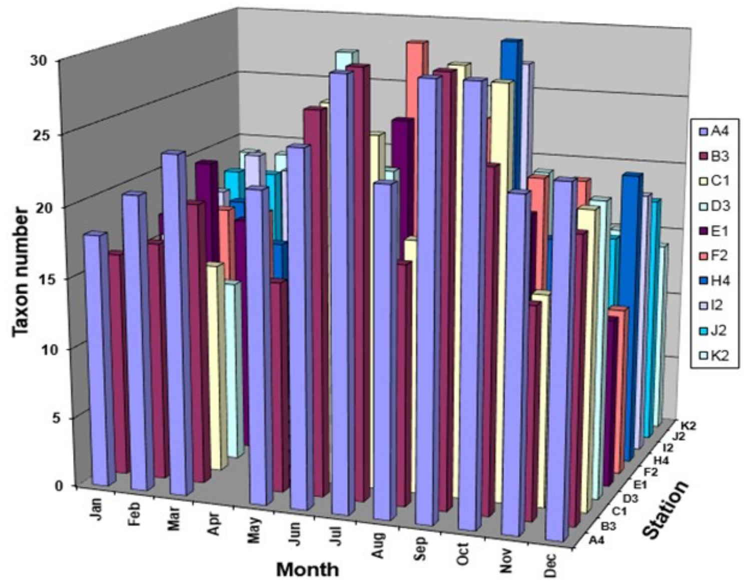
2014-2018 data are available in Appendix E.

Nutrients

DEEP has collected monthly nutrient data from 17 stations since 1991. IEC began collecting bi-weekly nutrient data in the summer of 2014 at 11 of their 22 stations. See Appendix F for dissolved organic carbon (DOC), dissolved inorganic phosphorus (DIP), dissolved silica (SiO2), and nitrate + nitrite (NOx) data from select stations for the last 5 years. Data for these and additional nutrient parameters from all 17 of DEEPs stations and 11 IEC stations are available upon request.

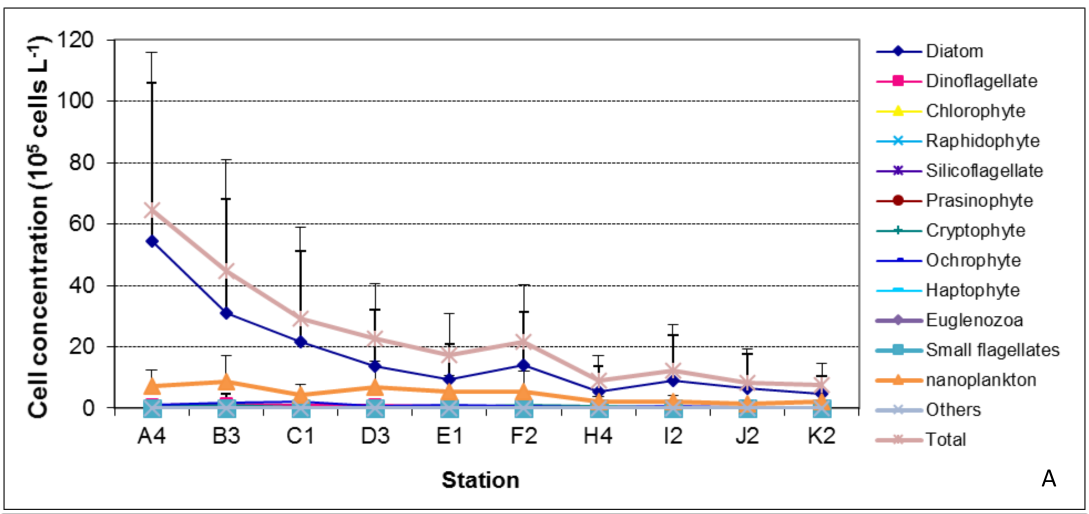
Phytoplankton

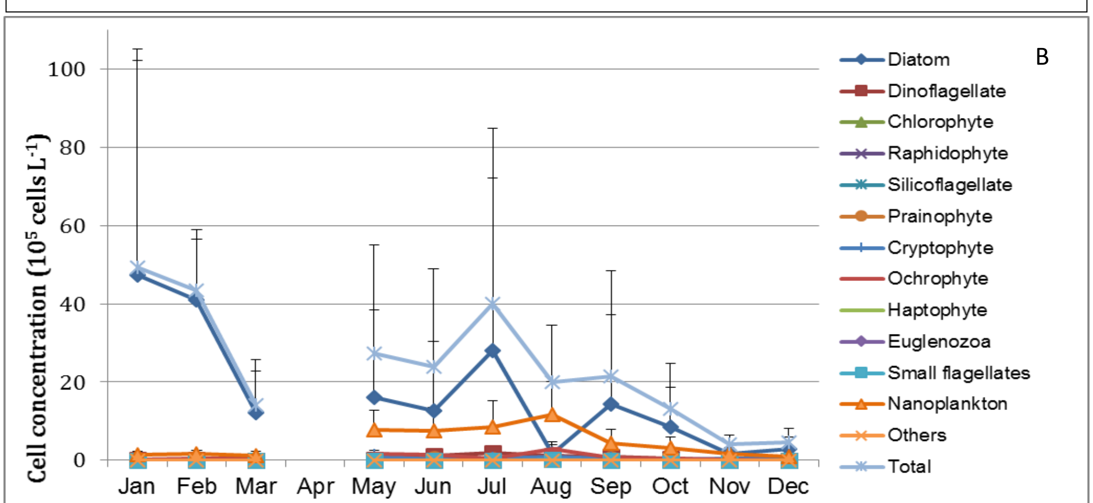
In 2018, UCONN researchers analyzed 110 surface and 110 bottom water samples for phytoplankton community abundance and composition. Ninety four (94) taxa were identified from the surface water samples. Phytoplankton abundance was classified by the scientists as medium. In 2018, in the surface waters, there was a major winter bloom in January, a major early summer bloom in July, and a smaller late summer bloom in September (Figure 8). The assemblages were dominated by diatoms throughout all four seasons in 2018 (Figure 9). Generally, Western Sound stations exhibited higher cell counts than Eastern Sound stations with A4 having the highest average monthly cell counts.



From [Zhang and Lin, 2018.]

(Above) Figure 8 . Temporal and spatial variation of phytoplankton species number in LIS surface water samples in 2018.





(Left) Figure 9. (A) Spatial distribution of phytoplankton abundance in LIS surface water samples and (B) Temporal changes in phytoplankton cell concentration in LIS surface water samples in 2018.

Zooplankton

Data presented are from **2017**, the most recent year available. Bullet points and graphs were excerpted from [Dam and McManus (2018).] Station B3 was not sampled in April 2017.

- Of the 10 phyla (Annelida, Arthropoda, Brachiopoda, Bryozoa, Chaetognatha, Chordata, Cnidaria, Ctenophora, Echinodermata, and Mollusca) typically found in LIS, the Arthropoda, especially copepods, dominated the mesozooplankton composition throughout the year.

- Mesozooplankton abundance increased at all stations during the first half of the year, with a spring peak in April, and reached the yearly maximum in June at all stations (Figure 10).

- For 2017 peak abundance occurred at station F2, followed by station H4. Station K2, in the easternmost Sound continues to show the lowest abundance

- The three dominant species among copepods continue to be *Acartia hudsonica* and *Temora longicornis* during the winter and spring, and *Acartia tonsa* during the summer. However, this latter species is now present in LIS almost year round. In 2017, it was only absent in May and June.

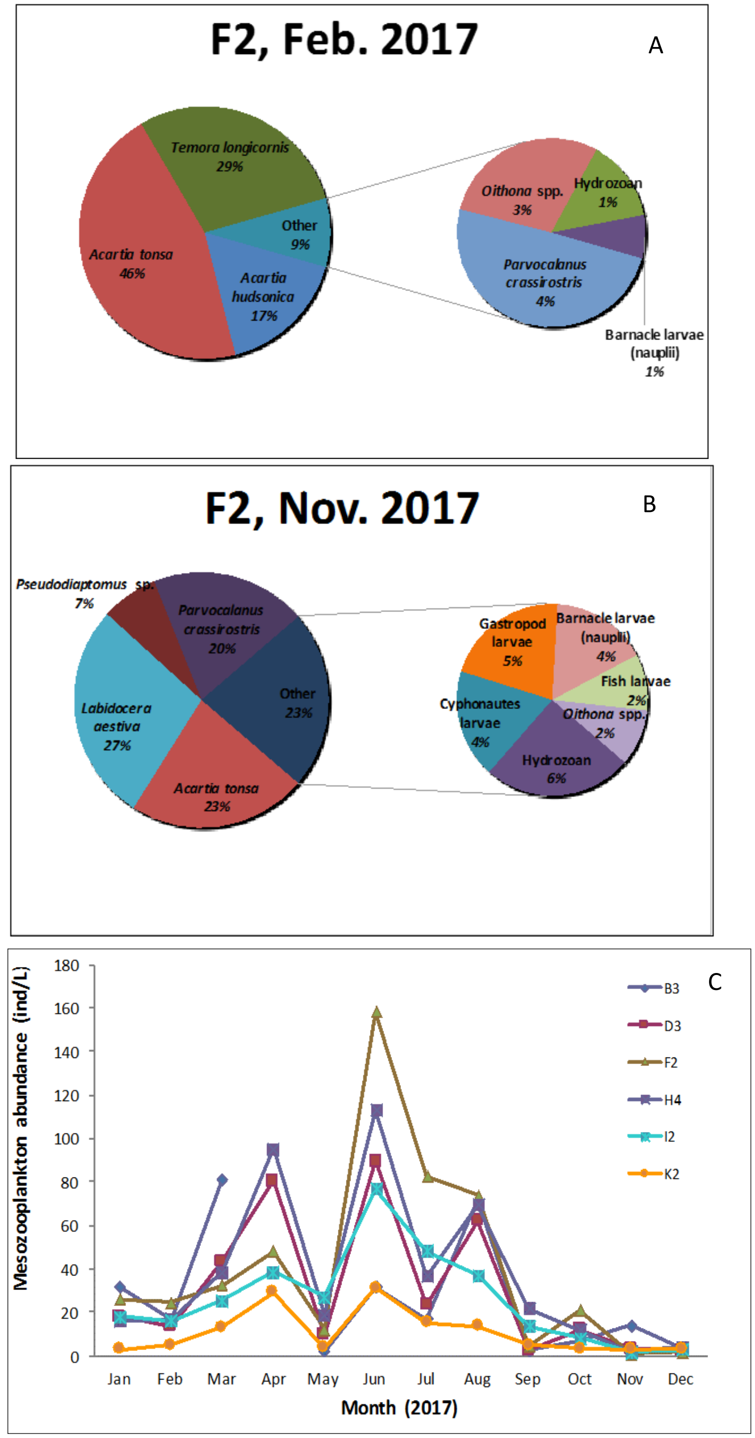


Figure 10. From Dam and McManus 2018.

A. Mesozooplankton composition (expressed as percentage abundance) at station F2, May, 2017

B. Mesozooplankton composition (expressed as percentage abundance) at station F2, November, 2017

C. Total mesozooplankton (200-2000 μm) abundance for the period Jan-Dec, 2017. Each point is the average of duplicate samples at each station.

Discussion

Weather

The Northeast Regional Climate Center (NRCC) at Cornell University is tasked with disseminating climate data and information for 12 states, including NY and CT. The summer of 2018 was warm and wet (Figures 11 and 12). The season started out with near normal temperatures and average rainfall in June but Mother Nature turned up the heat, humidity, and precipitation in July. August was the second warmest on record for the Northeast and the rains persisted. The deluge continued into September and through the first half of October; in fact it was the wettest September on record for Bridgeport with 8.59 inches of rain recorded (247% of normal). October temperatures were warmer than normal for the first part of the month although the second half of the month air temperatures trended toward colder than normal. This climate information is useful as physical processes influence the timing and duration of hypoxia. Bratton et. al. (2015), Wilson et. al., (2015) and O'Donnell et. al., (2008) note that the frequency of high pressure systems traveling to the North of LIS during the summer months impacts hypoxia, particularly that westerly winds increase stratification and easterly winds reduce stratification.

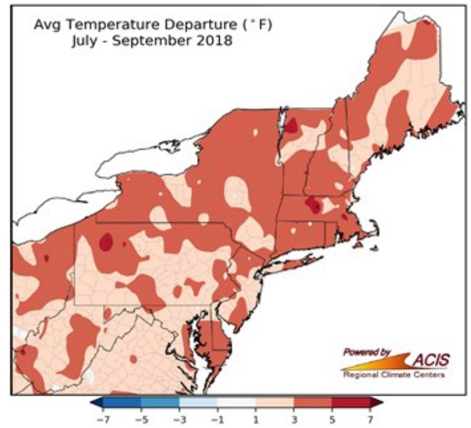


Figure 11. From NRCC. 2018 Average Summer Temperature Departure in ºF

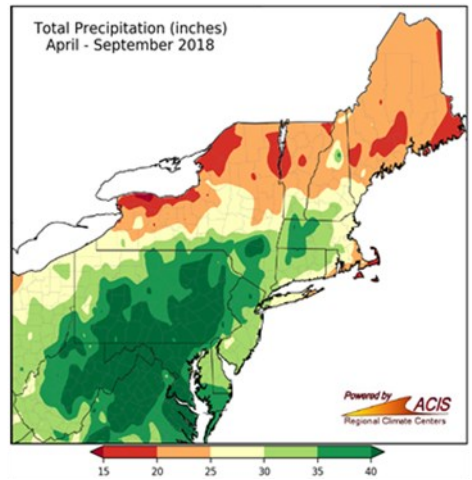


Figure 12. From NRCC. 2018 Northeast Region Total Precipitation

CCMP Goals

The Long Island Sound Study (LISS) updated the Comprehensive Conservation and Management Plan (CCMP) for LIS in 2015. One of the four CCMP Goals is to improve water quality by reducing contaminant and nutrient loads to the Sound. To achieve the goals, the LISS identified ecosystem targets and indicators related to **hypoxia, nitrogen loading, and water clarity**.

Hypoxia

- *The maximum area of hypoxia in the bottom waters of LIS (shall) measurably be reduced from pre-2000 TMDL averages to increase attainment of water quality standards for dissolved oxygen by 2035, as measured by the five-year running average size of the zone.*

Meeting the ecosystem target for maximum area of hypoxia is ahead of schedule. The LIS pre-2000 baseline for maximum area of hypoxia is 208 square miles. The 2014-2018 five-year running average is 89 square miles (Figure 2). This is a 57% reduction from the pre-TMDL baseline. However, further work is needed to achieve water quality standards and meet the CCMP goal. Considerable variability from year to year still exists and the extent is influenced by weather.

While outside the scope of this report, it would be beneficial to examine each station for attainment of water quality standards with respect to the 3.0 mg/L threshold, as well as the 4.8 mg/L threshold. This would be a better measure of the progress towards DO criteria attainment. Additionally, it would be useful to examine the duration of DO in the 3.0 –4.8 mg/L tiers at each station and examine the water column profiles at each station.

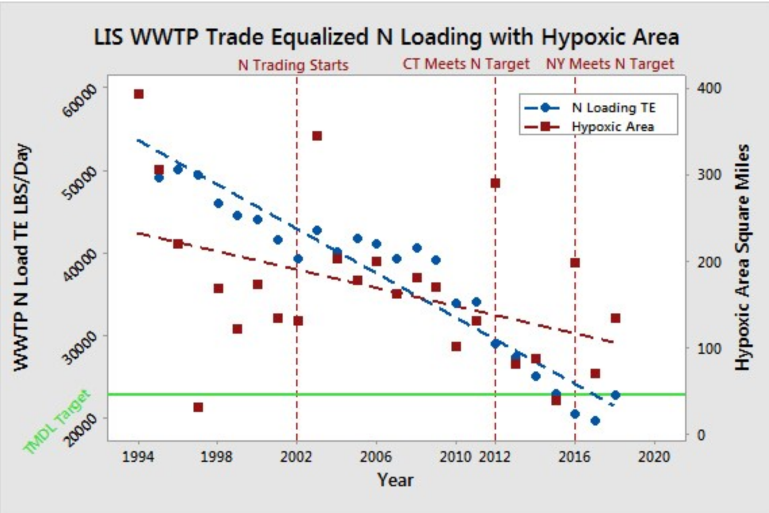


Figure 13. Graph of WWTP Nitrogen Discharge versus Hypoxic Area

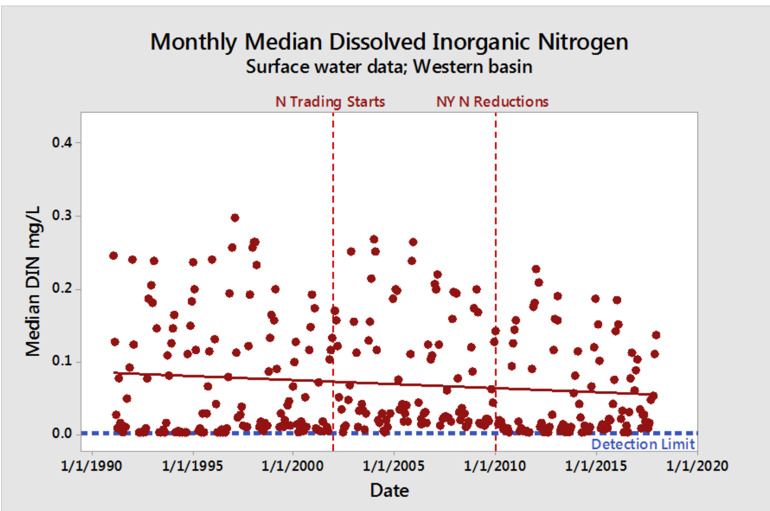


Figure 14. Graph of Monthly Median Surface Dissolved Inorganic Nitrogen Concentrations from Western Long Island Sound

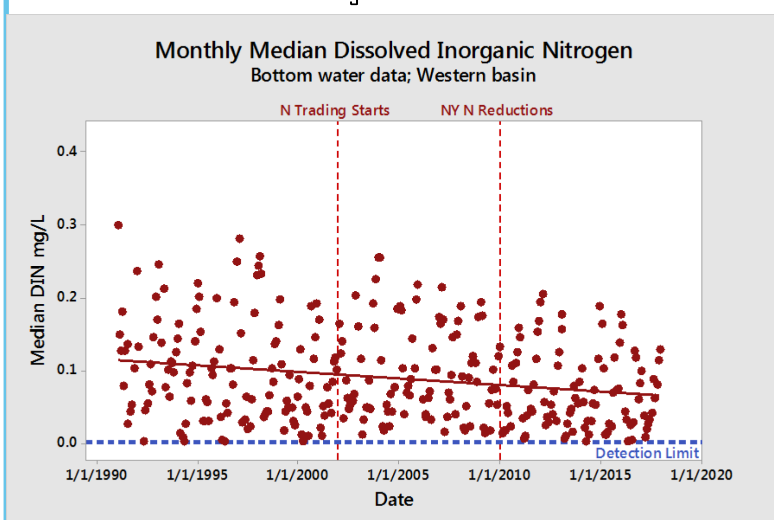


Figure 15. Graph of Monthly Median Surface Dissolved Inorganic Nitrogen Concentrations from Western Long Island Sound

Nitrogen Loading

Another goal of the CCMP relates to point source nitrogen loading from waste water treatment plants (WWTPs). The LIS 2000 Dissolved Oxygen TMDL specifies the primary pollutant contributing to hypoxia in LIS is nitrogen. The major source of nitrogen to LIS are WWTPs, combined sewer overflows, nonpoint sources including stormwater, and atmospheric deposition.

The TMDL requires a 58.5% reduction in nitrogen entering LIS via point source discharges (i.e., WWTPs).

- *Attain wastewater treatment facility nitrogen loading at the recommended 2000 Dissolved Oxygen Total Maximum Daily Load allocation level by 2017 and maintain the loading cap. Have all practices and measures installed to attain the allocations for stormwater and nonpoint source inputs from the entire watershed by 2025.*

Figure 13 illustrates the downward movement in hypoxic area as well as a downward trend in nitrogen discharges from both NY and CT WWTPs. Connecticut began requiring nitrogen reductions in WWTP discharges in 1998. The CT Nitrogen Trading program began in 2002, and the New York nitrogen reductions began in 2010.

In 2018 the cold, wetter than normal weather decreased the efficiency of nitrogen removal of the treatment systems resulting in an increase in loads to LIS for the first time since 2011. However, the 2018 loading to LIS was still 42 million pounds less than the early 1990s baseline.

Dissolved Inorganic Nitrogen (nitrate + nitrite + ammonia) is the most bioavailable form of nitrogen used by phyto-plankton. Figures 14 and 15 illustrate the monthly median concentration of Dissolved Inorganic Nitrogen measured from the surface and bottom waters of western LIS at CT DEEP stations. The general tendency of the data are in a downward direction.

Water Clarity

- *Improve water clarity by 2035 to support healthy eelgrass communities and attainment of the eelgrass extent target.*

Water clarity is a measure of how much light penetrates through the water column of Long Island Sound and is important in nearshore waters for the growth of eelgrass. Eelgrass, *Zostera marina,* is a rooted, underwater grass that provides habitat and protection for fish and invertebrates and food for many migratory birds. Healthy eelgrass beds trap sediment and reduce wave energy during storms, improving water quality and protecting coastal areas from erosion. Eelgrass in Long Island Sound is currently limited to embayments in the far eastern Sound, having disappeared from most of its historic range. Most of the eelgrass in Long Island Sound is found in <4 m of water, except where water quality is exceptionally good (i.e. seagrass beds near Fisher's Island). The depth limitation of seagrass in the Eastern Sound is used as the standard by which water clarity is judged throughout the Sound, including areas which do not currently support seagrass.

