2017 Long Island Sound Hypoxia Season Highlights

Connecticut Department of Energy & Environmental Protection

79 Elm Street, Hartford, CT 06106

Robert J. Klee, Commissioner

Interstate Environmental Commission

2800 Victory Boulevard, Building 6S Room 106 College of Staten Island—CUNY Campus

Staten Island, NY 10314

New England Interstate Water Pollution Control Commission

650 Suffolk St, Lowell, MA 01854

Background

Designated as an estuary of national significance by Congress in 1987, Long Island Sound is home to a diverse network of flora and fauna, and over 4 million people. 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 Maine and Quebec that encompasses over 16,000 square miles and 9 million people. 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). Seasonal weather patterns, particularly during the summer months, exacerbate the effects of nutrient loading, causing hypoxic conditions in the Sound; most prominently in the Western Basin. This, in turn, negatively impacts the water quality of the Sound, the ecosystem services and resources it provides, and the habitat that is home to many species.

In response to the critical need to document summer hypoxic conditions in Long Island Sound and its embayments, as defined in the Long Island Sound Study's Comprehensive Conservation and Management Plan, the Connecticut Department of Energy and Environmental Protection (CT DEEP) and the Interstate Environmental Commission (IEC), have monitored dissolved oxygen, as well as key water quality parameters relevant to hypoxia, in Long Island Sound since 1991.

This report presents a summary of *in situ* and surface chl a data collected by CT DEEP and IEC during the 2017 hypoxia season. Based on the 25 years of hypoxia monitoring, the LIS hypoxia season extends from June to September. Data from the Long Island Sound Integrated Coastal Observing System (LISICOS) are presented with permission for informational purposes. Sampling and analyses were conducted under EPA-approved Quality Assurance Project Plans.

Hypoxia

The term "hypoxia" means low dissolved oxygen ("DO") concentrations in the water. The DO concentration of a body of water can vary naturally, however; hypoxia is often driven by anthropogenic processes such as nutrient pollution (eutrophication, Figure 1). 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 3.0 mg/L, although research suggests that there may be adverse effects to organisms above this level depending upon the length of exposure (EPA, 2000 and Simpson *et al.,* 1995).

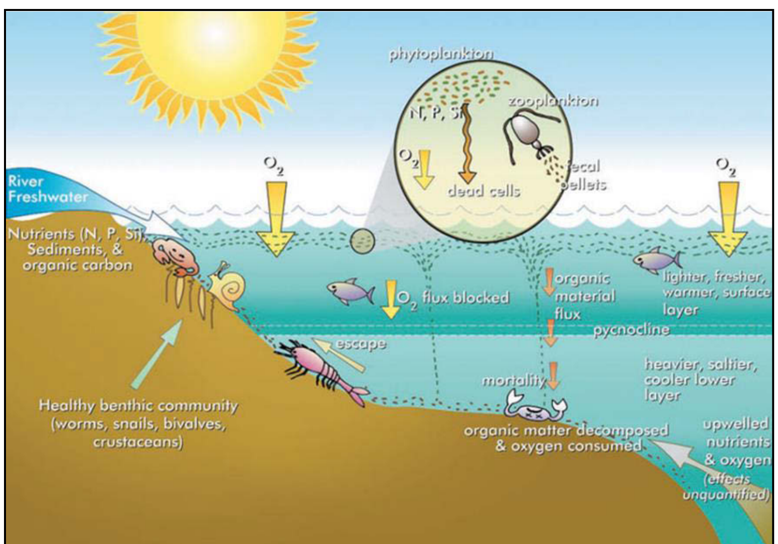


Figure 1: biogeochemical cycles in aquatic environments; from: https://www.epa.gov/sites/production/files/2015-03/eutro_big.jpg

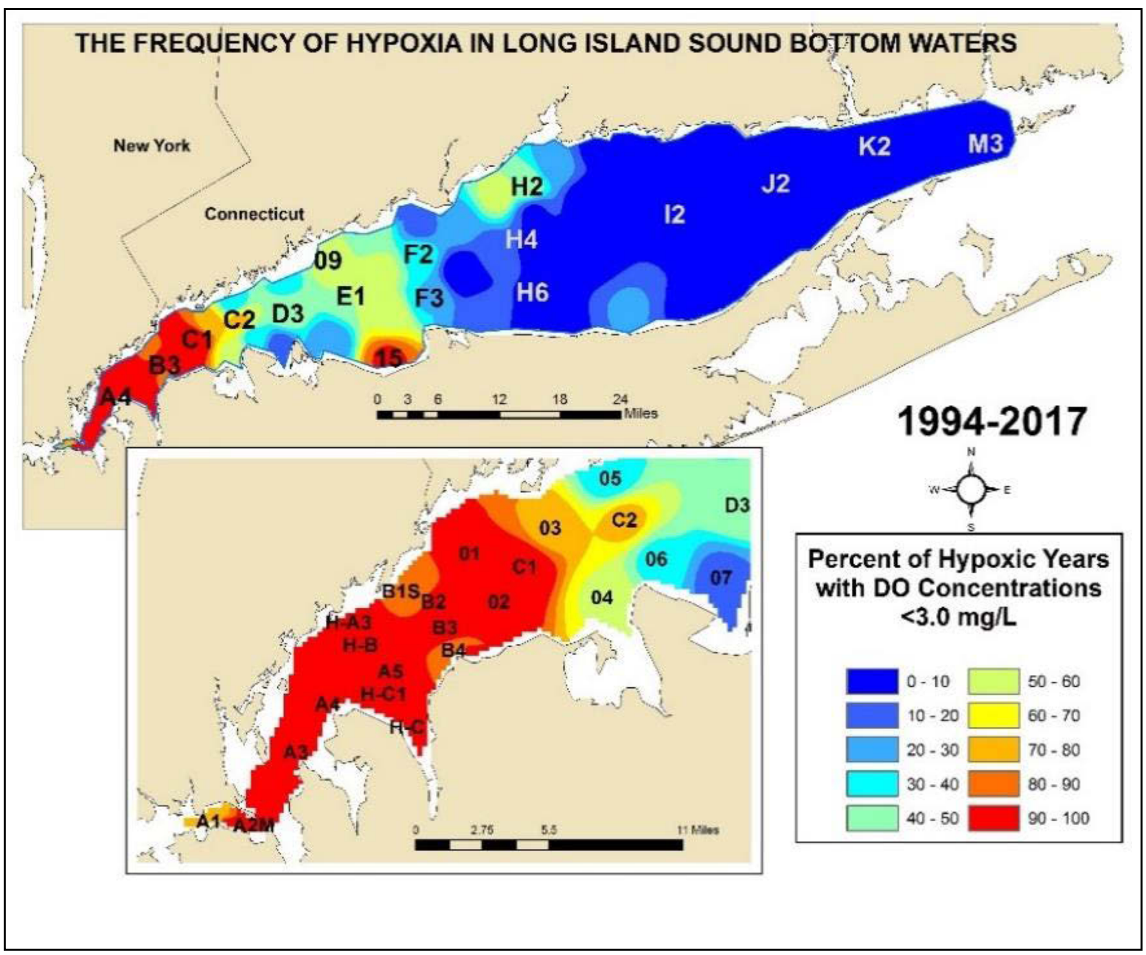
Factors that Influence Dissolved Oxygen

In LIS, water temperature plays a major role in the ecology of the Sound especially in the timing and severity of the summer hypoxia event. IEC's monitoring program records water temperature and salinity data weekly from June to September while CT DEEP's monitoring program records water temperatures and salinity year-round. In LIS, there are two key contributors to hypoxia: nutrient enrichment and stratification. Nutrients, especially nitrogen, flow into the Sound from numerous sources including point sources like wastewater treatment plants and nonpoint sources such as stormwater runoff.

This enrichment leads to excessive growth of phytoplankton, particularly in the spring. Temperature can stimulate or impede phytoplankton growth. As the plankton die, they begin to decay and settle to the bottom. Bacterial decomposition breaks down the organic material from the algae, using up oxygen in the process.

Recent History of Hypoxia in LIS

Each summer low oxygen levels render hundreds of square miles of bottom water unhealthy for aquatic life. Dissolved oxygen levels follow seasonal patterns with a decrease in bottom water DO over the course of the summer. Hypoxic conditions during the summer are mainly confined to the Narrows and Western Basin of Long Island Sound (Figure 3). Those areas comprise the section of the Sound west of a line from Stratford, CT to Port Jefferson, NY. The maximum extent of the hypoxic condition typically occurs in early August.