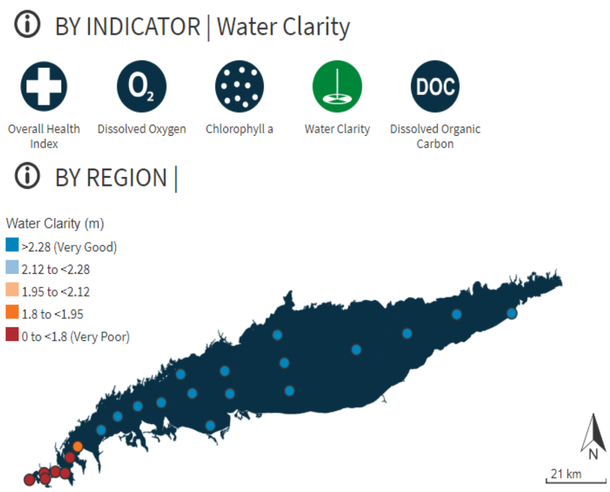


Figure 16. Image form the Long Island Sound Report Card showing station data for the water clarity indicator. Image shows the 2015 data.

The CCMP target utilizes 2015 data as the baseline and threshold values developed as part of the [Long Island Sound Report Card]() to track progress (Figure 16). Generally, eelgrass beds need about 22% of the light at the surface to reach the plant; at 3.65 m of total water depth, this equates to a Secchi depth of ~2.4 m. At 1.1 m of total water depth (almost too shallow for eelgrass), this equates to a Secchi depth of ~0.7 m. These two endpoints were used to develop an equation to relate Secchi depth to a score, where <0.7 m gets a 0% and >2.4m gets a 100%. A Secchi depth <1.85 m receives a score of <60% (F). Annual average Secchi disk depths greater than 2.28 meters are considered very good while depths less than 1.8 meters are considered very poor.

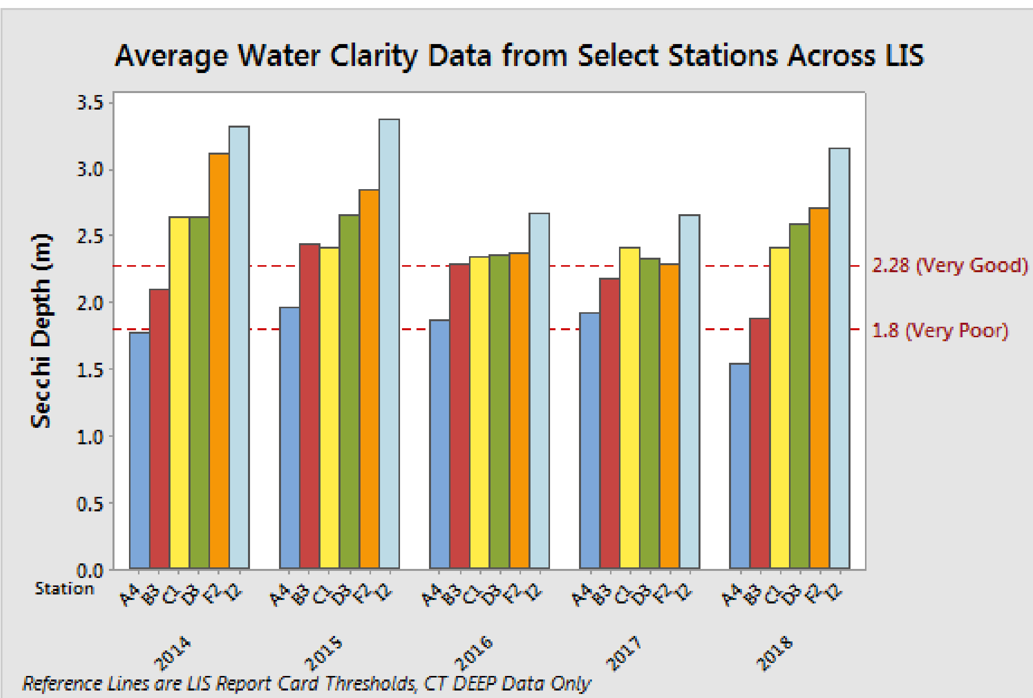


Figure 17. Year round averages of water clarity data from select stations across LIS

Generally, with the exception of stations in the western narrows, water clarity across LIS is good (Figure 17). Water clarity in the Western Sound is especially impacted by suspended sediments, organic matter and plankton in the water column.

Future Monitoring Recommendations

Carbonate chemistry parameters

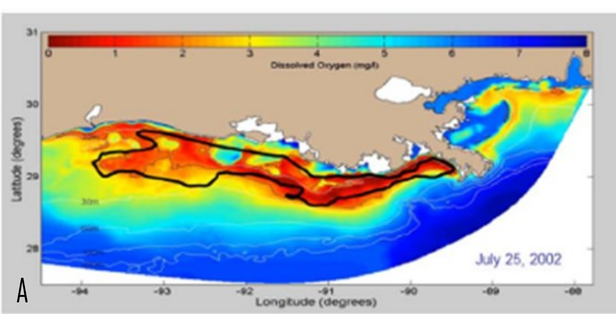
Two of four parameters are needed to describe the seawater carbonate system- pCO2, Dissolved Inorganic Carbon (DIC), alkalinity, and pH, along with temperature and salinity measurements. The CT DEEP and IEC monitoring programs only measure one of these parameters – pH. The LISICOS Western Sound buoy is equipped with a continuous pCO2 sensor. New projects to examine productivity and carbonate chemistry across LIS (The Respire Project, Vlahos 2018 and Shell Day 2019, NECAN) highlight the fact that the LISWQMP and IEC WSMP do not currently collect sufficient data to assess changes to the LIS carbonate system. In March 2018, EPA released guidelines for measuring changes in carbonate chemistry in eastern coastal waters and NOAA presented considerations for managers and developing acidification monitoring programs (Goldsmith et. al., in press). The LISS Science and Technical Advisory Committee should explore options to increase carbonate chemistry analysis as part of the ship based monitoring program.

Embayments

While LIS proper has been well sampled for decades, the embayments across LIS have not. This is beginning to change; the embayments have been recognized as a priority area in the CCMP and the LISS dedicated additional funds for monitoring. The Unified Waters Study, a citizen science based monitoring program, has been successfully implemented by Save the Sound and is in it's third year of sampling. CTDEEP has begun a project to examine the benthic macroinvertebrate communities in embayments as a way to assess the biological community in response to management actions, including nutrient reductions. Data collection activities in embayments to support model calibration will begin in late 2019.

Hypoxia Related Projects

Hypoxia in LIS has typically been reported in terms of area and duration but there may be metrics that could be used. The University of Connecticut and CTDEEP have entered into an agreement to develop tools to calculate and map the hypoxic volume observed across LIS. The project will analyze all existing data, summarize trends related to specific management questions, and develop visual graphics, similar to those in Figure 18, to convey the results to the public. Scavia, et al., (2019) found hypoxic volume is more relevant to the biota than hypoxic area.



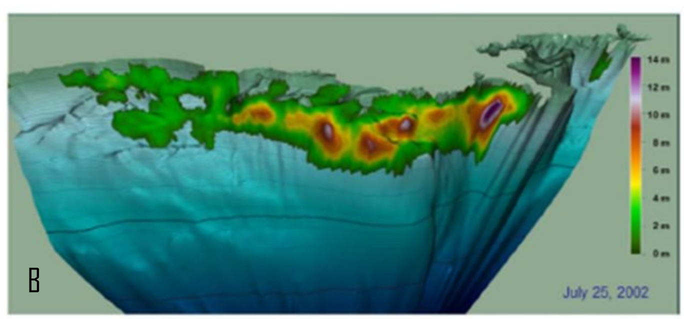


Figure 18. From Scavia et. al., 2019

A) Graphical representation of hypoxic area in the Gulf of Mexico.

B) Graphical representation of hypoxic volume in the Gulf of Mexico.

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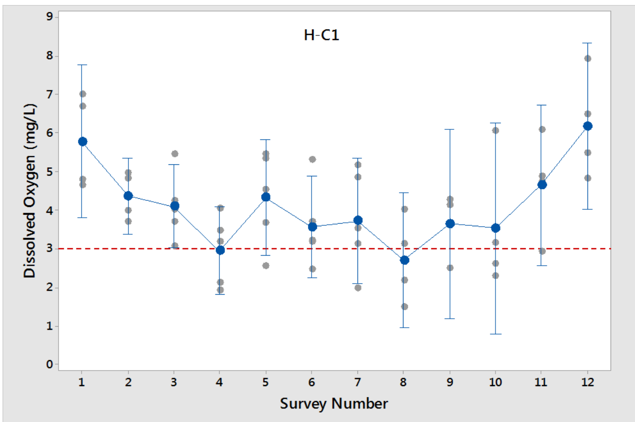
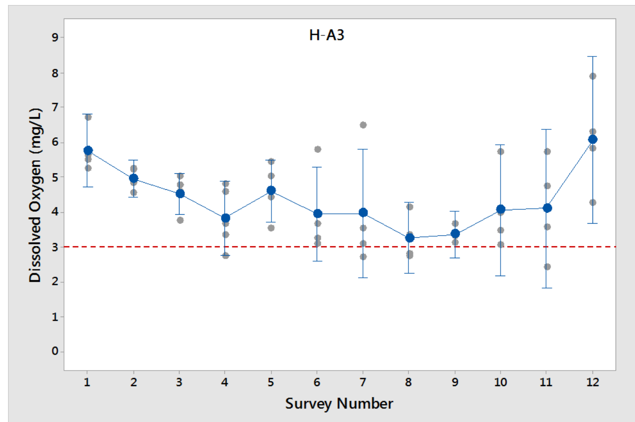
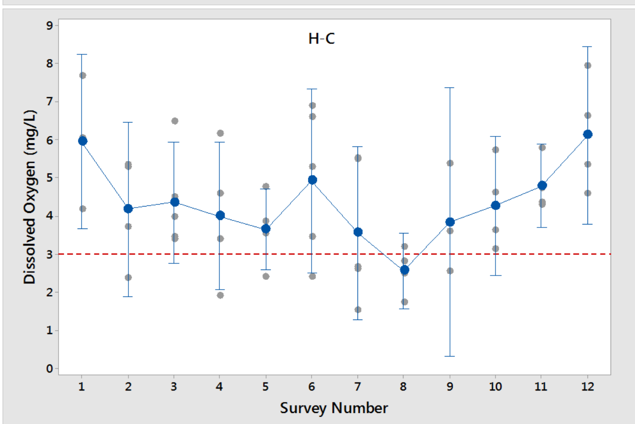
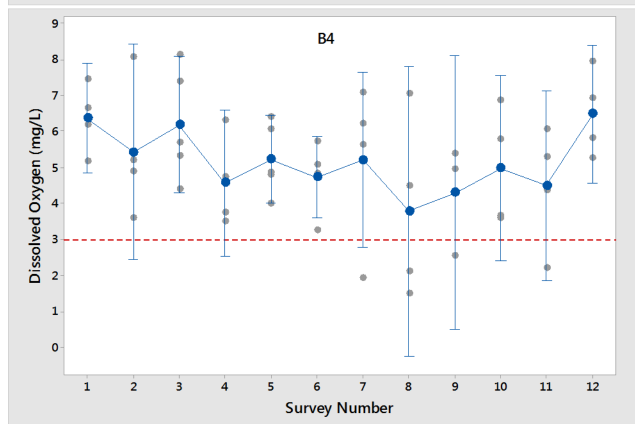
Appendix A– 2014-2018 IEC Summer Dissolved Oxygen Data

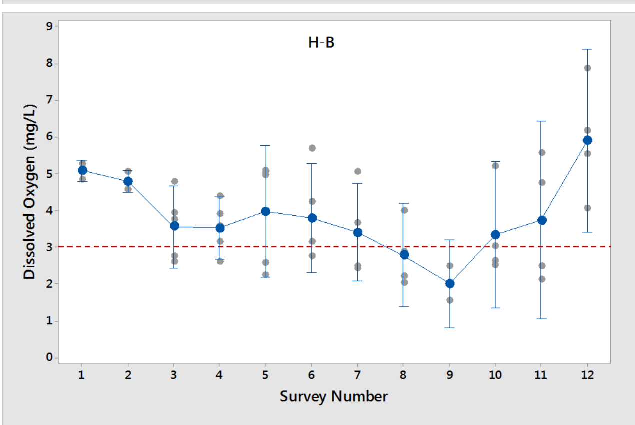
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. See Figure 1 for station locations. The red 3.0 line represents the hypoxia threshold. Data from Survey #1 in 2014 were not included as this survey occurred two weeks earlier than other historic Survey #1s and dissolved oxygen concentrations were greater than 9 mg/L. The lowest DO documented by IEC at an open water station in 2018 was 1.53 mg/L and occurred at Station H-C during Survey #7 on 8/7/18.

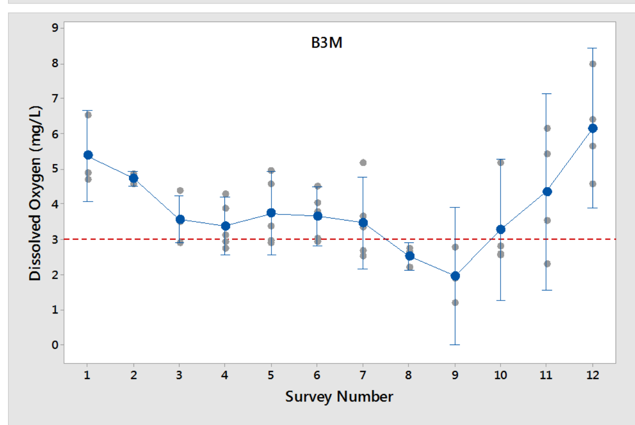


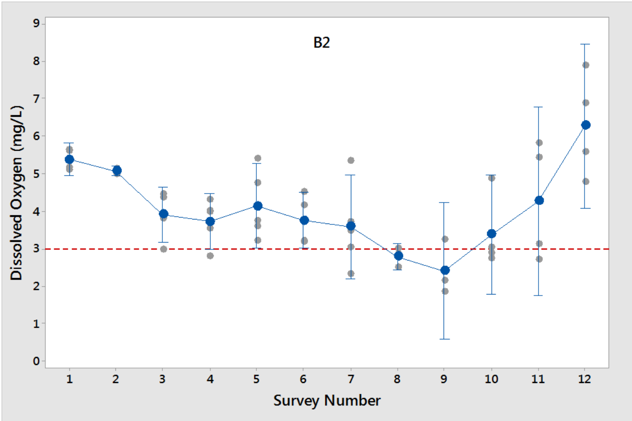








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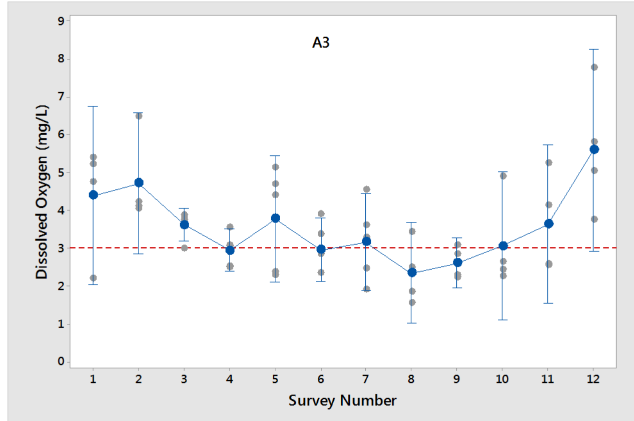
Dissolved Oxygen (mg/L)
Survey Number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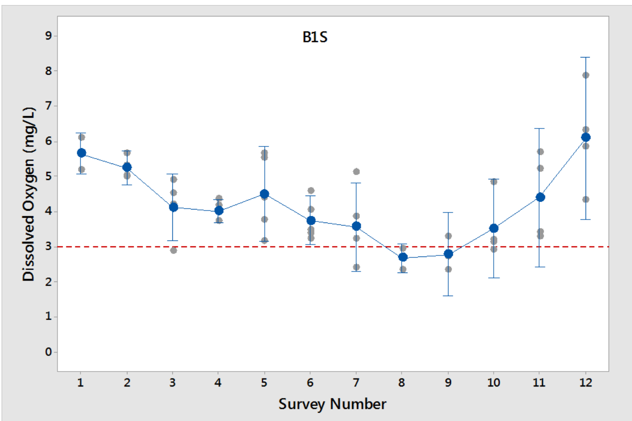
Survey Number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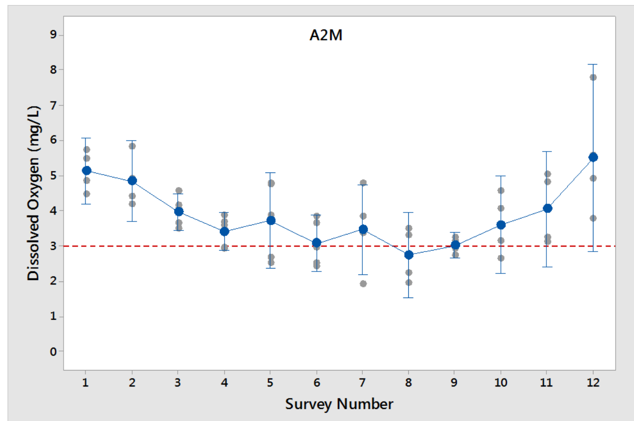
Dissolved Oxygen (mg/L)
Survey Number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Dissolved Oxygen (mg/L)
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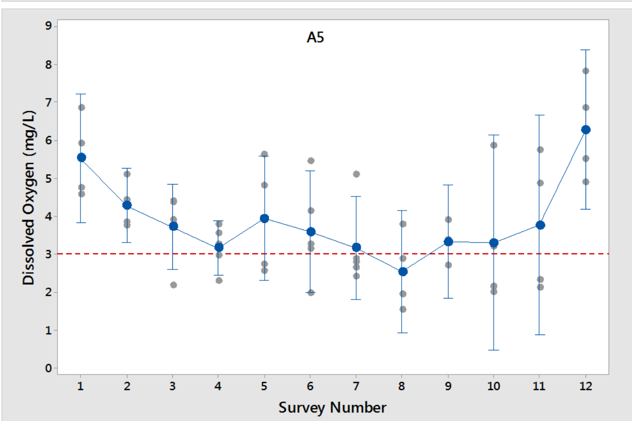
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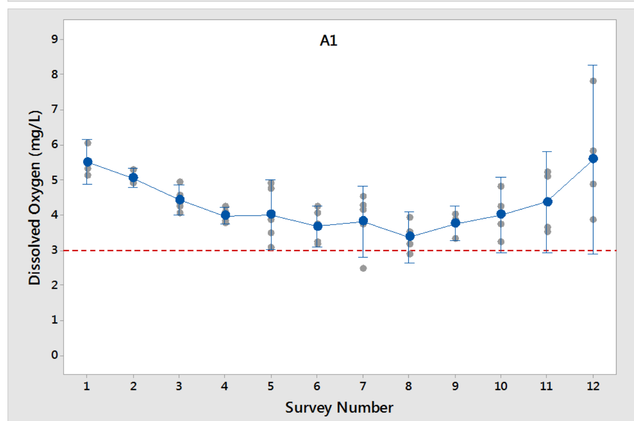
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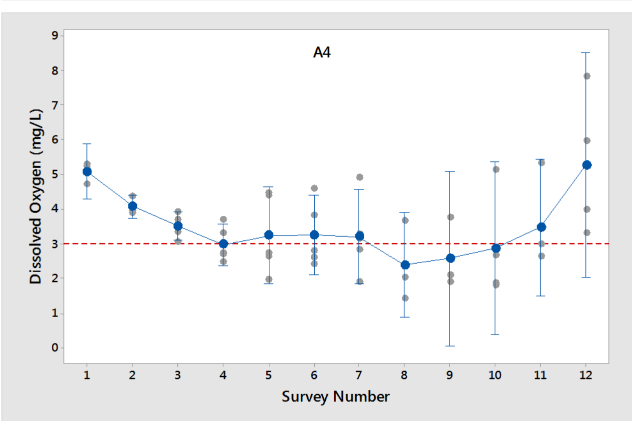
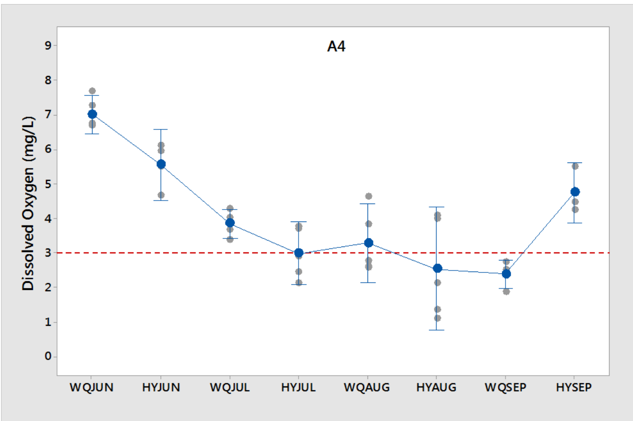
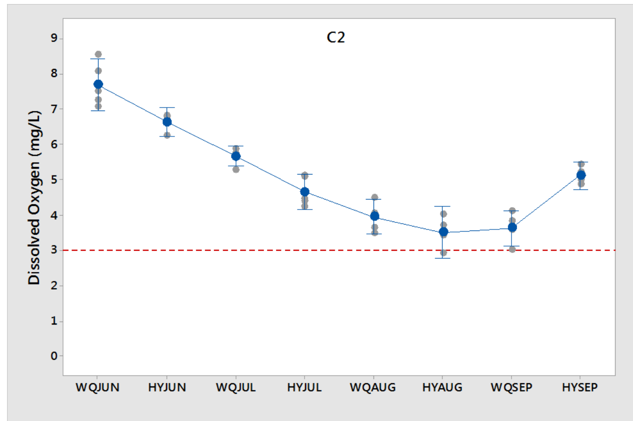
Survey Number

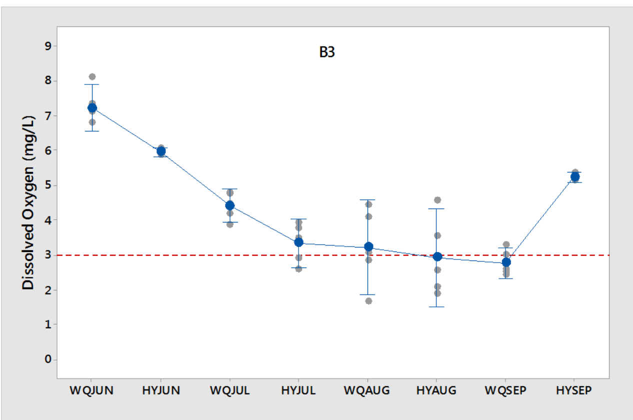

A4
Dissolved Oxygen (mg/L)
Survey Number

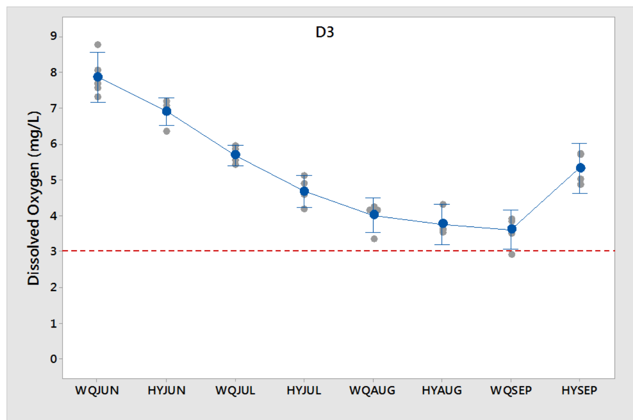
Appendix A– 2014-2018 DEEP Summer Dissolved Oxygen Data

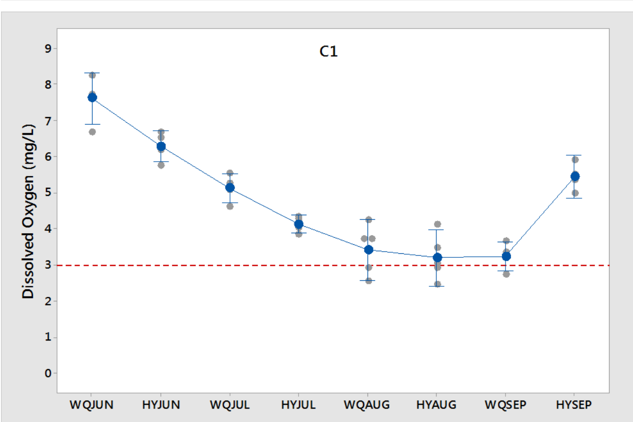
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Data are from stations in western Long Island Sound. Data from all stations are available upon request. See Figure 1 for station locations. The lowest dissolved oxygen concentration measured by CT DEEP in 2018 was 2.34 mg/L and occurred during the WQSEP survey on 8/27/18 at Station A4.