Summary of Monitoring Activities

Monitoring Agency	Program Overview	Duration	Parameters and Methods
LICOS	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. Funding for the program was first provided through the Environmental Protection Agency Environmental Monitoring for Public Access and Community Tracking (EMPACT) grant program and is now provided, in part, by the National Oceanic and Atmospheric Administration.	2003-Present	LISICOS monitors water quality parameters (*e.g.*, salinity, temperature, dissolved oxygen, surface waves, photosynthetically available radiation, chlorophyll) and meteorological parameters (*e.g.*, wind speed, direction, barometric pressure, wave height) 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: http://lisicos.uconn.edu/index.php. The system is maintained by the University of Connecticut.
CT DEEP	CT DEEP, The Connecticut Department of Energy & Environmental Protection (CT DEEP, formerly the Department of Environmental Protection, (CTDEP) conducts an intensive year-round water quality monitoring program on Long Island Sound (LIS). Water quality is monitored at up to forty-eight (48) sites by staff aboard the Department's Research Vessel *John Dempsey*. Data from the surveys are used to quantify and identify annual trends and differences in water quality parameters relevant to hypoxia (low dissolved oxygen). These data are also used to evaluate the effectiveness of the management program to reduce nitrogen concentrations.	1991-present In situ data and nutrient samples are collected monthly year-round and at 17 sites from October to May. Bi-weekly hypoxia surveys start in mid-June and end in September with up to 48 stations sampled during each survey for in situ parameters.	***In situ parameters*:** Dissolved oxygen, temperature, pH, and salinity **Instruments:** Conductivity Temperature Depth recorder (CTD) that takes measurements from the surface to the bottom of the water column. The CTD, a Sea-Bird model SBE-19 SeaCat Profiler equipped with auxiliary dissolved oxygen, photosynthetically-active radiation (PAR) and pH sensors, is attached to a Rosette Sampler and lowered through the water column at a rate of approximately 0.2 meters per second and measurements are recorded every 0.5 seconds. *In situ* data are reviewed in real-time. **Sampling:** Surface and bottom water samples are collected using Niskin water sampling bottles that are attached to the Rosette Sampler. Samples are filtered aboard the mini laboratory and preserved for later analyses at the University of Connecticut's Center for Environmental Science and Engineering in Storrs, Connecticut. **Parameters tested:** Dissolved silica, particulate silica, particulate carbon, dissolved organic carbon, dissolved nitrogen, particulate nitrogen, ammonia, nitrate + nitrite, particulate phosphorus, total dissolved phosphorus, orthophosphate, chlorophyll a, BOD, and total suspended solids.

			Since 2002, CT DEEP has collected zooplankton samples from six stations and phytoplankton from ten stations across Long Island Sound.
IEC	The Interstate Environmental Commission (IEC) is a tri-state water and air pollution control agency located in Staten Island, NY on the College of Staten Island campus. Established in 1936, the IEC serves the states of New York, New Jersey, and Connecticut. IEC conducts seasonal water quality monitoring in the far Western Long Island Sound and the Upper East River. The overall goal of IEC's seasonal monitoring program is to effectively measure key water quality indicators identified by the Long Island Sound Study (LISS). IEC's WLIS monitoring program, including sampling and analytical methods, is outlined in a Quality Assurance Project Plan (QAPP) that is revised annually and approved by EPA Region 1. IEC collects *in situ* data from 22 stations in the far western (Narrows) portion of the Sound on a weekly basis (see figure). IEC monitoring data incorporated in this report for hypoxia maps uses data from 13 of 22 stations. The nine stations not included are representative of embayments. IEC data represented in this report that is not dissolved oxygen data were derived from IEC's six axial stations, which were combined with CT DEEP's seven axial stations. IEC's six axial stations include the following: A1, A2M, A3, A4, A5, B3. CT DEEP's seven axial stations include the following: A4, B3, D3, F3, H4, I2, and M3. Additional IEC data can be derived from IEC's weekly season summaries.	1991-present IEC's monitoring program is conducted between June and September when dissolved oxygen concentrations in western Long Island Sound are typically at their lowest levels. This allows for better characterization of hypoxia and identification of critical areas in the far western Sound.	***In situ* parameters:** water temperature, dissolved oxygen, salinity, pH, and water clarity (Secchi disk depth). **Instruments:** In situ parameters are collected using a YSI EXO 1 Multiparameter Sonde at bottom, mid, and surface depths at all 22 stations on a weekly basis. For stations with a depth of less than 10 meters, only surface and bottom measurements are collected. Data collection includes recording observations of percent cloud cover, sea state, and the measurement of water clarity (Secchi disk depth) as well as weather and precipitation data. **Sampling:** IEC collects samples biweekly for chlorophyll a, biochemical oxygen demand (BOD), total suspended solids (TSS), and a suite of nutrient parameters. Surface grab samples (within one meter of the surface) are collected on a biweekly basis for chlorophyll a and Total Suspended Solids (TSS) at all 22 stations and a suite of nutrient parameters and Biochemical Oxygen Demand (BOD) at 11 of the 22 stations. **Parameters tested:** Ammonia, nitrate+nitrite, particulate nitrogen, orthophosphate/DIP, total dissolved phosphorus, particulate phosphorus, dissolved organic carbon, particulate carbon, dissolved silica, and biogenic silica. chlorophyll a, TSS, BOD All nutrient parameters (with the exception of dissolved organic carbon and particulate carbon) are analyzed at the IEC laboratory. Samples for dissolved organic carbon and particulate carbon analysis are subcontracted to the University of Maryland's Center for Environmental Science, Chesapeake Biological Laboratory, Nutrient Analytical Services Laboratory in Solomons, MD. The IEC laboratory is a nationally certified environmental testing laboratory with National Environmental Laboratory Accreditation Program (NELAP) accreditation.

2017 Important Facts

CT DEEP conducted seven surveys during the summer of 2017 between June 6th and September 1st. Over the course of the season, fifteen (15) stations exhibited hypoxia. Of the 275 site visits completed in 2017 hypoxic conditions were found during three surveys.

IEC conducted twelve surveys during the summer of 2017 between June 27th and September 11th. Hypoxic conditions were found during five surveys (embayment stations included). Fifteen stations exhibited hypoxic conditions over the course of the season.

Extent and Duration of Hypoxia

The 2017 hypoxic event was estimated to have begun on July 18th. There was a clear period between July 21st and August 6th when DO concentrations rose above 3.0 mg/L and remained above this threshold for 18 days. This is also evident in data collected by the LISICOS Execution Rocks Buoy. This increase is partly attributable to a rare summertime Nor'easter that swept through the area July 27-31 (NWS 2017, NYC Patch 2017). DO concentrations decreased below the hypoxia threshold again on August 7th and remained there for another 23 days, until the 29th of August when concentrations climbed above the 3.0 mg/L threshold. Compared to the previous 24 years, 2017 was the SHORTEST event lasting 26 days, and was well below the average of 53 days.

LISCOS

While real-time data were not available from the LISCOS buoys in 2017, data was logged internally. Data were periodically uploaded by UConn staff during maintenance cruises

Based on LISICOS Western LIS Buoy Data Collected Between June 1 to October 1

- Estimated Dates: 8/9-8/11, 8/14-8/21, 8/26-8/28
- Duration below 3.0 mg/L (cumulative days): 10.88
- Duration below 2.0 mg/L (cumulative days): 0
- Duration below 1.0 mg/L (cumulative days): 0
- Minimum DO value (mg/L): 2.25 (August 18)

Based on LISICOS Execution Rocks Buoy Data Collected Between June 1 to October 1

- Estimated Dates Event #1: 7/17/17-7/24/17
- Estimated Dates Event #2: 8/2/17-8/29/17
- Duration below 3.0 mg/L (cumulative days): 31.31
- Duration below 2.0 mg/L (cumulative days): 12.45
- Duration below 1.0 mg/L (cumulative days): 0.35
- Minimum DO value (mg/L): 0.78 (August 16)

Results

CTDEEP and IEC have been collecting summer dissolved oxygen data across the Sound since 1991. Recent data from the past ten years (2008-2017) are presented in box plots in figure 3 to demonstrate the spatial (top) and temporal (bottom) variability. Moving from West to East, DO concentrations in Long Island Sound typically increase. The average DO from each survey tends to decrease in late June and then rebounds in late August.