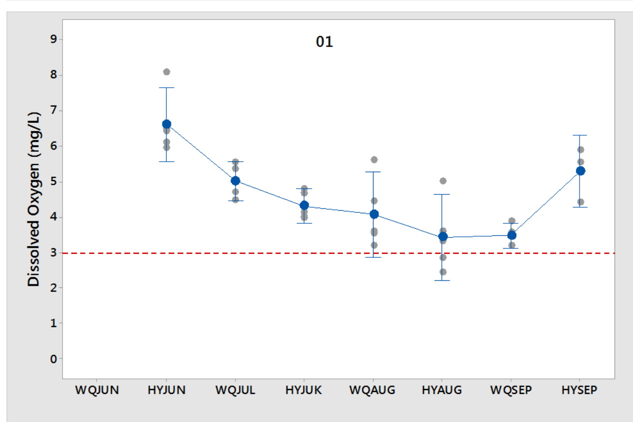


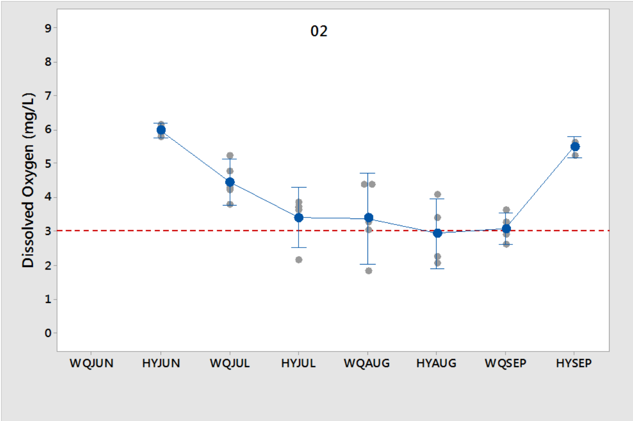








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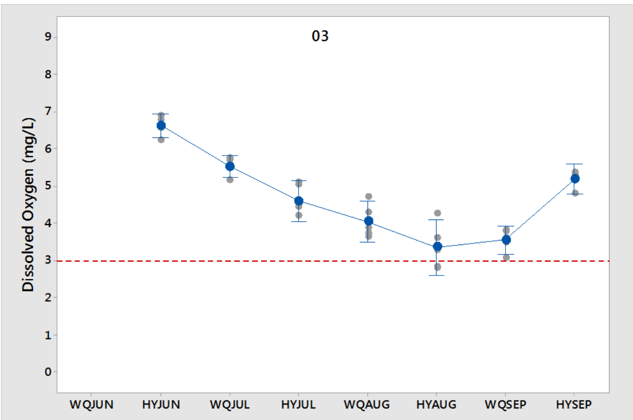
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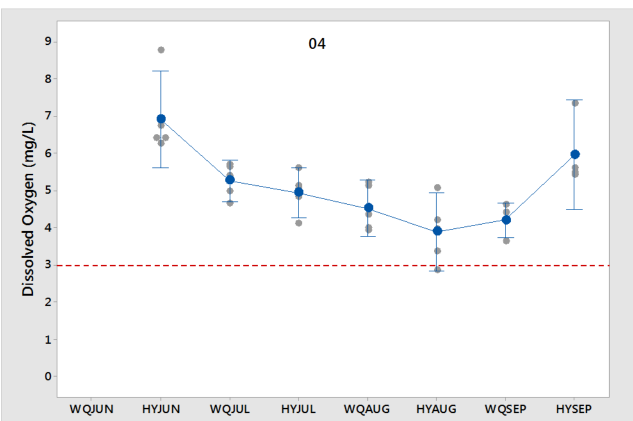
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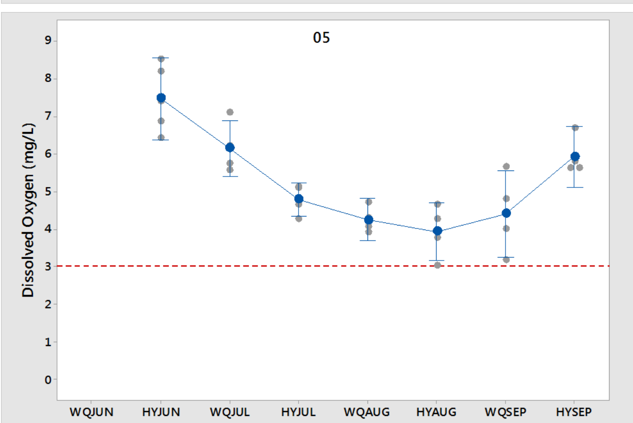
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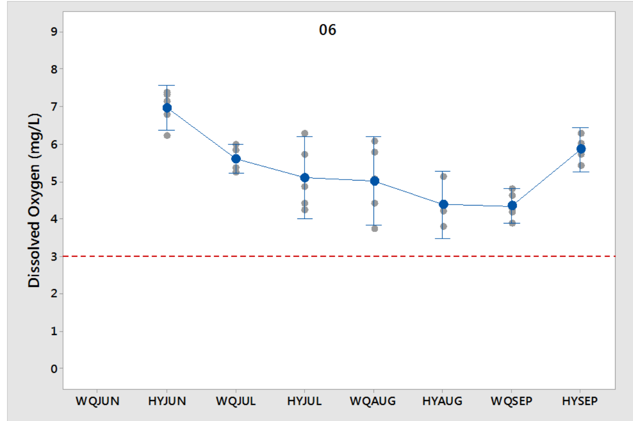
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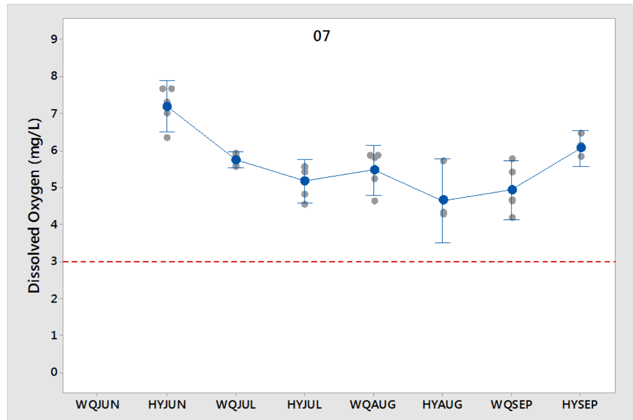
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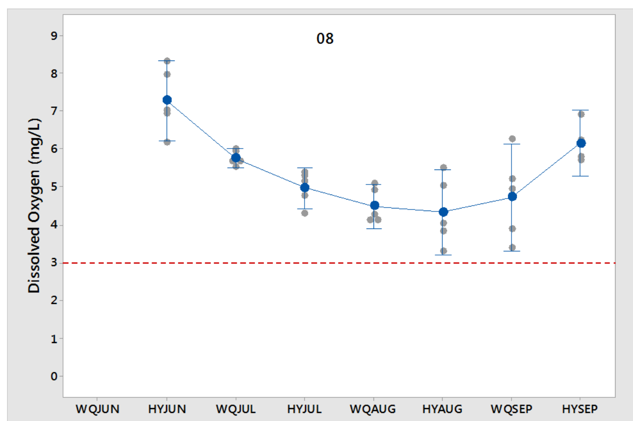
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Dissolved Oxygen (mg/L)
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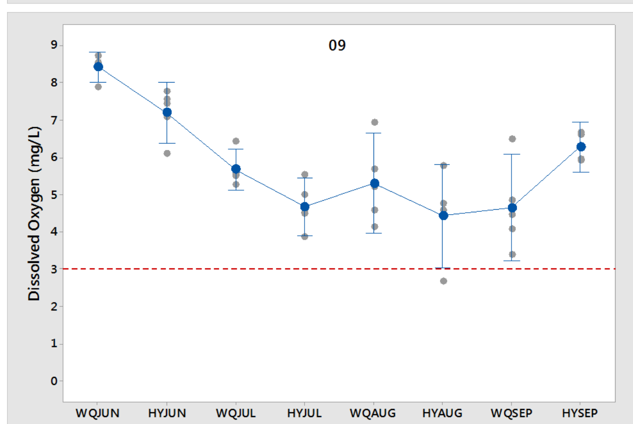
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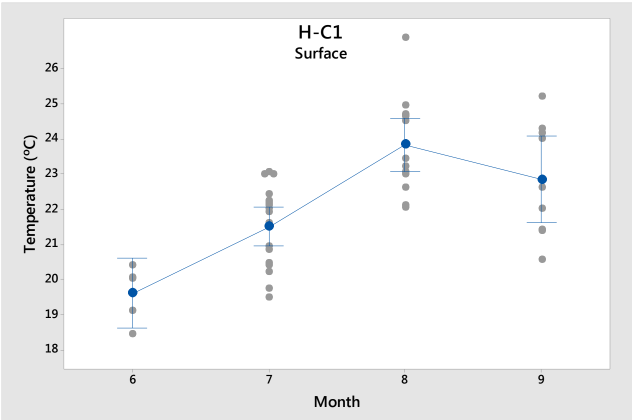
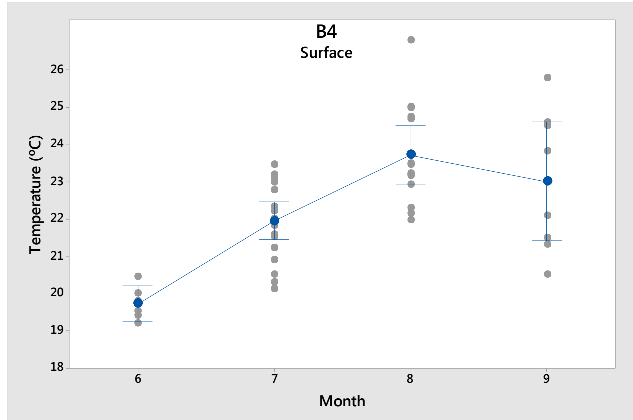
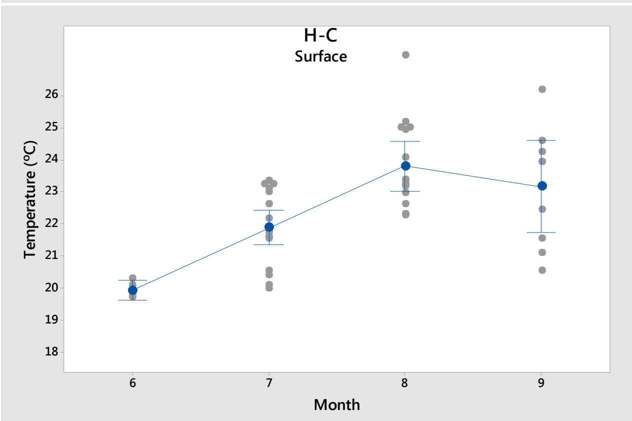
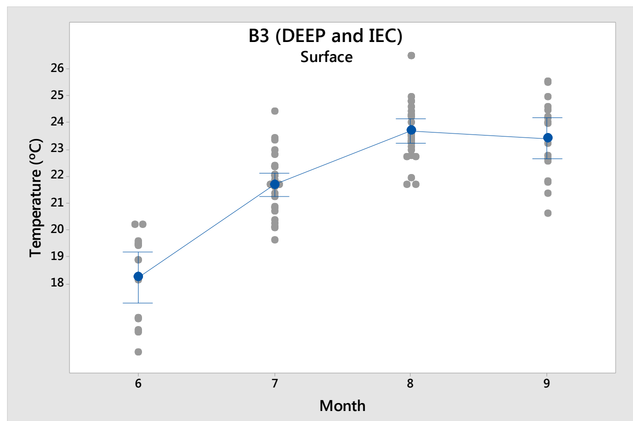
Appendix B- 2014-2018 Summer Surface Temperature Data– DEEP and IEC

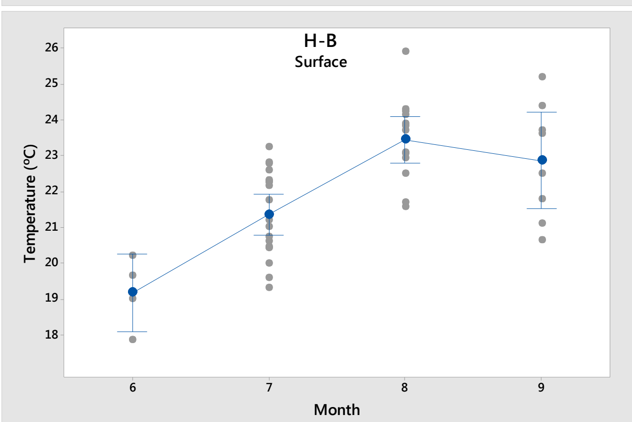
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. See Figure 1 for station locations

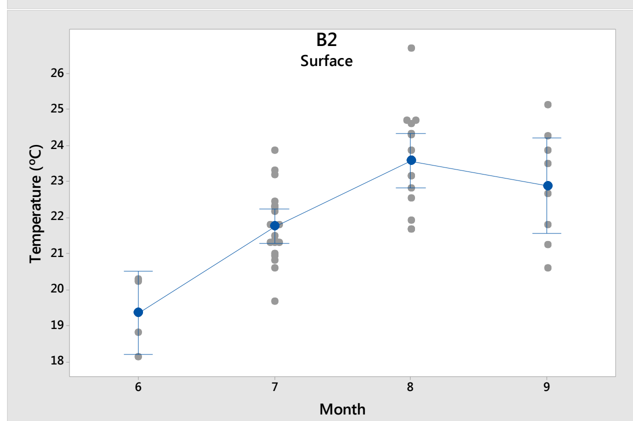


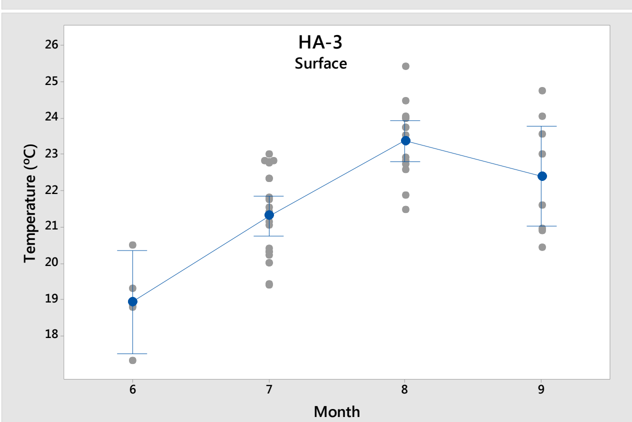


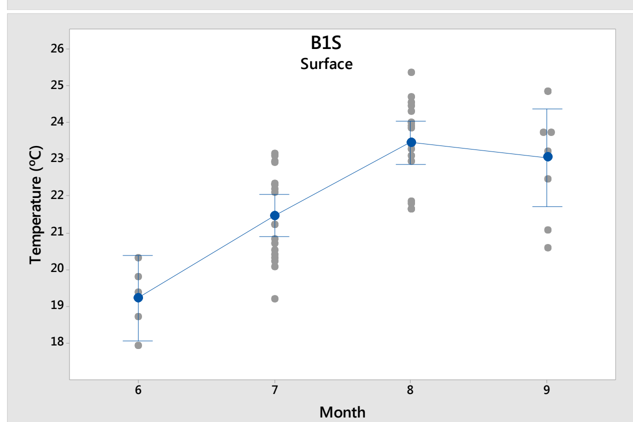


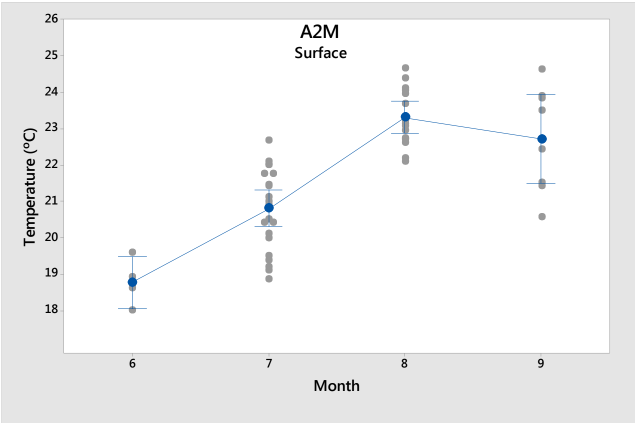


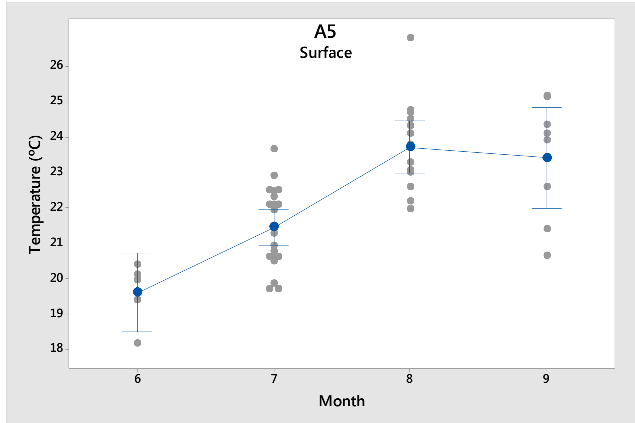


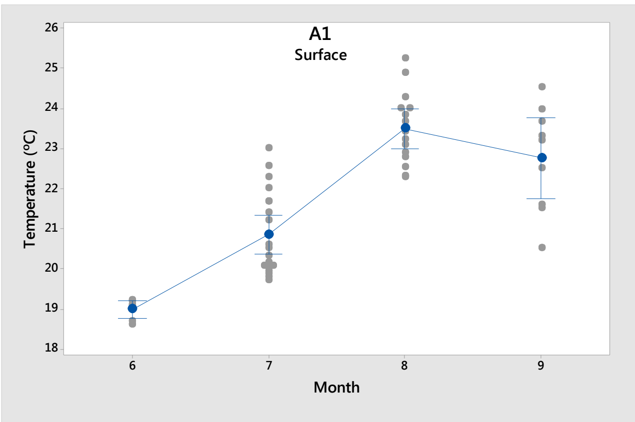


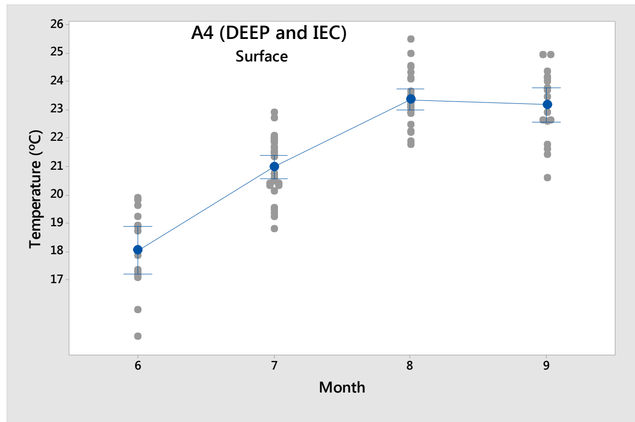


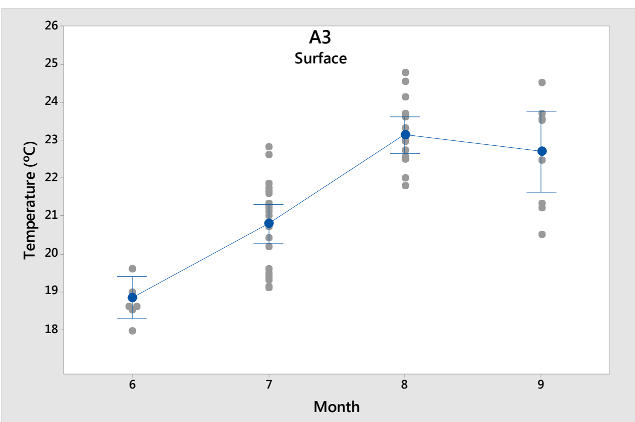



A2M
Surface
Temperature (°C)
Month

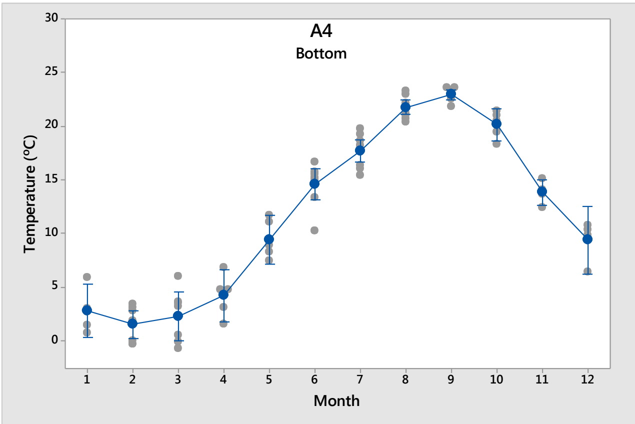

A5
Surface
Temperature (°C)
Month

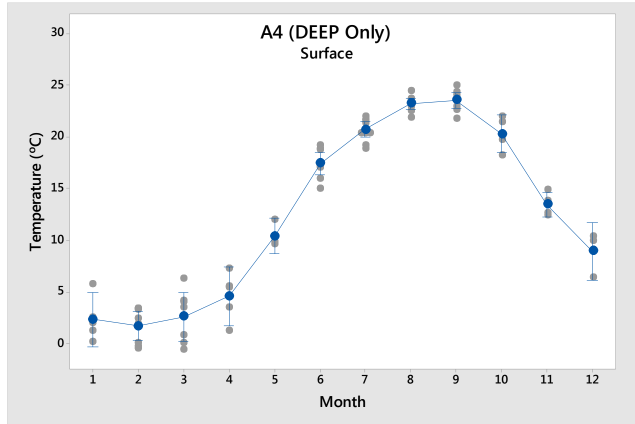

A1
Surface
Temperature (°C)
Month

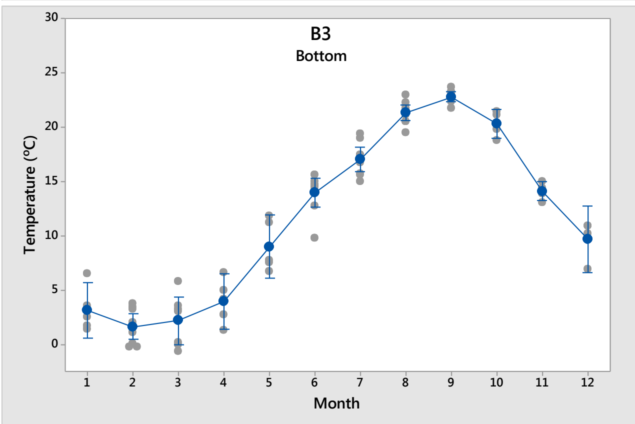

A4 (DEEP and IEC)
Surface
Temperature (°C)
Month

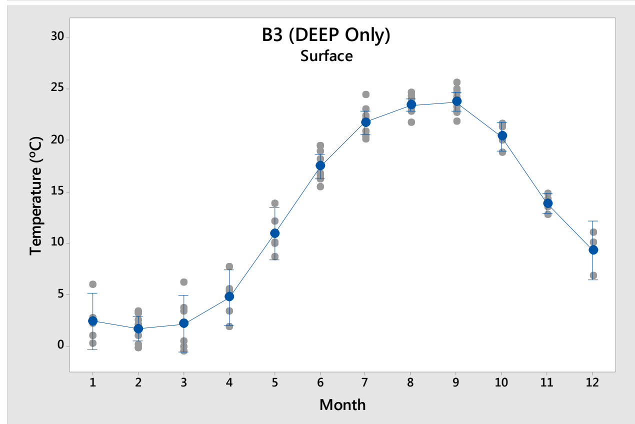

A3
Surface
Temperature (°C)
Month

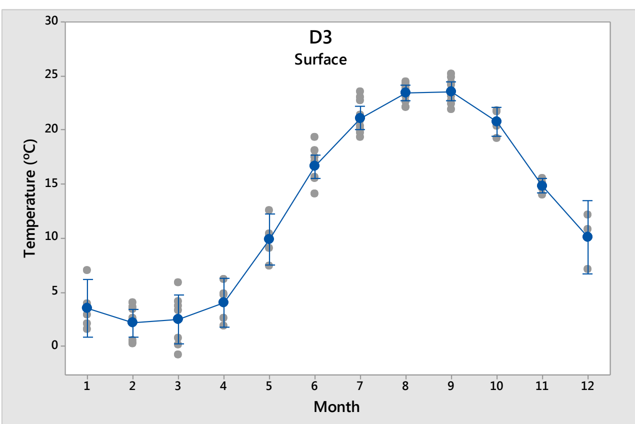
Appendix B– 2014-2018 Year Round Temperature Data, DEEP Only

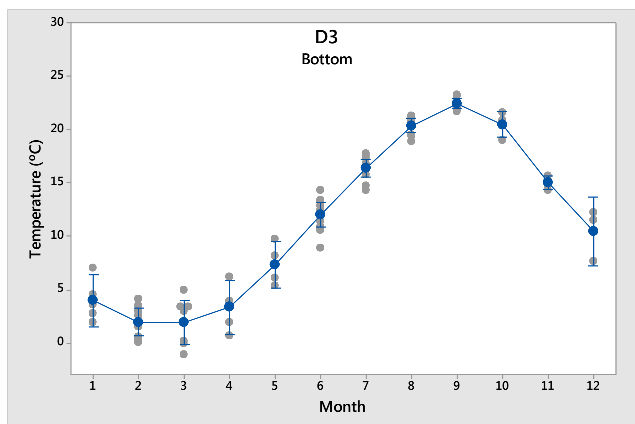


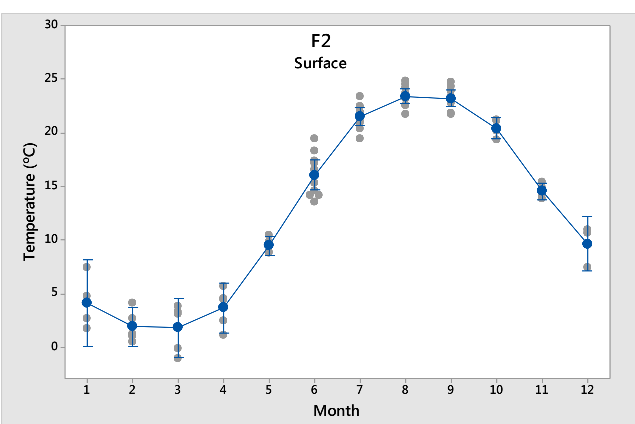


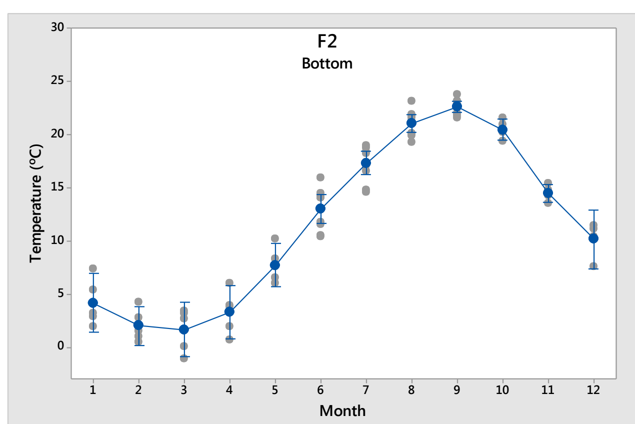


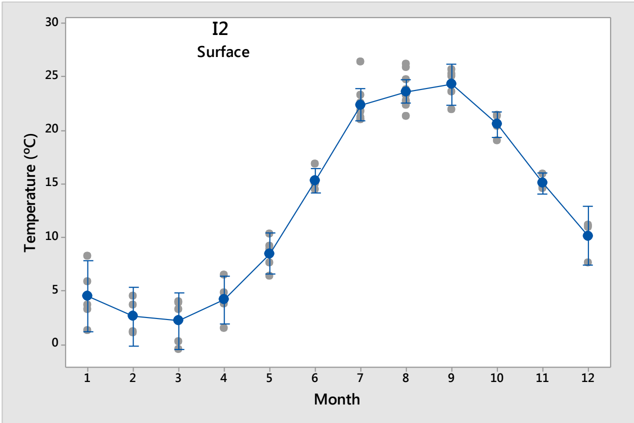


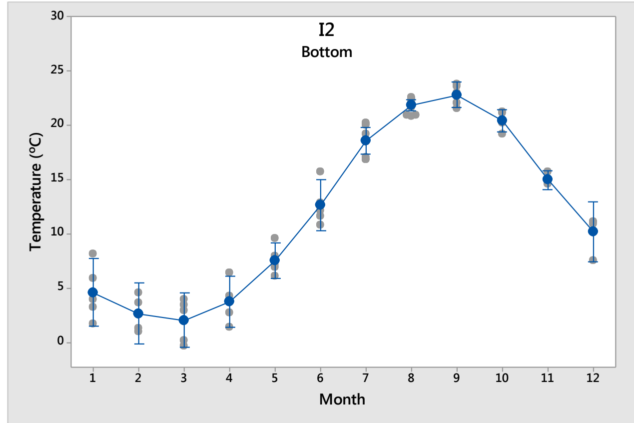






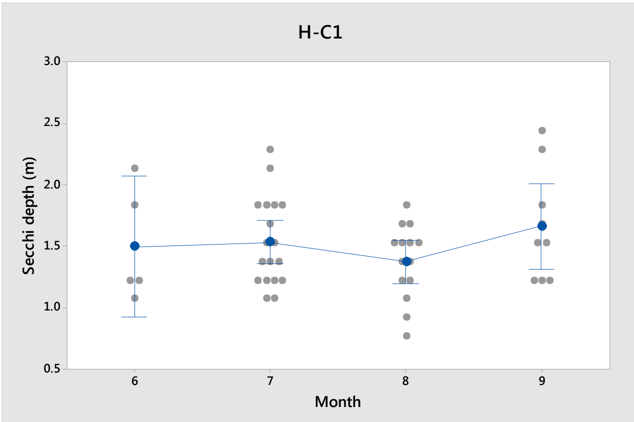


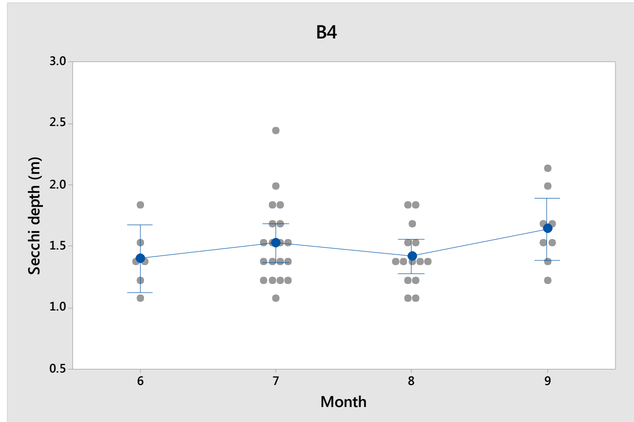

I2
Surface
Temperature (°C)
Month

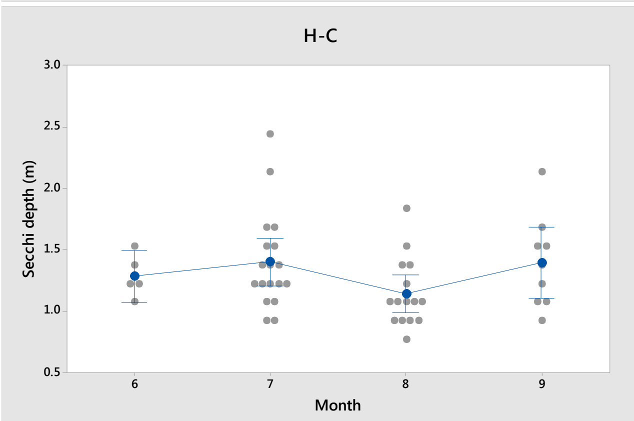

I2
Bottom
Temperature (°C)
Month

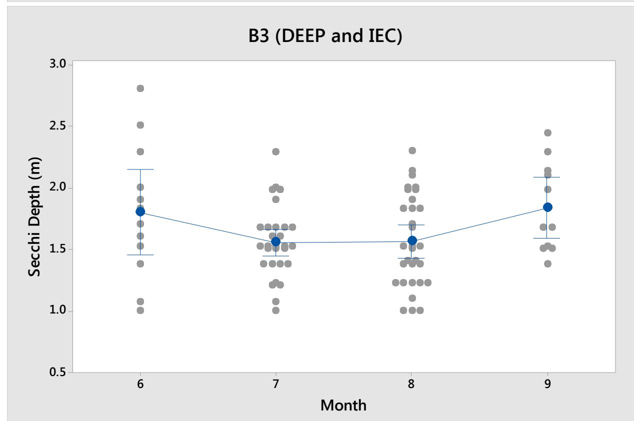
Appendix C– 2014-2018 Summer Water Clarity (Secchi Disk Depth) Data

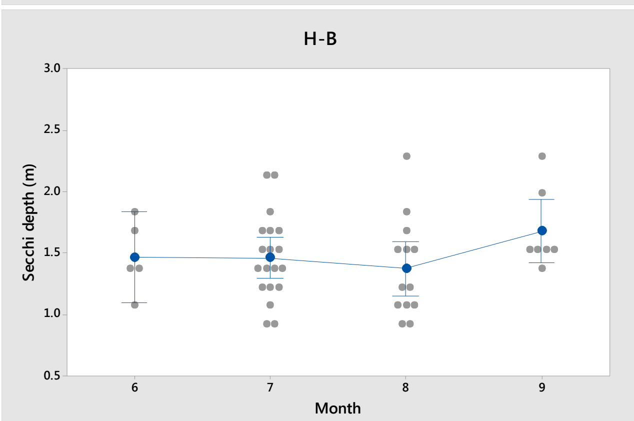
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See Figure 1 for station locations