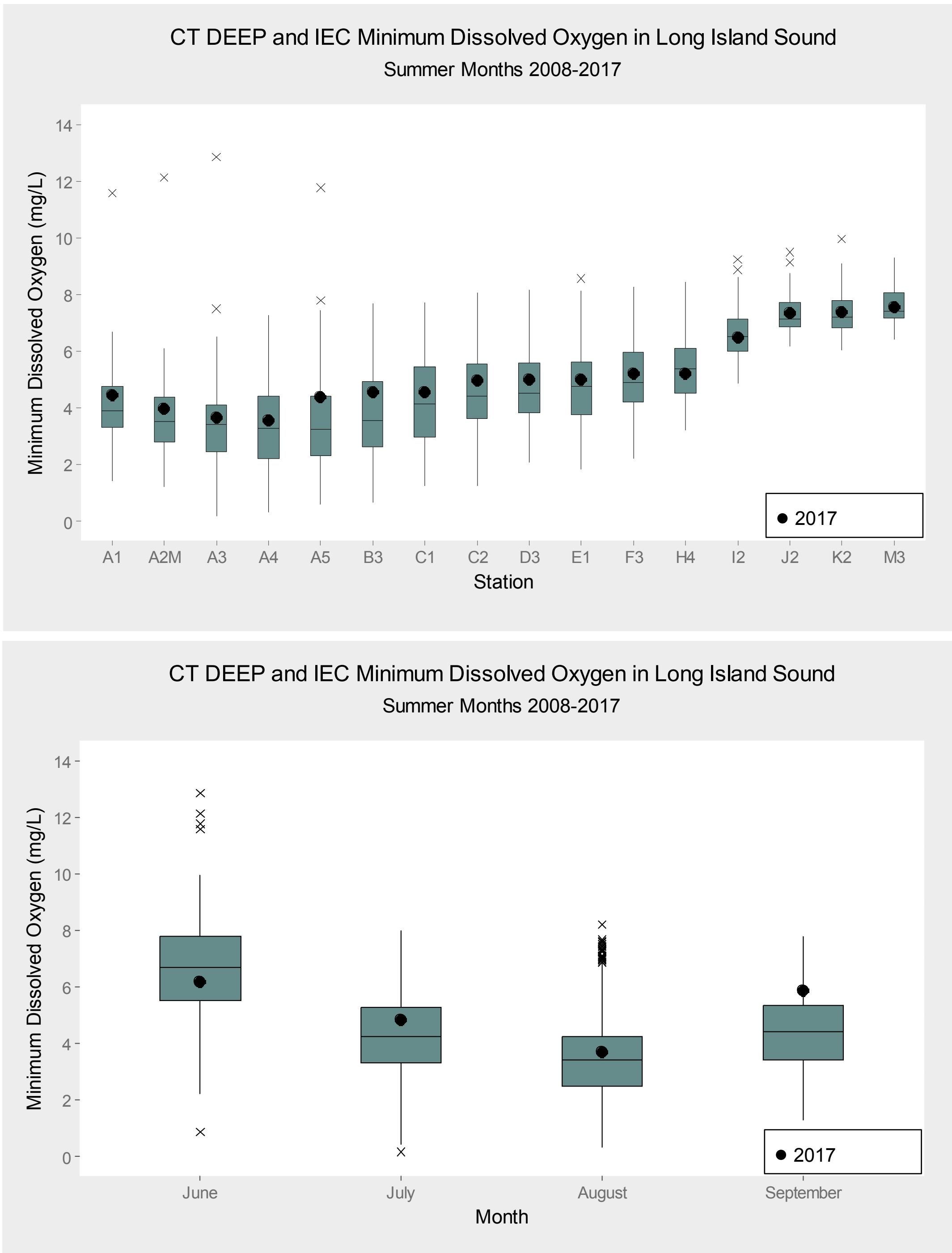


Figure 3: Spatial and temporal distribution of minimum dissolved oxygen in Long Island Sound; 2008-2017. Summer is defined as June-September.