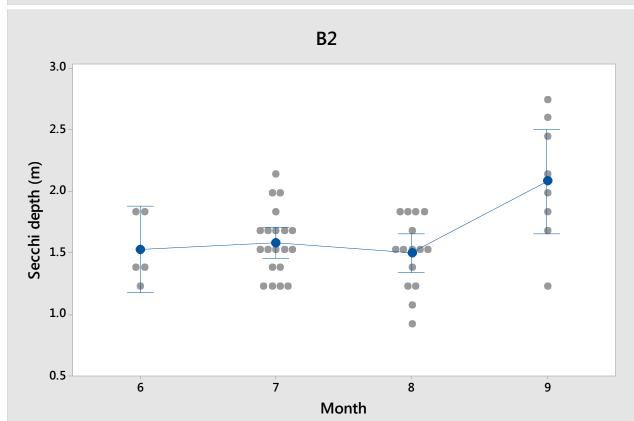


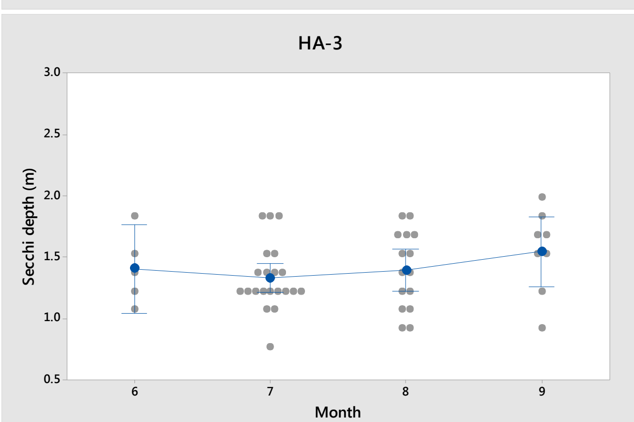


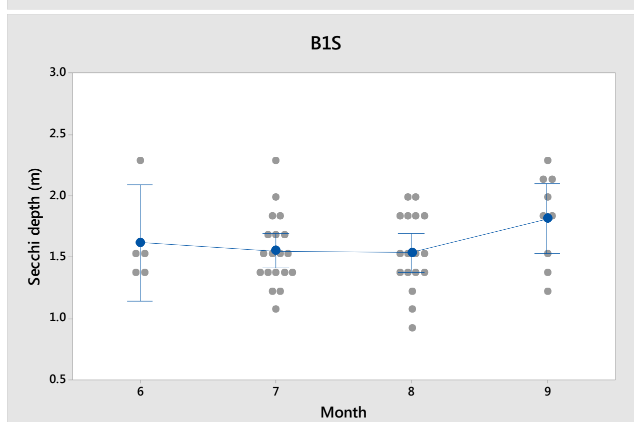


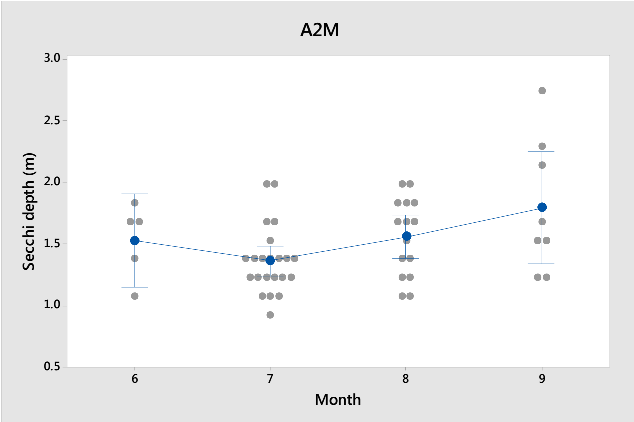


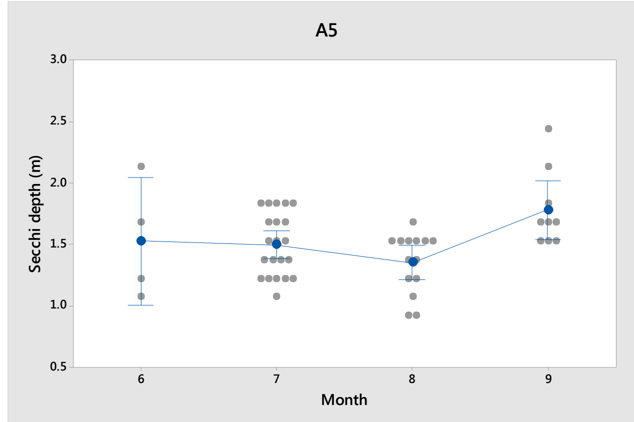


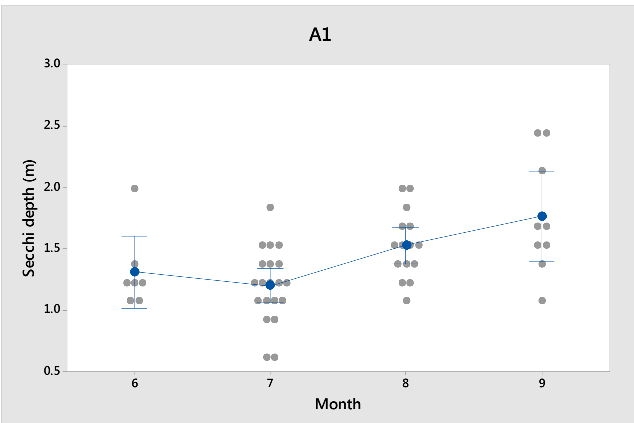


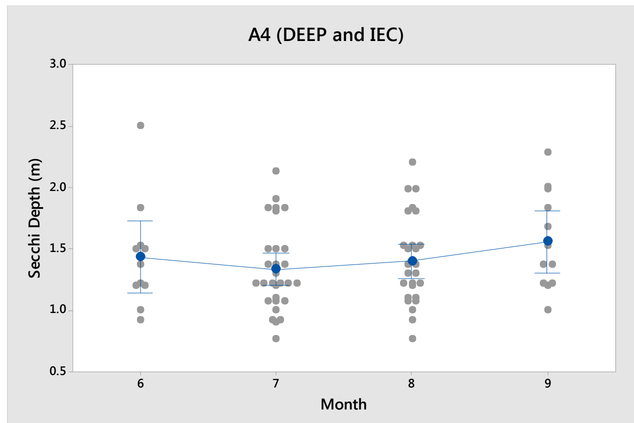


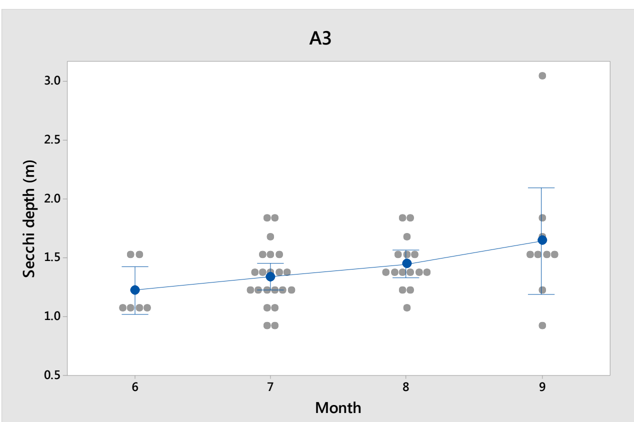


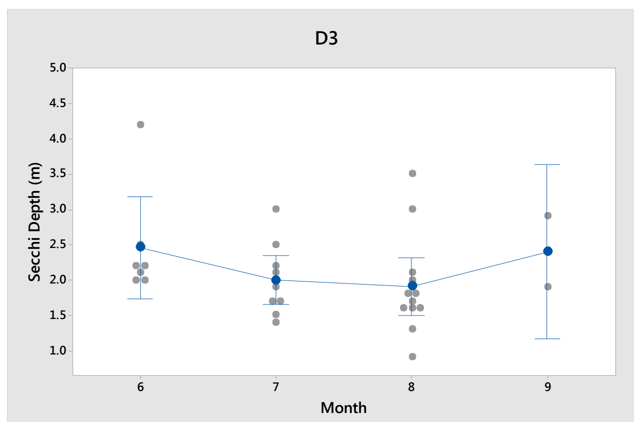

A2M
Secchi depth (m)
3.0
2.5
2.0
1.5
1.0
0.5
6
7
8
9
Month

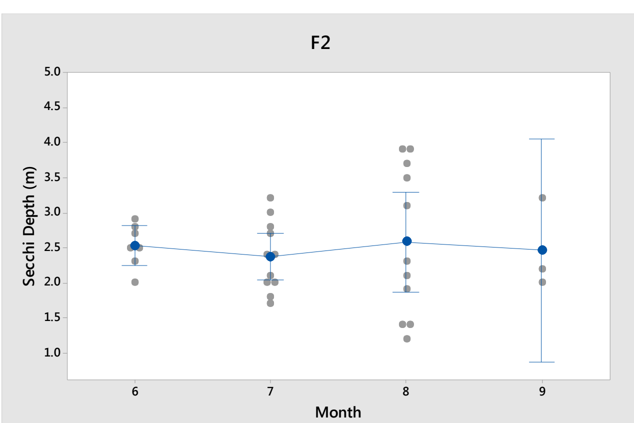

A5
Secchi depth (m)
3.0
2.5
2.0
1.5
1.0
0.5
6
7
8
9
Month

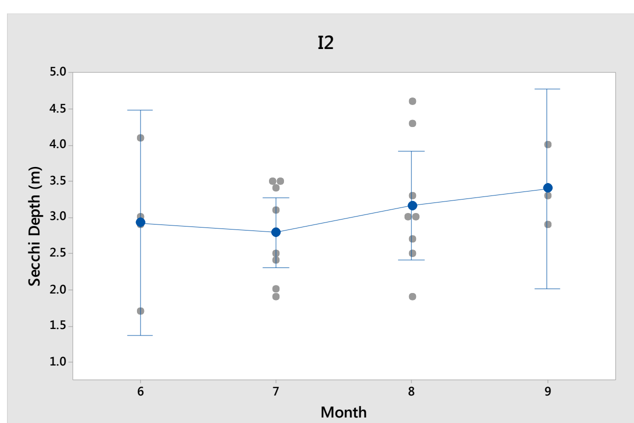

A1
Secchi depth (m)
3.0
2.5
2.0
1.5
1.0
0.5
6
7
8
9
Month


A4 (DEEP and IEC)
Secchi Depth (m)
3.0
2.5
2.0
1.5
1.0
0.5
6
7
8
9
Month


A3
Secchi depth (m)
3.0
2.5
2.0
1.5
1.0
0.5
6
7
8
9
Month

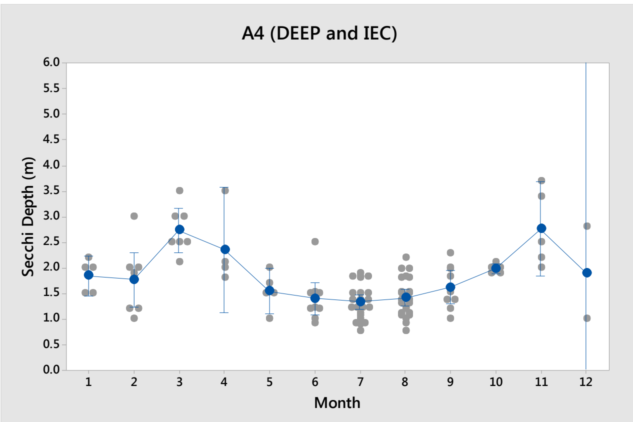

D3
Secchi Depth (m)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
6
7
8
9
Month

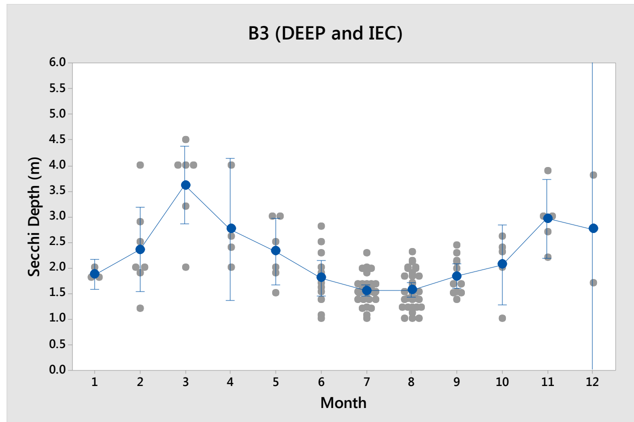

F2
Secchi Depth (m)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
6
7
8
9
Month

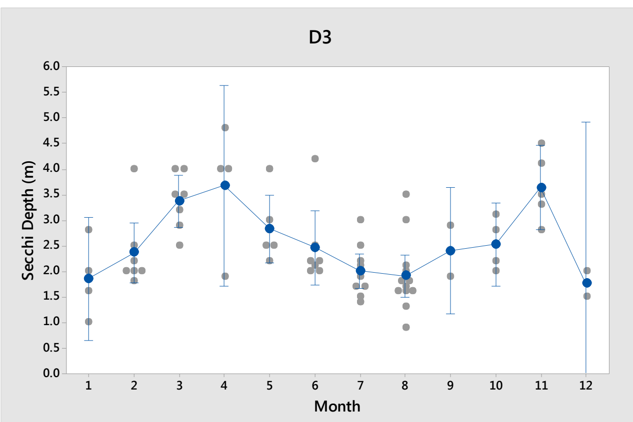

I2
Secchi Depth (m)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
6
7
8
9
Month

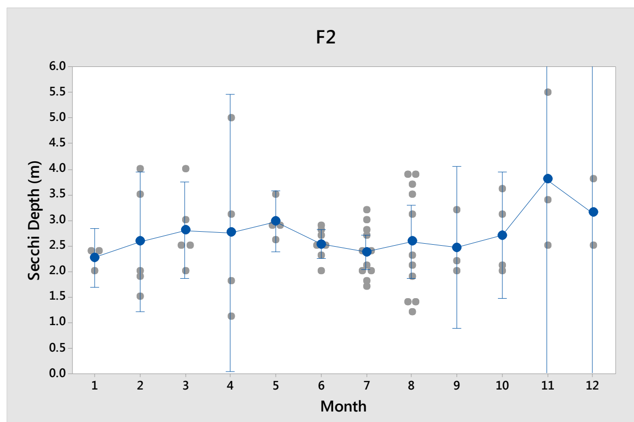
Appendix C– 2014-2018 DEEP Year Round Axial Station Water Clarity (Secchi Disk Depth) Data

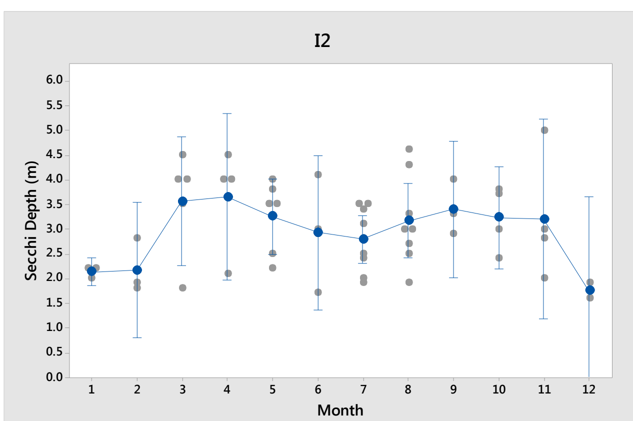
Interval plots showing the mean ( ), 95% confidence interval (I), and individual data points ( ) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Graphs for stations A4 and B3 include IEC data collected during the summer months. Data from additional stations are available upon request.





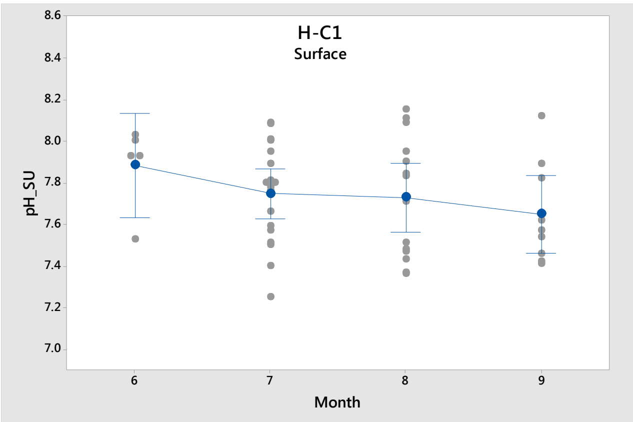


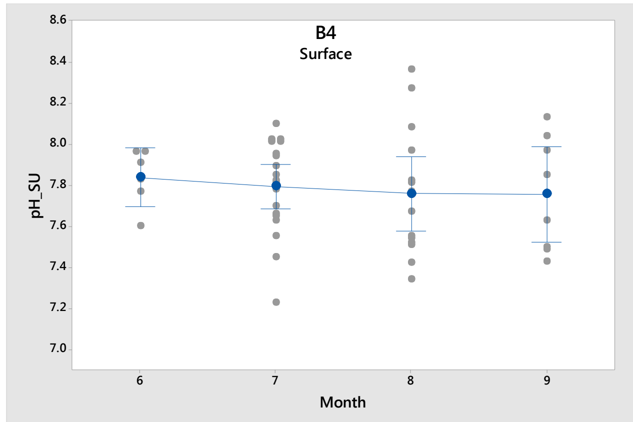


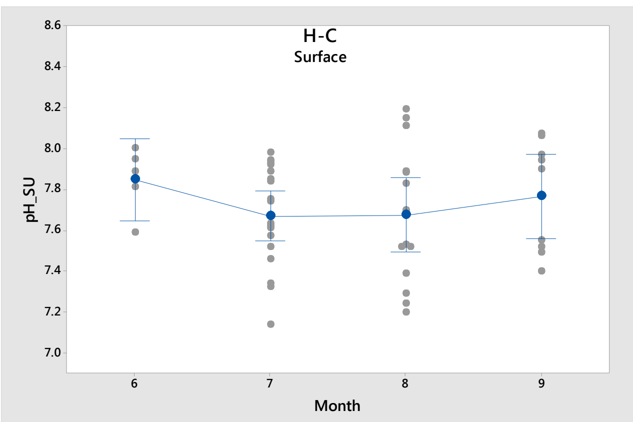


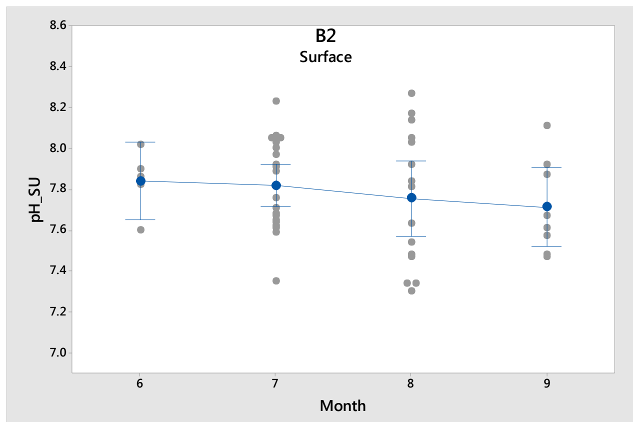
Appendix D– 2014-2018 IEC Summer Surface pH Data

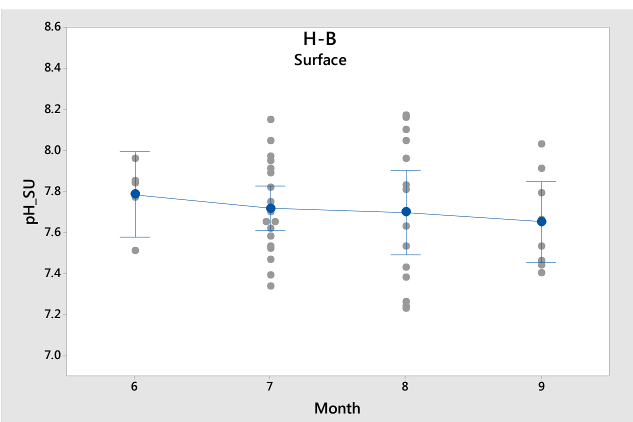
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Bottom data and additional stations are available upon request. See Figure 1 for station locations.

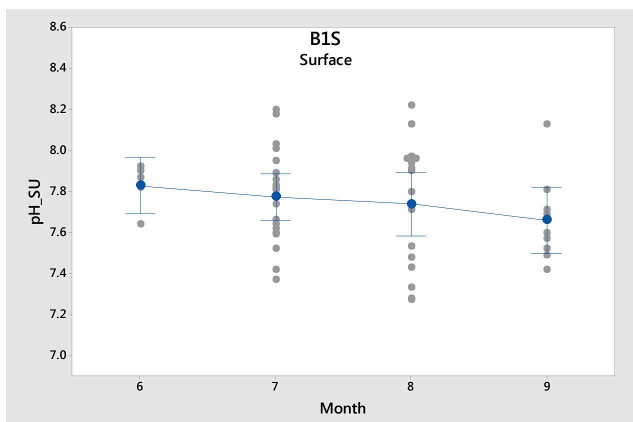


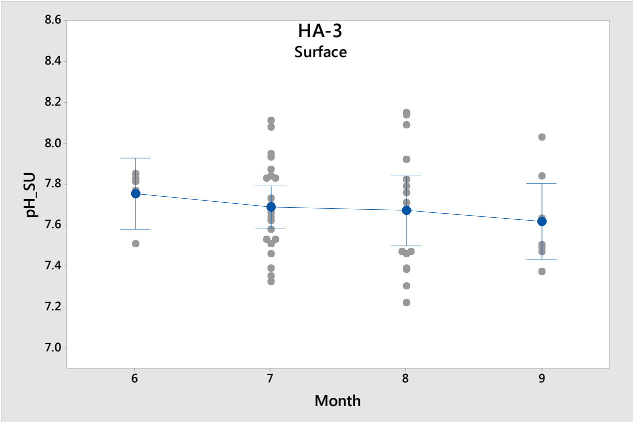


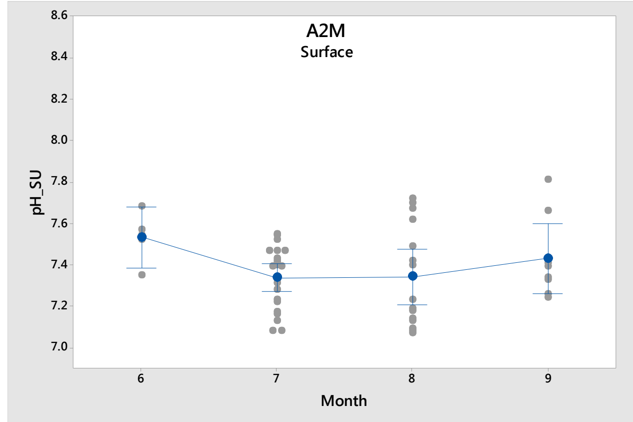


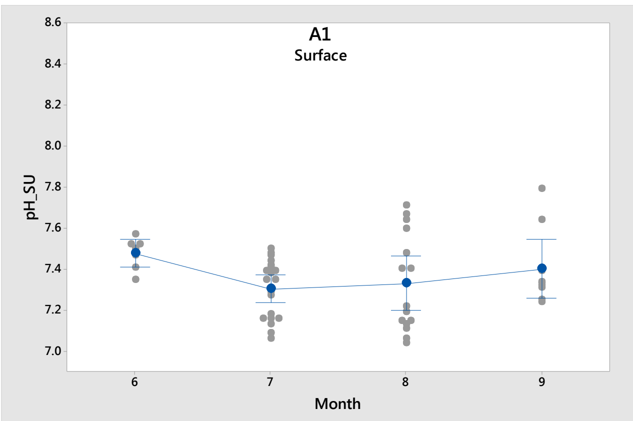


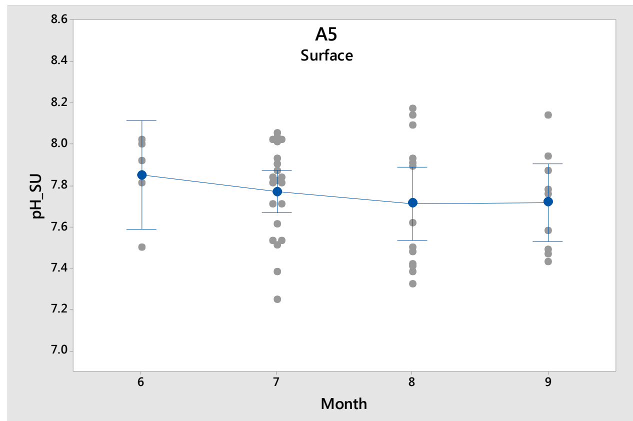


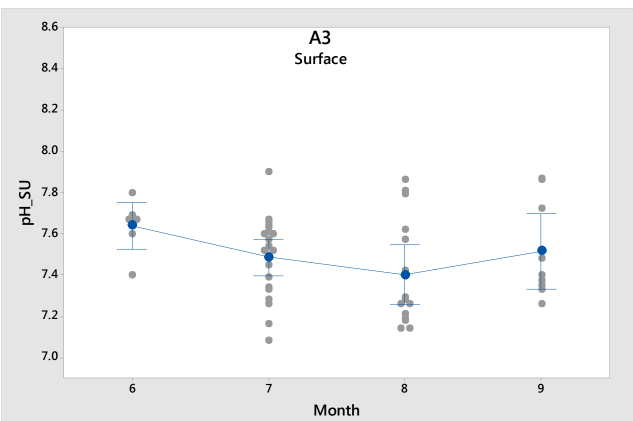



HA-3
Surface
pH_SU
Month


A2M
Surface
pH_SU
Month

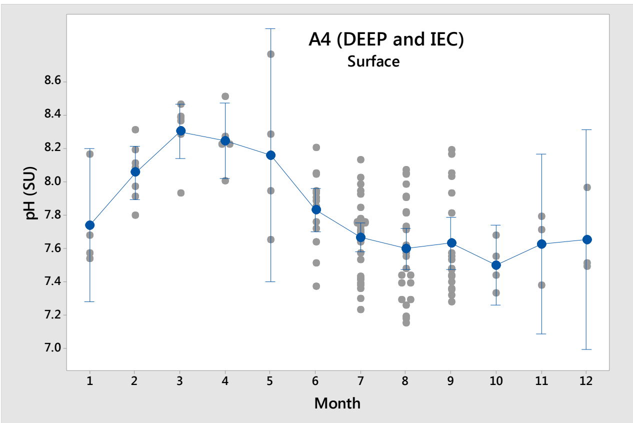

A1
Surface
pH_SU
Month

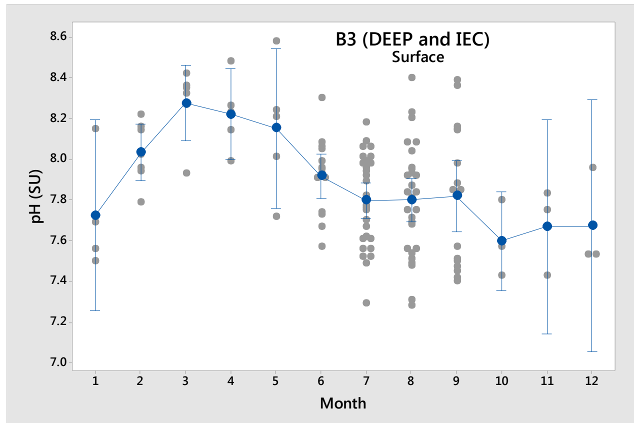

A5
Surface
pH_SU
Month

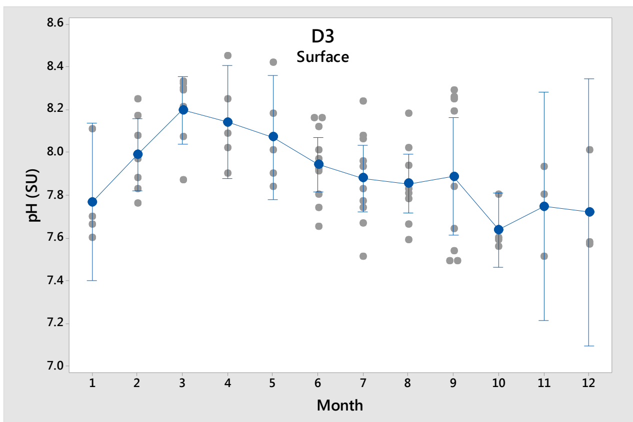

A3
Surface
pH_SU
Month

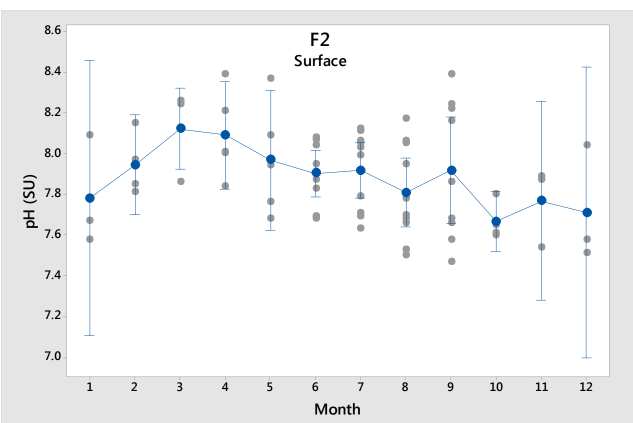
Appendix D– 2014-2018 DEEP Year Round Axial Station Surface pH Data

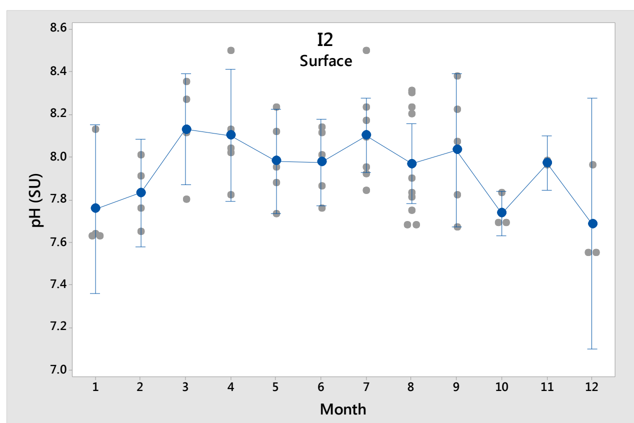
Interval plots showing the mean ( ), 95% confidence interval (I), and individual data points ( ) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Graphs for stations A4 and B3 include IEC data collected during the summer months. Bottom data and data from additional stations are available upon request.



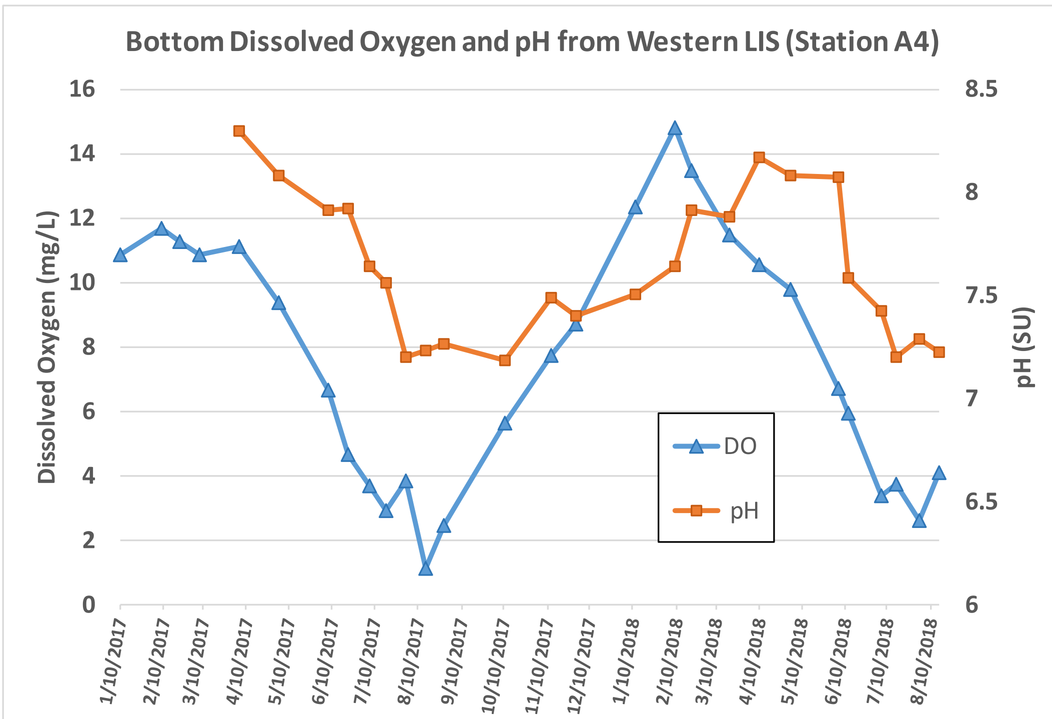






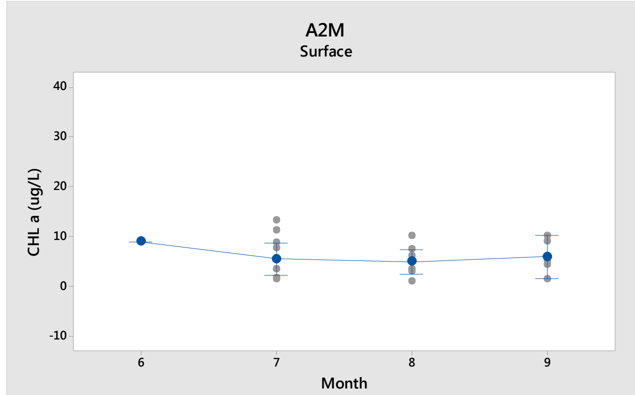


Many LIS stakeholders know that hypoxia is exacerbated by increased nutrient loading into LIS and its embayments. The excess nutrients lead to increased algal biomass. As this biomass dies and decays, oxygen levels decrease contributing to hypoxia. One thing you might not know is that as the organic matter undergoes microbial degradation, carbon dioxide (CO_2) is produced. Excess CO_2 lowers seawater pH and contributes to coastal acidification. The graph below illustrates the decline in bottom water DO concentrations and pH levels at Station A4 from 2017 through 2018. This pattern is evident in other stations across western LIS.

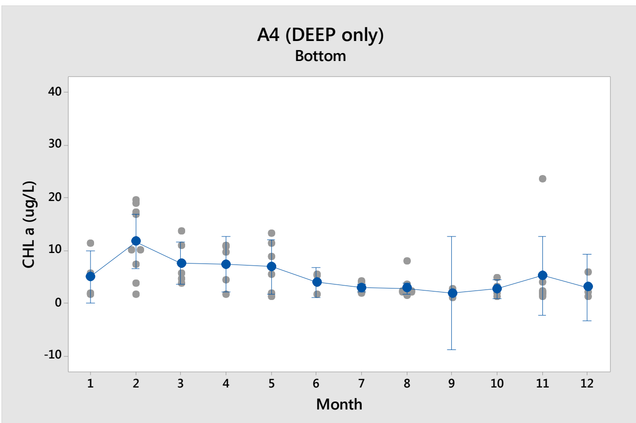


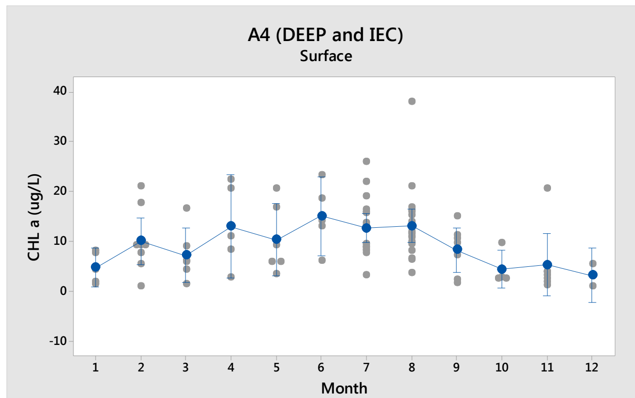
Appendix E– 2014-2018 Chlorophyll Data

Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See Figure 1 for station locations. IEC station A2M is only sampled during the summer months; beginning in October 2018, IEC stations will be sampled year-round.

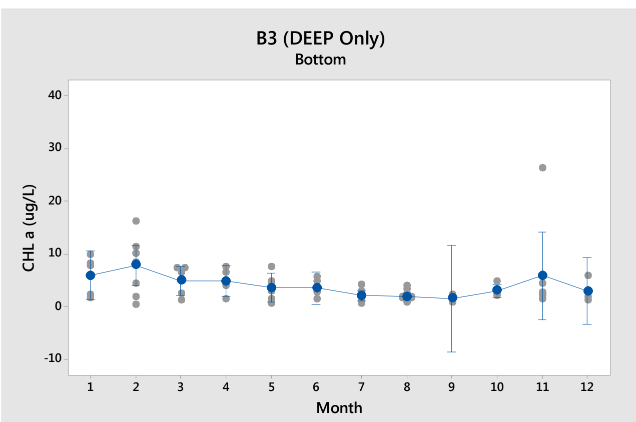


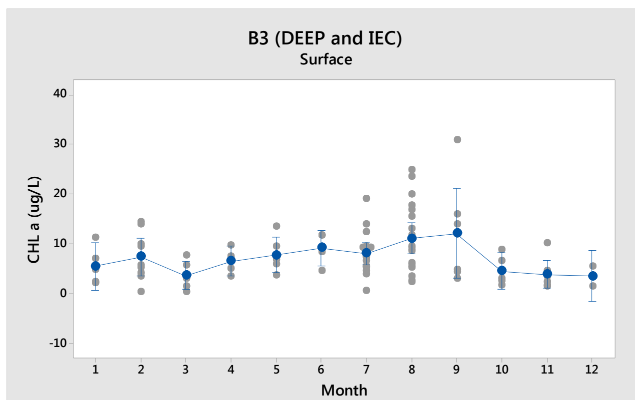
2016 data not included due to calibration issue



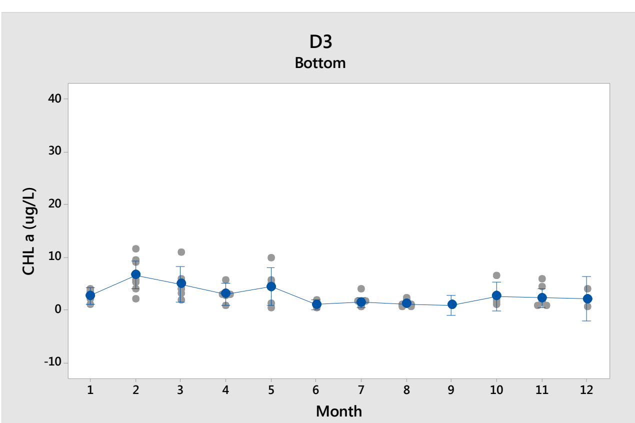


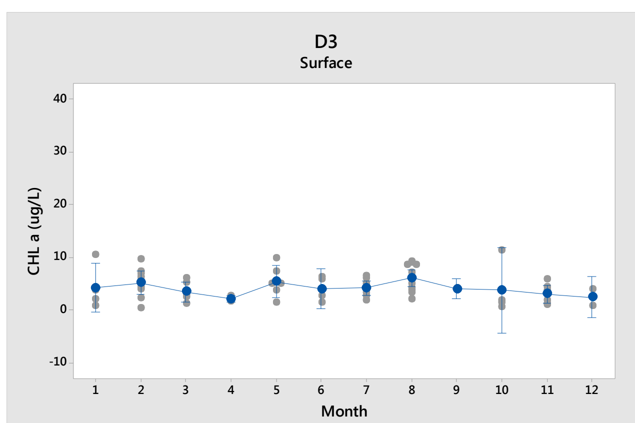
2016 IEC data not included due to calibration issue

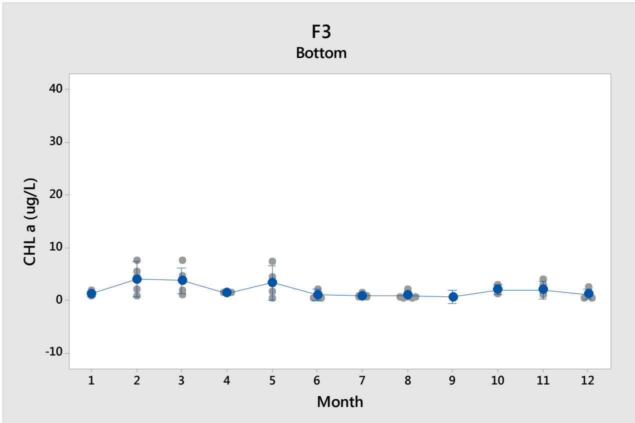


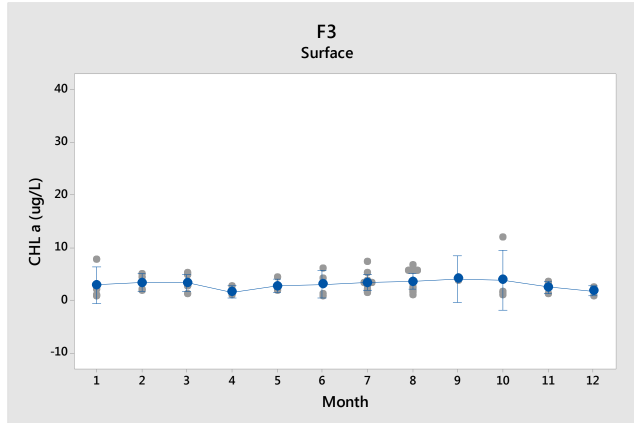


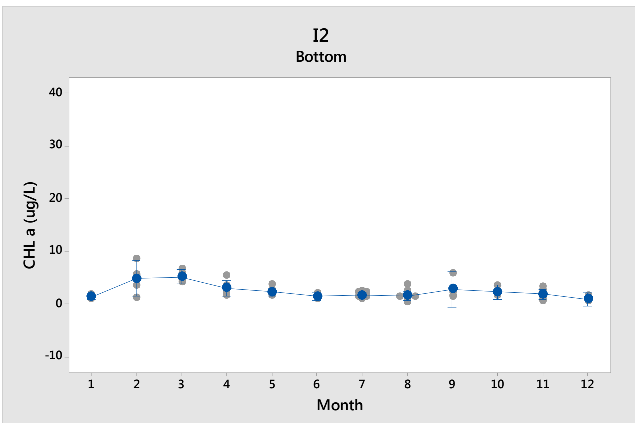
2016 IEC data not included due to calibration issue

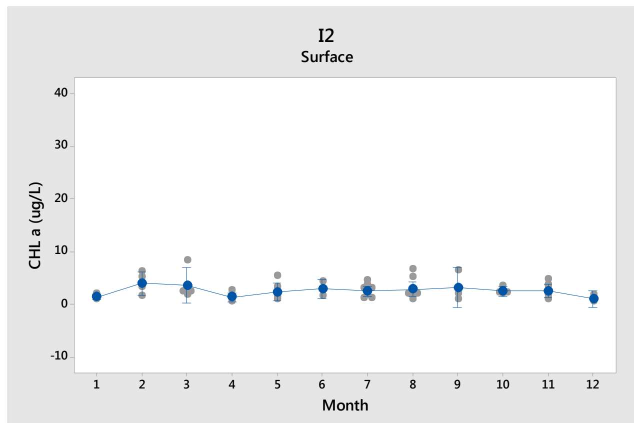





F3
Bottom
CHL a (ug/L)
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12
Month

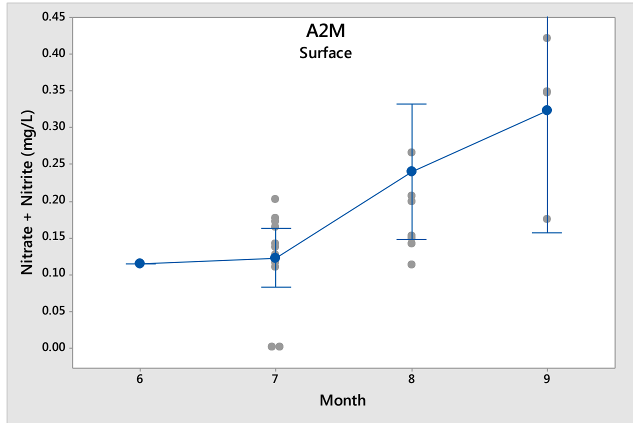

F3
Surface
CHL a (ug/L)
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12
Month

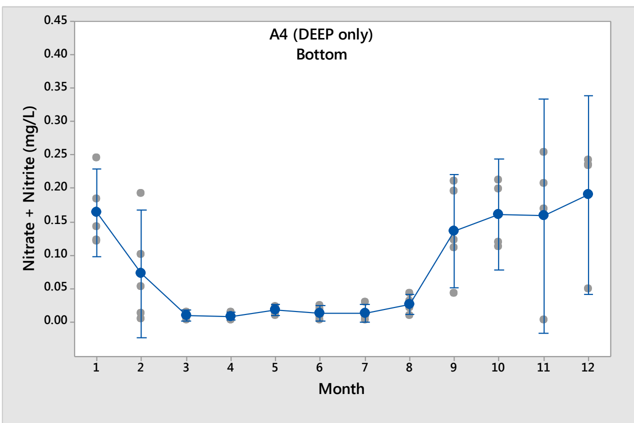

I2
Bottom
CHL a (ug/L)
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12
Month

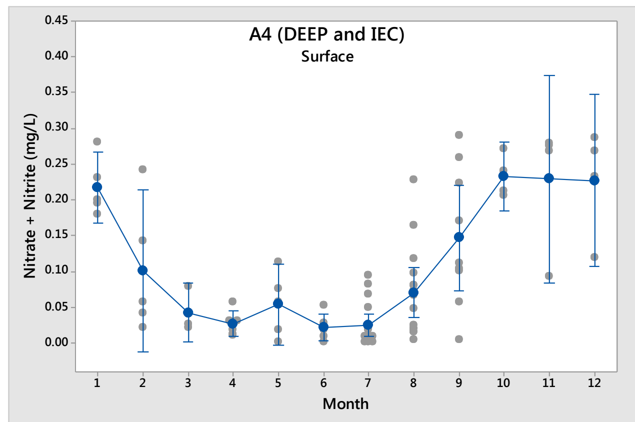

I2
Surface
CHL a (ug/L)
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12
Month

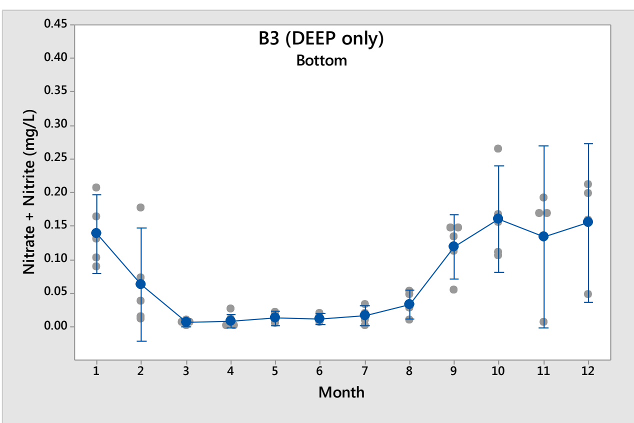
Appendix F– 2014-2018 Nutrient Data- Nitrate + Nitrite

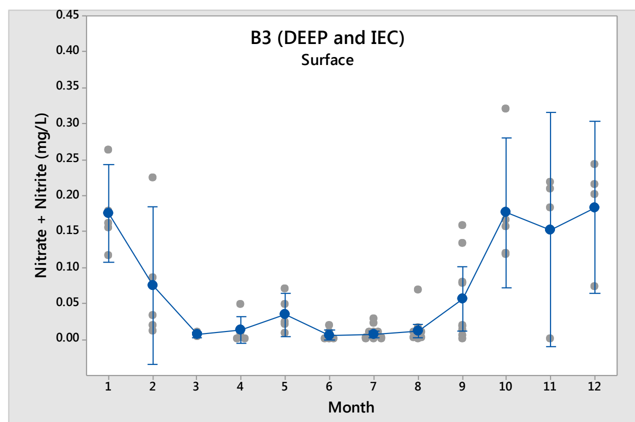
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See [Figure 1](#) for station locations. IEC station A2M is only sampled during the summer months; beginning in October 2018, IEC stations will be sampled year-round.