Survey	Survey Date	Agency	Results
HYJUN17	**06/20/2017 - 06/21/2017**	**CT DEEP**	CT DEEP sampled 23 stations. The lowest dissolved oxygen recorded during this survey was at station A4 with a concentration of 4.65 mg/ L. There were 40.5 km^2 of bottom water that had dissolved oxygen concentrations less than 4.8 mg/L during the HYJUN17 survey.
RUN 1	**06/28/2017**	**IEC**	Four stations had concentrations below 4.8 mg/L; A4, H-C1, A5, and A3. The lowest dissolved oxygen recorded during this survey was at station A4 with a concentration of 0.86 mg/L. *However, this value is considered an outlier and was not used to calculate the start date or duration of the 2017 Hypoxia Season.* **The historic lowest dissolved oxygen concentration recorded by IEC at Station A4 during a June survey was 2 mg/L in 2004 and the historic lowest dissolved oxygen concentration recorded by CT DEEP at Station A4 during an HYJUN survey was 2.84 mg/L also in 2004.
WQJUL17 **Run 2**	**07/05-07/07/2017** **07/05/2017**	**CT DEEP** **IEC**	Dissolved oxygen concentrations in the bottom waters of LIS were less than 4.8 mg/L at six CT DEEP stations and ten IEC stations.
RUN 3	**07/11/2017**	**IEC**	Two stations (A4 and H-C) had concentrations below 3.5 mg/L. Twelve (12) additional stations had concentrations below 4.8 mg/L. The lowest dissolved oxygen recorded during this survey was at station A4 with a concentration of 3.35 mg/L.
HYJUL17 **RUN 4**	**07/18-07/20/2017** **07/18/2017**	**CT DEEP** **IEC**	During IEC's RUN 4 only four stations exhibited DO concentrations above 4.8 mg/L. Two stations were below 3.0 mg/L and four stations were below 3.5 mg/L. During the CT DEEP HYJUL17 survey, DO concentrations dropped below 4.8 mg/L at 20 stations with one station below 3.5 mg/L and six stations below 3.0 mg/L.
RUN 5	**07/26/2017**	**IEC**	DO measurements at 11 stations were less than 4.8 mg/L. The lowest dissolved oxygen recorded during this survey was 1.23 mg/L at H-D.
WQAUG17 **RUN 6**	**07/31-08/02/2017** **08/01/2017**	**CT DEEP** **IEC**	During the CT DEEP WQAUG17 survey, conditions improved with dissolved oxygen concentrations at all stations above 3.0 mg/L. CT DEEP Stations 19 and F3 remained below 3.5 mg/L. Twenty-two (22) stations were less than 4.8 mg/L. During the sixth IEC survey only one embayment station was below 3.0 mg/L and 15 stations were less than 4.8 mg/L.

RUN 7	**08/07/2017**	**IEC**	DO concentrations were below 4.8 mg/L at five stations (A3, A4, A5, H-C, and H-D). Seven additional stations had concentrations below 3.5 mg/L. The lowest dissolved oxygen recorded during this survey was at Station A5 with a concentration of 2.45 mg/L.
HYAUG17 **RUN 8**	**08/14-08/16/2017** **08/15/2017**	**CT DEEP** **IEC**	During the HYAUG17 survey, CT DEEP recorded one station, A4, with a DO concentration less than 2.0 mg/L, and IEC documented four stations with DO below 2.0 mg/L. CT DEEP also logged 4 stations with concentrations less than 3.0 mg/L, and IEC measured DO's less than 3.0 mg/L at 11 stations.
RUN 9	**08/22/2017**	**IEC**	Two stations exhibited DO concentrations below 2.0 mg/L (A4 and 9-413). Nine additional stations remained below 3.0 mg/L. The lowest dissolved oxygen recorded during this survey was at station 9-413 with a concentration of 0.90 mg/L.
WQSEP17 **RUN 10**	**08/28-09/01/2017** **08/31/2017**	**CT DEEP** **IEC**	Hypoxic conditions persisted in the Western Sound during the WQSEP17 survey and IEC Run #10. During the WQSEP17 survey Stations A4, B3, and 02 were still below 2.0 mg/L. Station C1 was less than 3.5 mg/L. During the IEC survey only one embayment station, 9-413 remained below 3.0 mg/L and Station H-D was less than 3.5 mg/L.
RUN 11	**09/05/2017**	**IEC**	IEC conducted its eleventh survey on August 31st. The bottom waters of Western Long Island Sound showed marked improvement; only Stations had concentrations below 4.8 mg/L. The dissolved oxygen concentration at Station A4 was 3.0 mg/L and Station 9-413 was at 0.62 mg/L. There was no CT DEEP HYSEP17 survey due to engine trouble with the R/V Patricia Lynn.
RUN 12	**09/11/2017**	**IEC**	During IEC's final survey of 2017, dissolved oxygen concentrations at all stations were above 3 mg/L. The lowest DO recorded was 4.36 mg/L at Station 9-413

Water Temperature

Water temperature plays a major role in the timing and severity of the summer hypoxia event. 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.