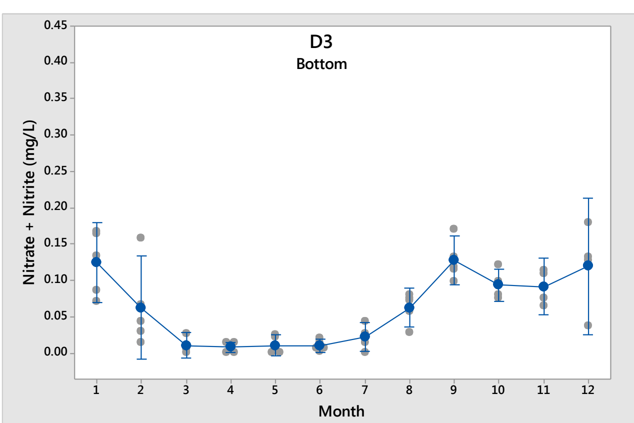


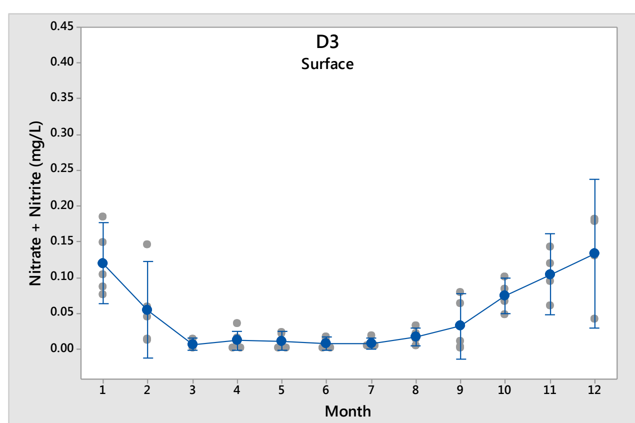


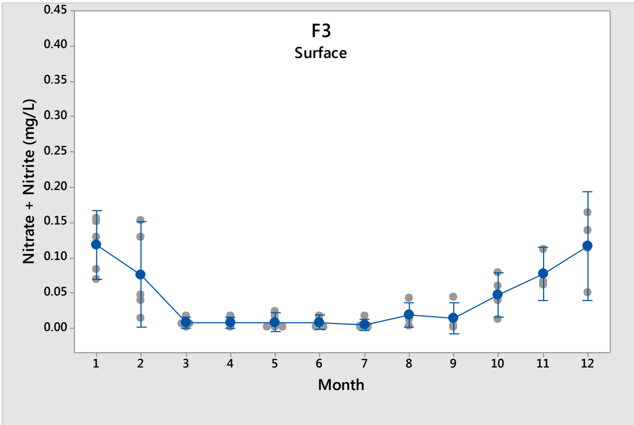


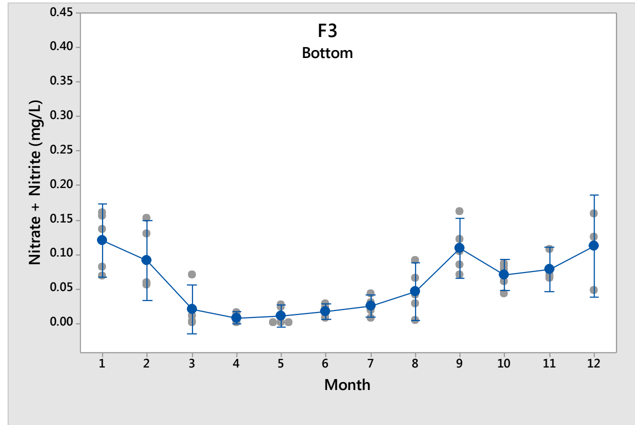


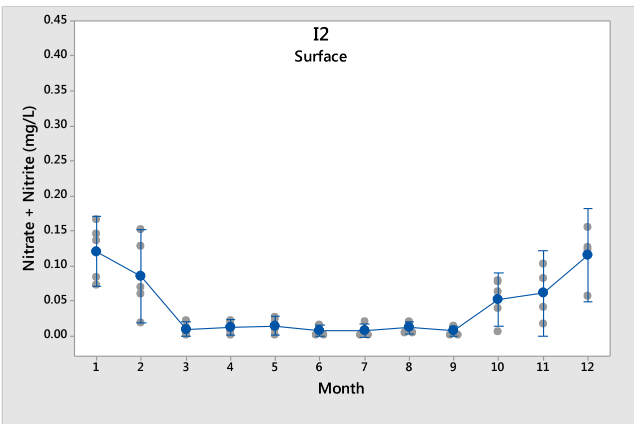


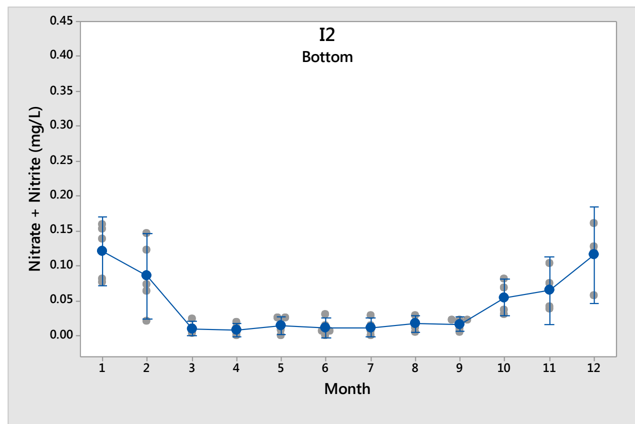





F3
Surface
Nitrate + Nitrite (mg/L)
Month

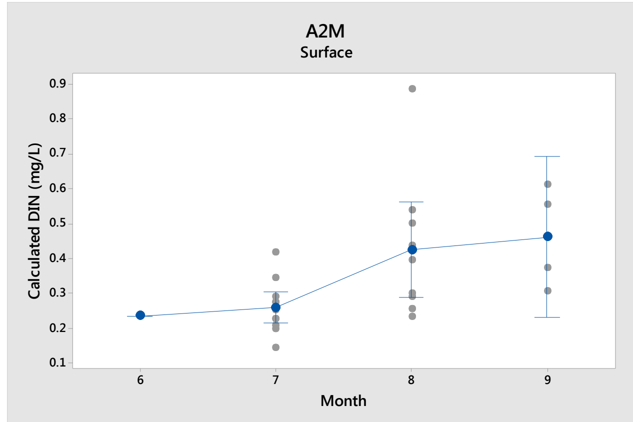

F3
Bottom
Nitrate + Nitrite (mg/L)
Month

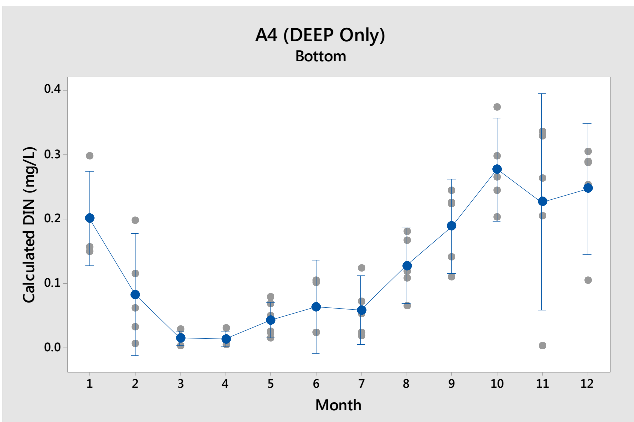

I2
Surface
Nitrate + Nitrite (mg/L)
Month

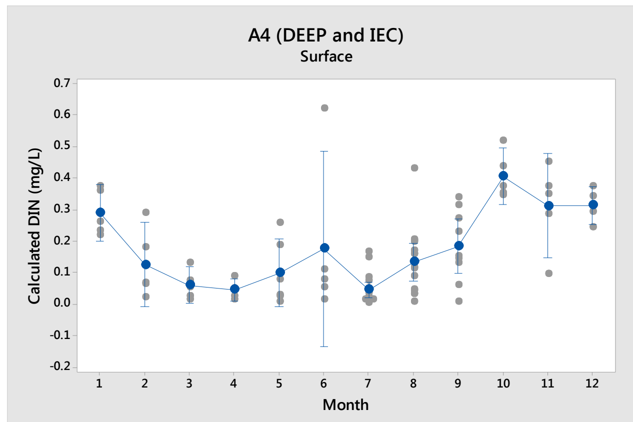

I2
Bottom
Nitrate + Nitrite (mg/L)
Month

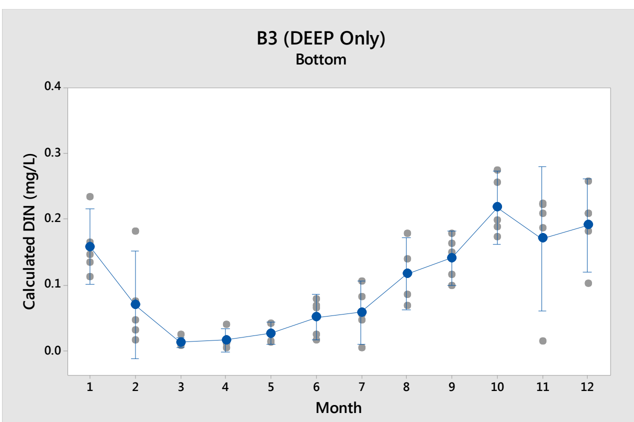
Appendix F– 2014-2018 Nutrient Data- Dissolved Inorganic Nitrogen

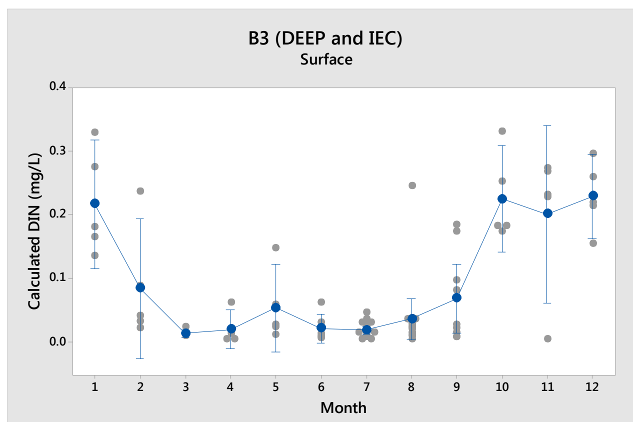
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See Figure 1 for station locations. IEC station A2M is only sampled during the summer months; beginning in October 2018, IEC stations will be sampled year-round. Please note the different scales for Stations A2M and A4. DIN is calculated by adding Nitrate+Nitrite together with Ammonia.

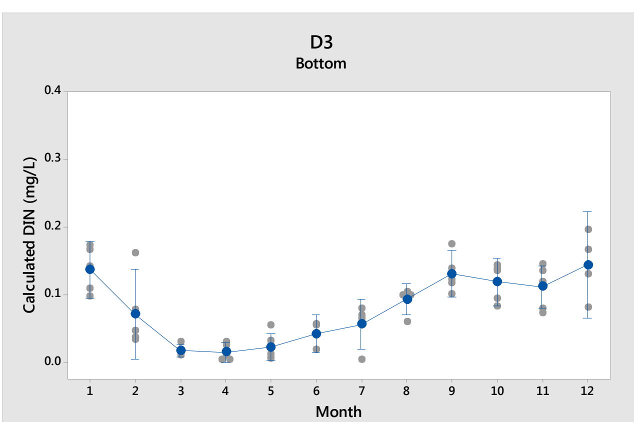


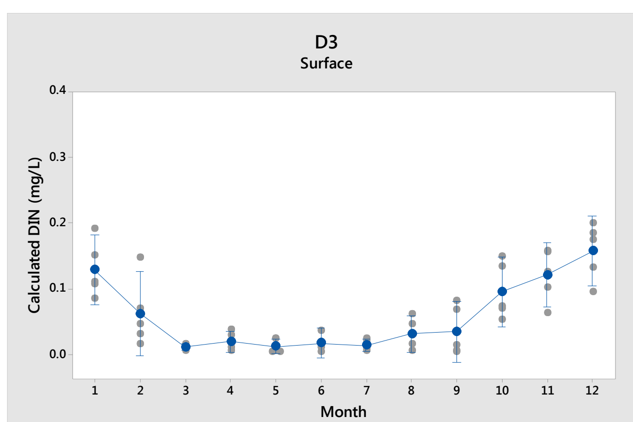


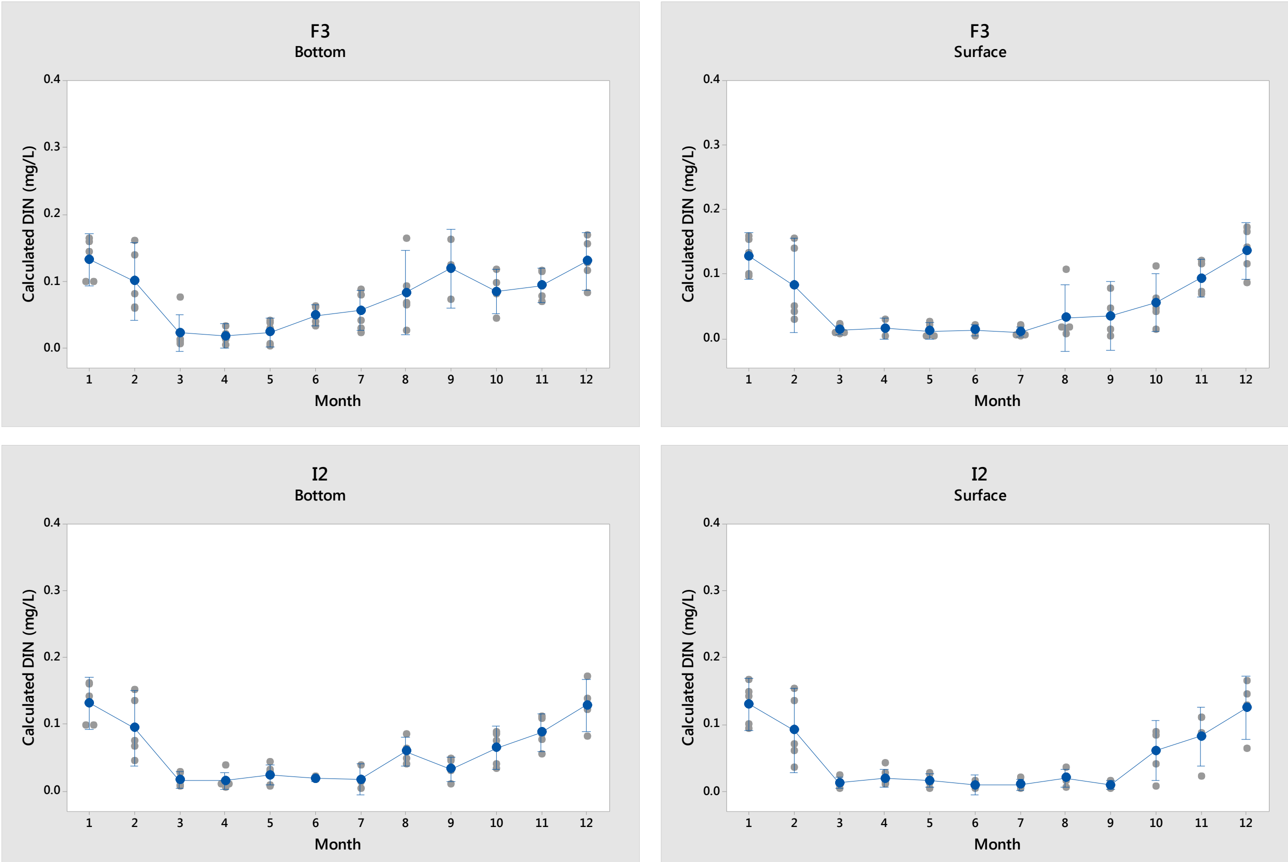






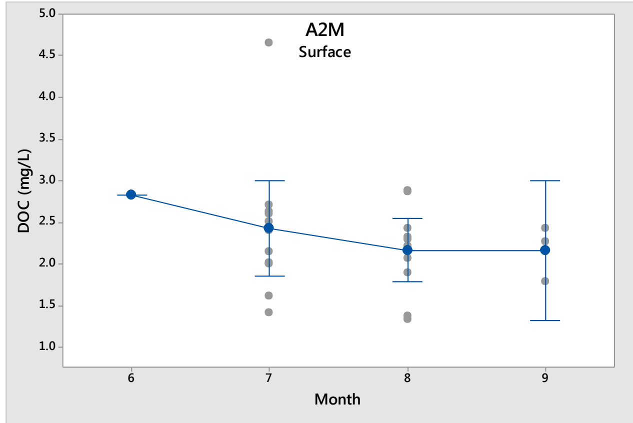


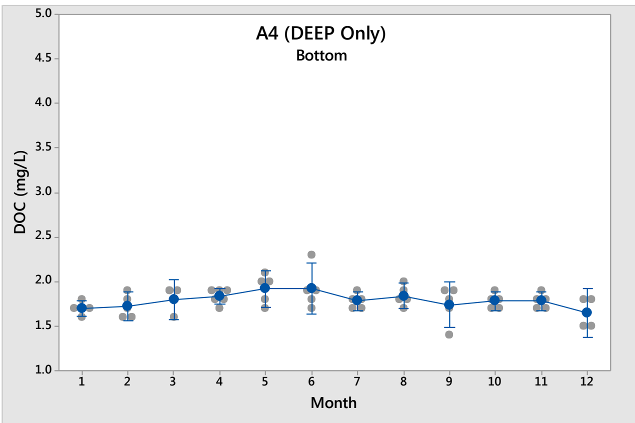


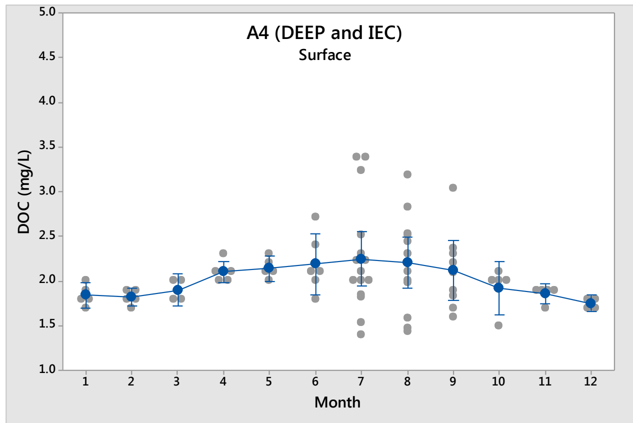

F3
Bottom
Calculated DIN (mg/L)
Month
F3
Surface
Calculated DIN (mg/L)
Month
I2
Bottom
Calculated DIN (mg/L)
Month
I2
Surface
Calculated DIN (mg/L)
Month

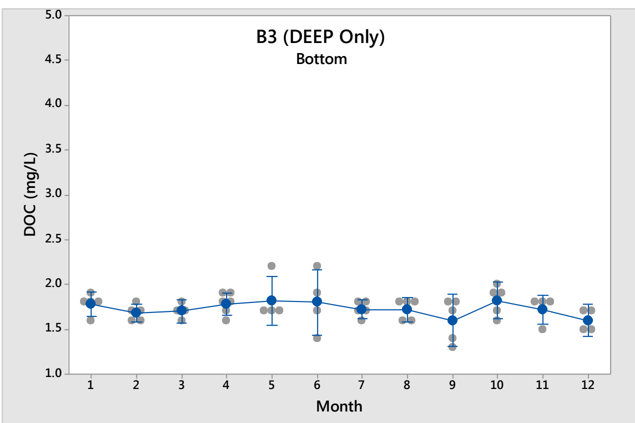
Appendix F– 2014-2018 Nutrient Data- Dissolved Organic Carbon

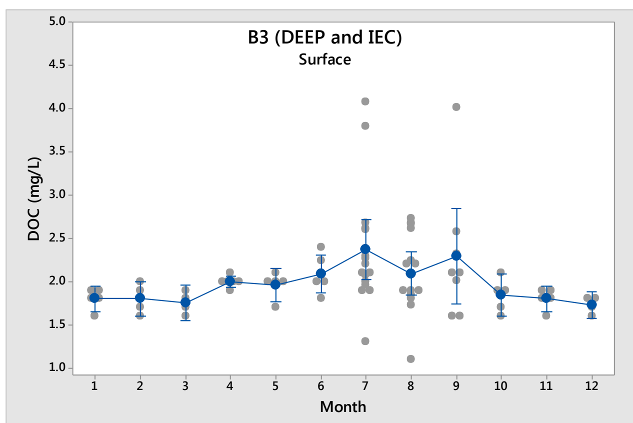
Interval plots showing the mean (●), 95% confidence interval (I), and individual data points (●) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See Figure 1 for station locations. IEC station A2M is only sampled during the summer months; beginning in October 2018, IEC stations will be sampled year-round.

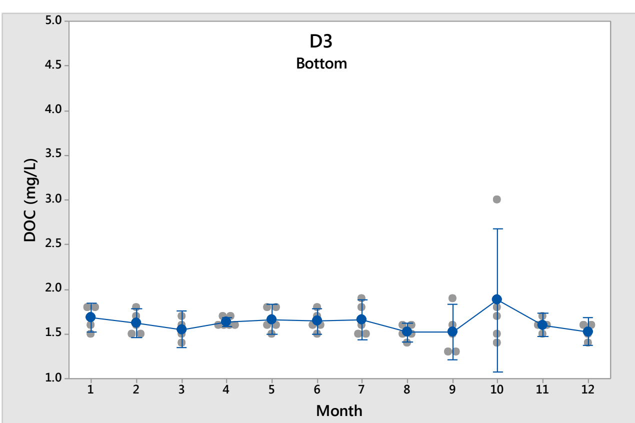


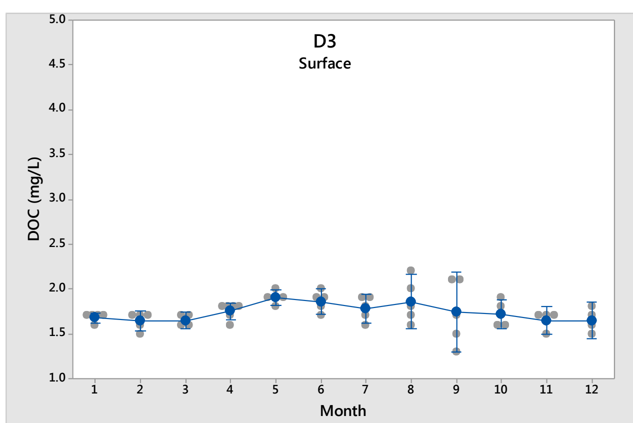


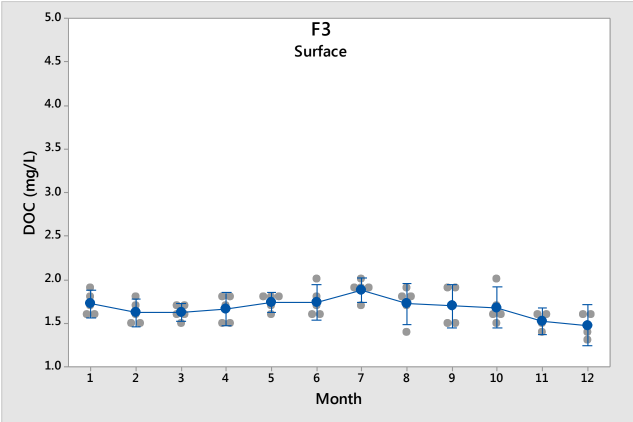


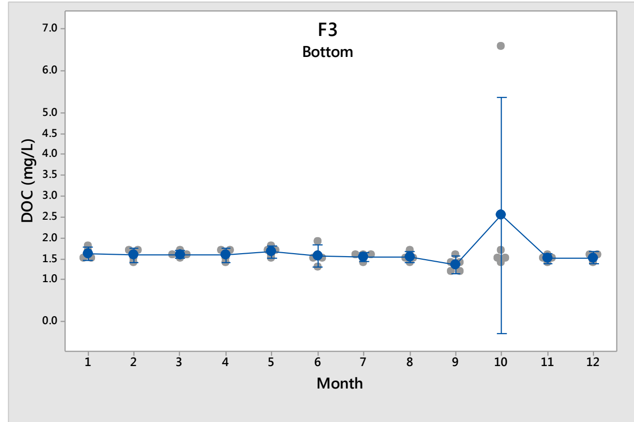


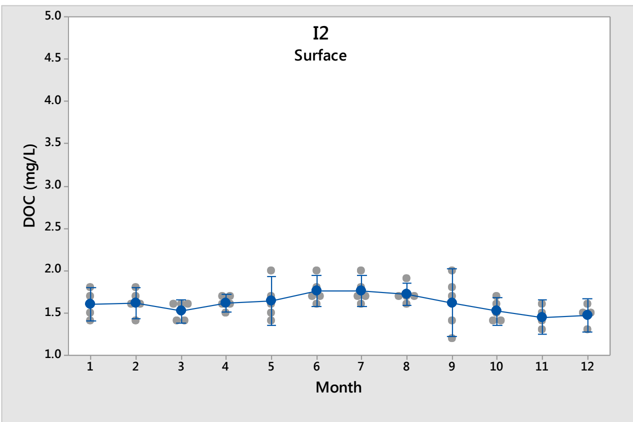


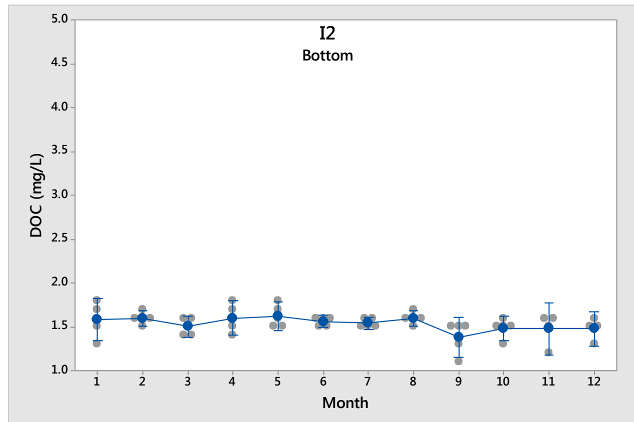





F3
Surface
DOC (mg/L)
Month
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1 2 3 4 5 6 7 8 9 10 11 12

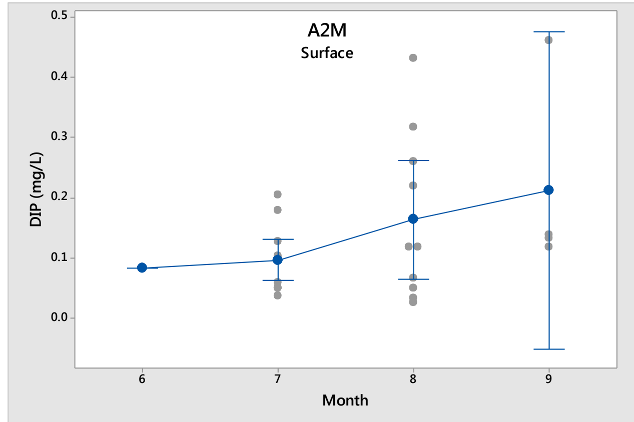

F3
Bottom
DOC (mg/L)
Month
7.0
6.0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.0
1 2 3 4 5 6 7 8 9 10 11 12

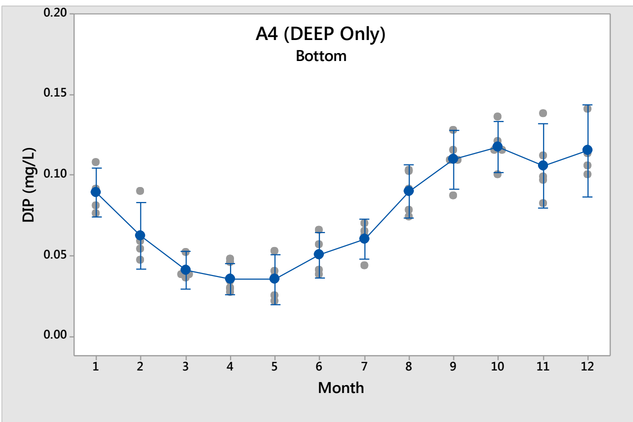

I2
Surface
DOC (mg/L)
Month
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1 2 3 4 5 6 7 8 9 10 11 12

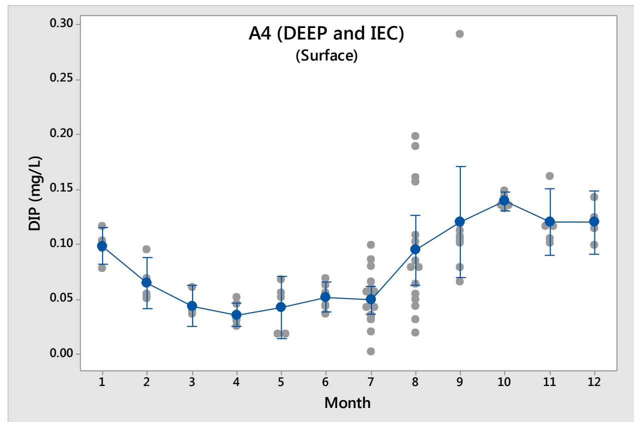

I2
Bottom
DOC (mg/L)
Month
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1 2 3 4 5 6 7 8 9 10 11 12

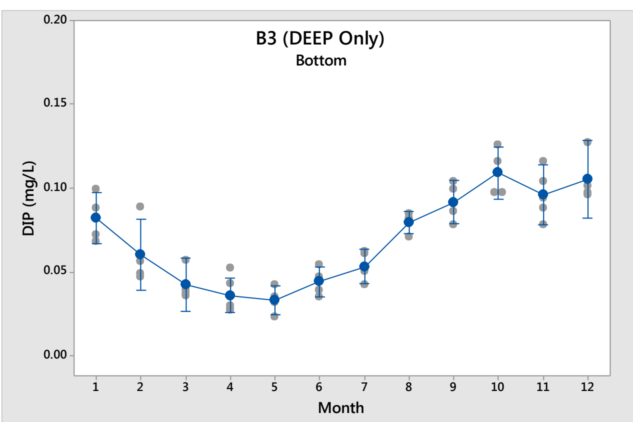
Appendix F– 2014-2018 Nutrient Data -Dissolved Inorganic Phosphate

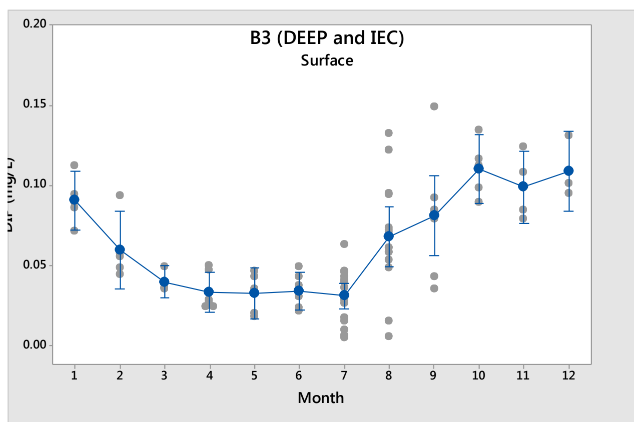
Interval plots showing the mean ( ), 95% confidence interval (I), and individual data points ( ) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See Figure 1 for station locations. IEC station A2M is only sampled during the summer months; beginning in October 2018, IEC stations will be sampled year-round.

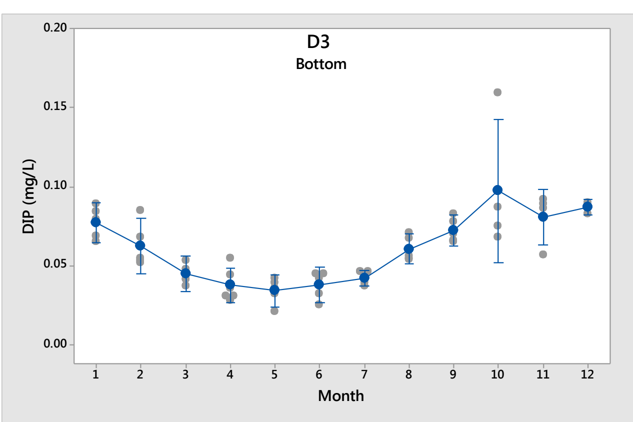


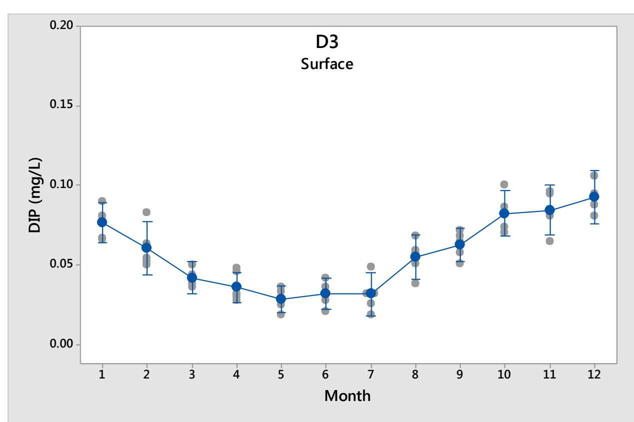


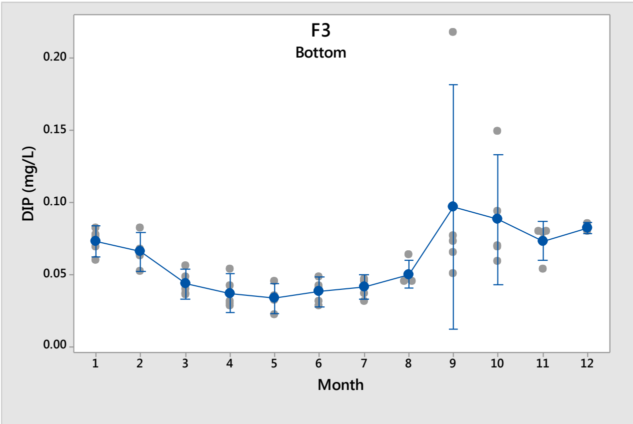


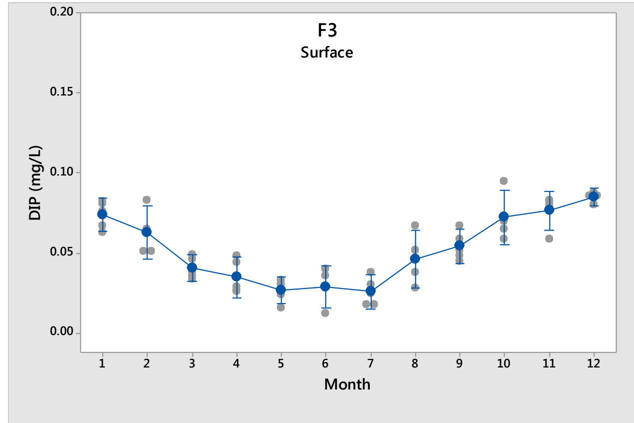


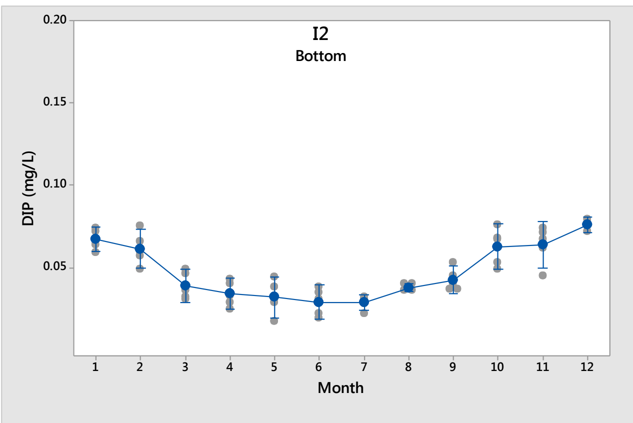


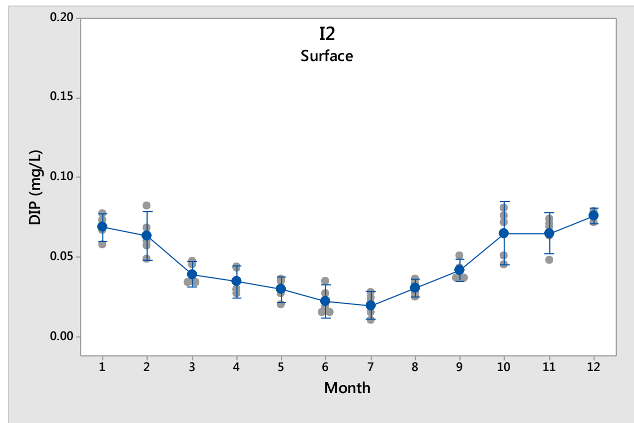





F3
Bottom
DIP (mg/L)
0.00
0.05
0.10
0.15
0.20
1 2 3 4 5 6 7 8 9 10 11 12
Month

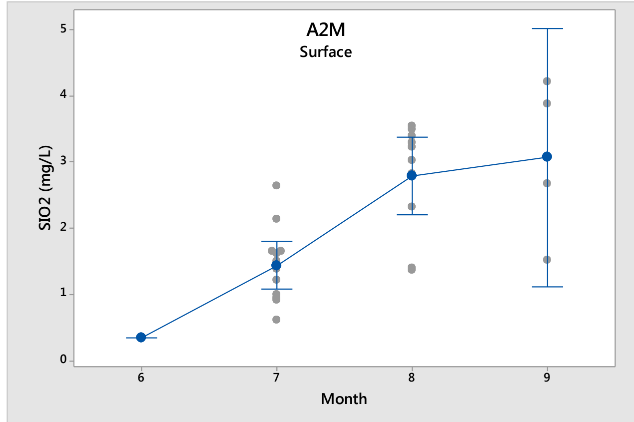

F3
Surface
DIP (mg/L)
0.00
0.05
0.10
0.15
0.20
1 2 3 4 5 6 7 8 9 10 11 12
Month

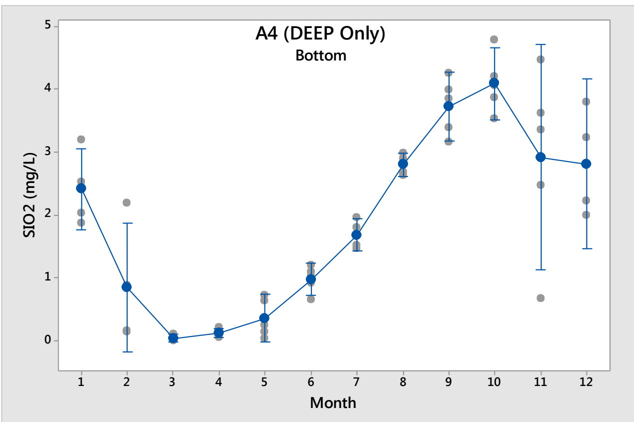

I2
Bottom
DIP (mg/L)
0.05
0.10
0.15
0.20
1 2 3 4 5 6 7 8 9 10 11 12
Month

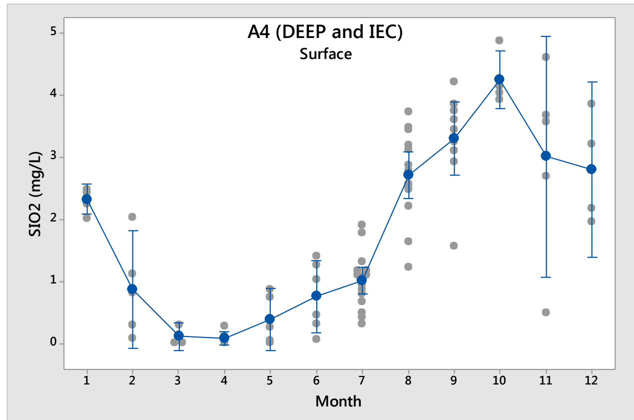

I2
Surface
DIP (mg/L)
0.00
0.05
0.10
0.15
0.20
1 2 3 4 5 6 7 8 9 10 11 12
Month

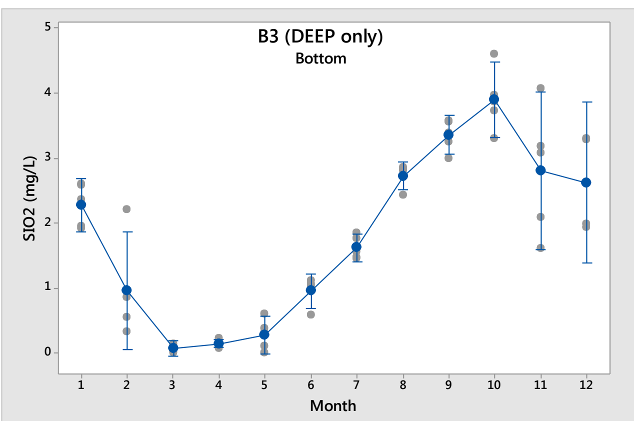
Appendix F– 2014-2018 Nutrient Data - Dissolved Silica

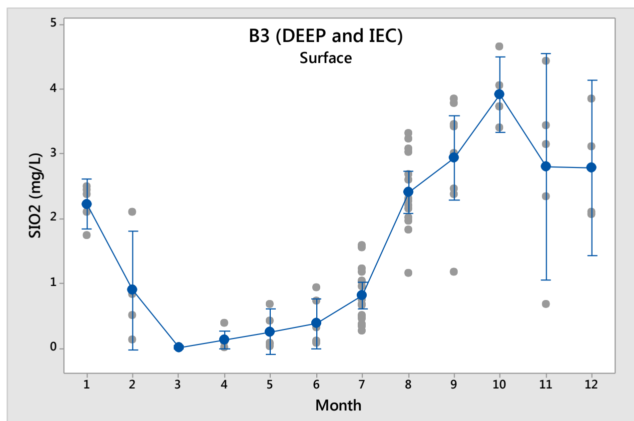
Interval plots showing the mean ( ), 95% confidence interval (I), and individual data points ( ) by survey from 2014-2018. Individual standard deviations were used to calculate the intervals. Additional stations are available upon request. See Figure 1 for station locations. IEC station A2M is only sampled during the summer months; beginning in October 2018, IEC stations will be sampled year-round.

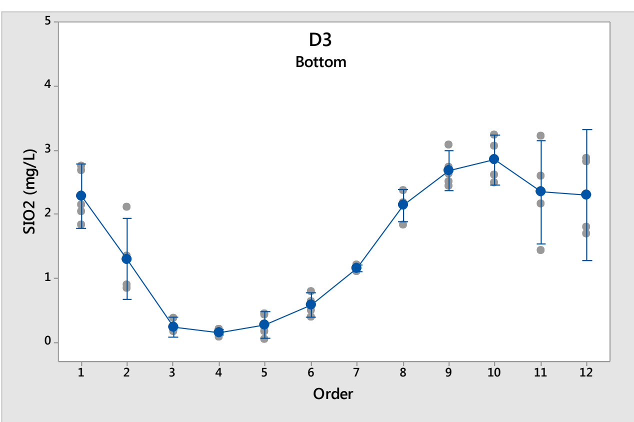


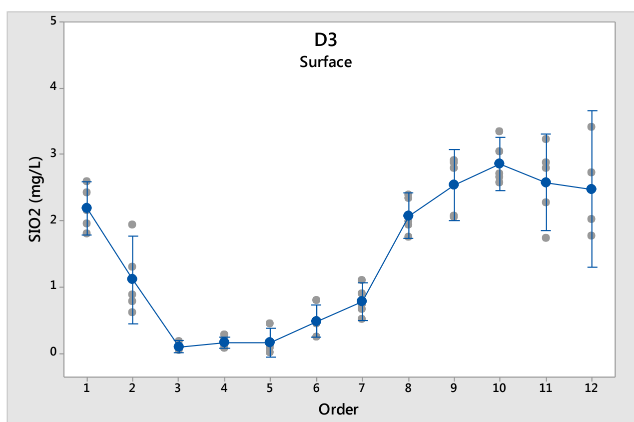


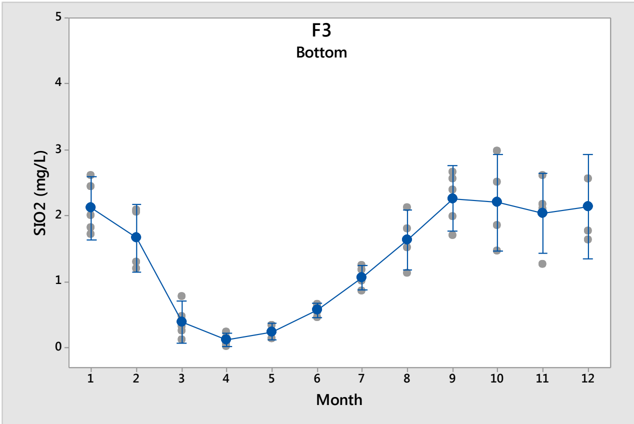


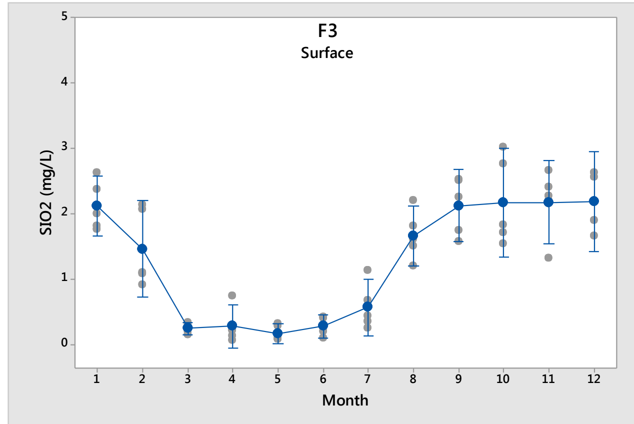


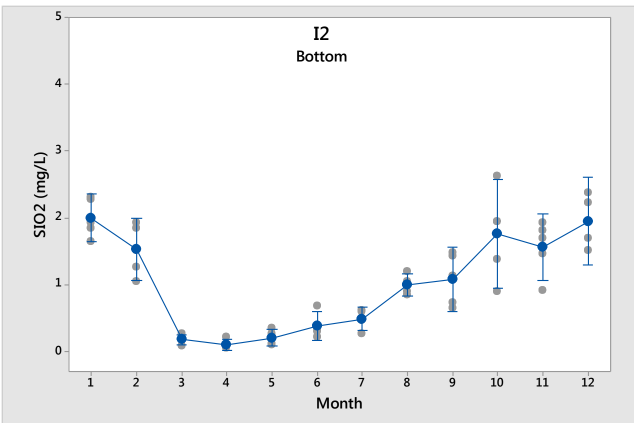


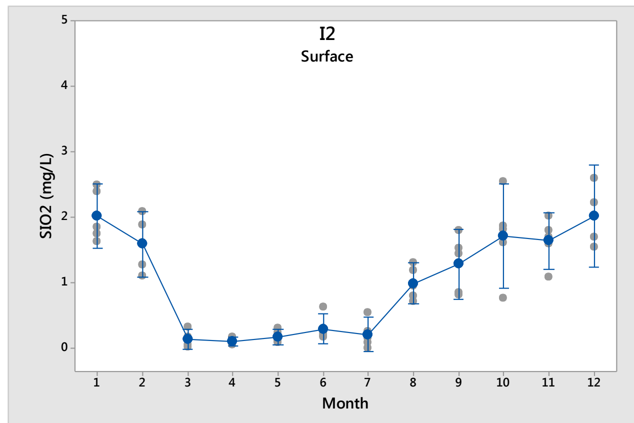





F3
Bottom
SIO2 (mg/L)
Month


F3
Surface
SIO2 (mg/L)
Month


I2
Bottom
SIO2 (mg/L)
Month


I2
Surface
SIO2 (mg/L)
Month

Acknowledgements

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long island sound study