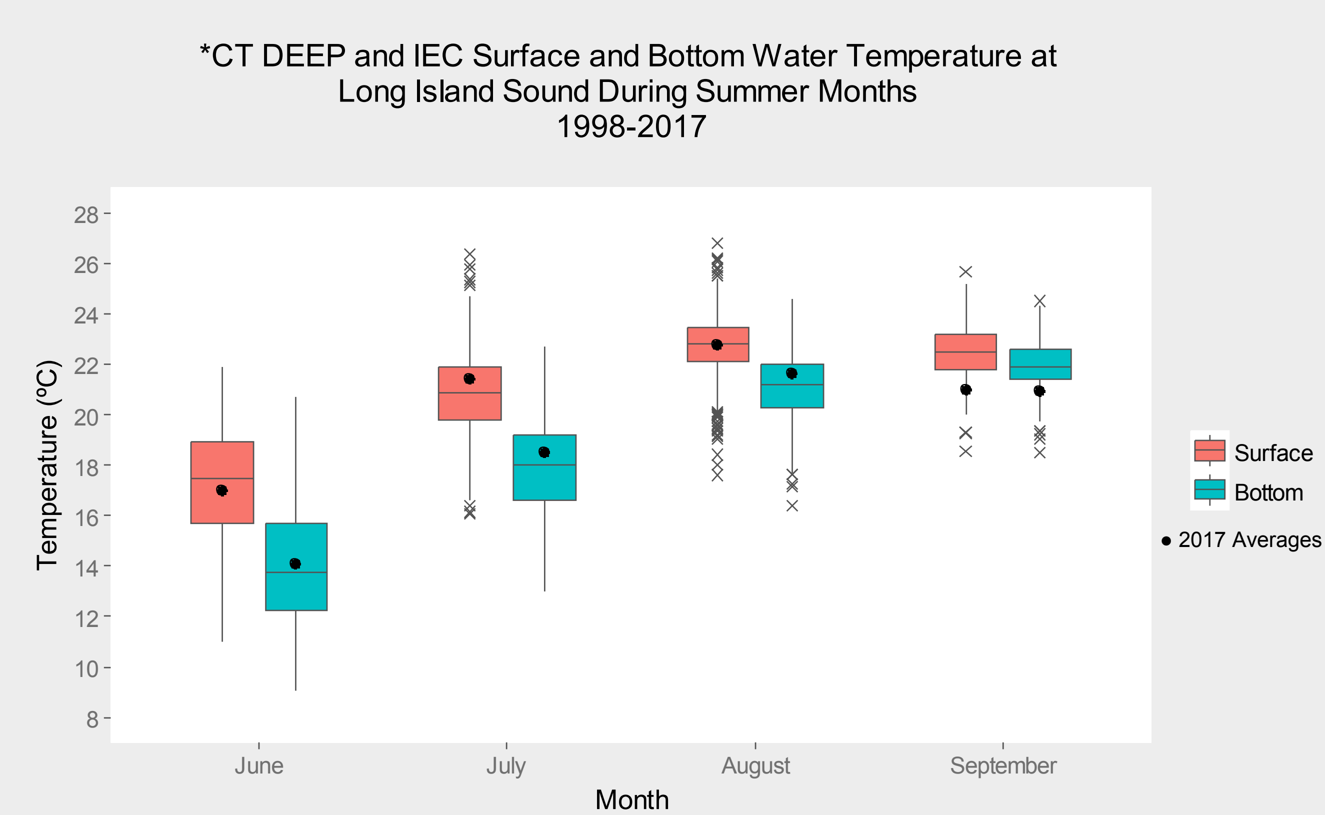


Figure 4

CT DEEP collects temperature data year-round while IEC monitors during the summer months (June-September). Average surface and bottom water data collected by both programs from 2008-2017 are presented in Figure 4. The water column is usually already stratified by June and remains that way until late August/early September.

Delta T and Stratification

The temperature difference between the bottom waters and the surface waters is known as "Delta T". This Delta T, along with salinity differences, creates a density difference, or density gradient, resulting in a separation or stratification, of water layers. Stratification hinders the oxygenated surface waters from circulating downward and mixing with the oxygen starved bottom waters. The pycnocline, or zone where water density increases rapidly with depth due to the changes in temperatures and salinity, inhibits oxygenated surface waters from mixing with oxygen depleted bottom waters, exacerbating hypoxia. The pycnocline typically develops in LIS in late spring/early summer when rapid surface water warming exceeds the rate of warming in the bottom waters. The pycnocline generally persists into early fall when it is disrupted by strong winds associated with storms which lead to mixing or cooling air temperatures. With the dissolution of the pycnocline, hypoxic conditions are alleviated or eliminated. The smallest Delta T's occur during the winter when the water column is well mixed. The largest Delta T's occur during the early summer. The greater the Delta T the greater is the potential for hypoxia to be more severe.

Figures 6-7 show computer interpolations along the west-east axis of LIS generated from profile data collected during two surveys by CT DEEP and IEC. During the mid-July IEC and DEEP surveys, surface water temperatures had warmed to an average of 23.2ºC while the bottom water remained cooler around an average of 19.4ºC. This set up the largest differences in temperatures between the surface and bottom waters with Delta T's between 0 and 8.04ºC and the largest extent of hypoxic conditions. The second graph shows how the water column was thermally stratified during the mid-August survey when dissolved oxygen concentrations were at their lowest. The Western Sound typically has higher Delta T's due to the limited flushing capacity, bathymetry, and geology. In the east where cooler, oxygen rich, off-shore ocean water mixes with the Sound water, Delta T's are much lower and hypoxia rarely occurs. This year the Central Sound had the highest Delta T's.

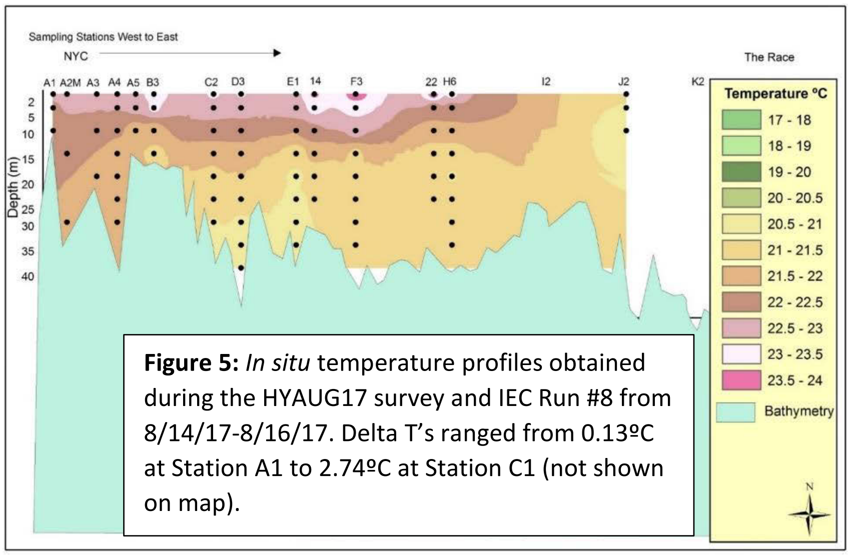


Figure 5: *In situ* temperature profiles obtained during the HYAUG17 survey and IEC Run #8 from 8/14/17-8/16/17. Delta T's ranged from 0.13ºC at Station A1 to 2.74ºC at Station C1 (not shown on map).

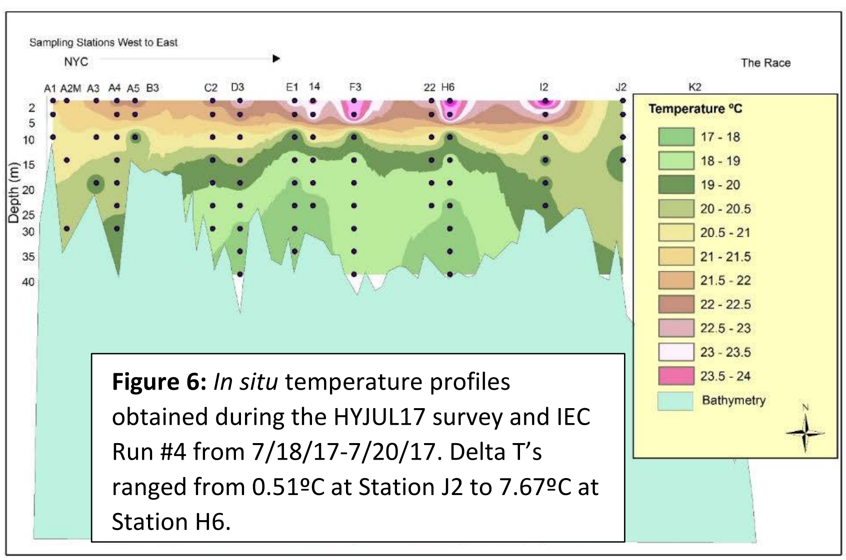


Figure 6: *In situ* temperature profiles obtained during the HYJUL17 survey and IEC Run #4 from 7/18/17-7/20/17. Delta T's ranged from 0.51ºC at Station J2 to 7.67ºC at Station H6.

Salinity Data

Salinity is a measure of the concentration of dissolved salts in seawater. During the summer months, Long Island Sound waters stratify, and bottom waters become cool, dense, and more saline while surface waters are warmer, less dense, and have lower salinity. Salinity data collected by IEC and DEEP during the summer months are shown in Figure 7. The salinity (both surface and bottom) tends to drop from January until late June, then in early July the salinities start to increase again.

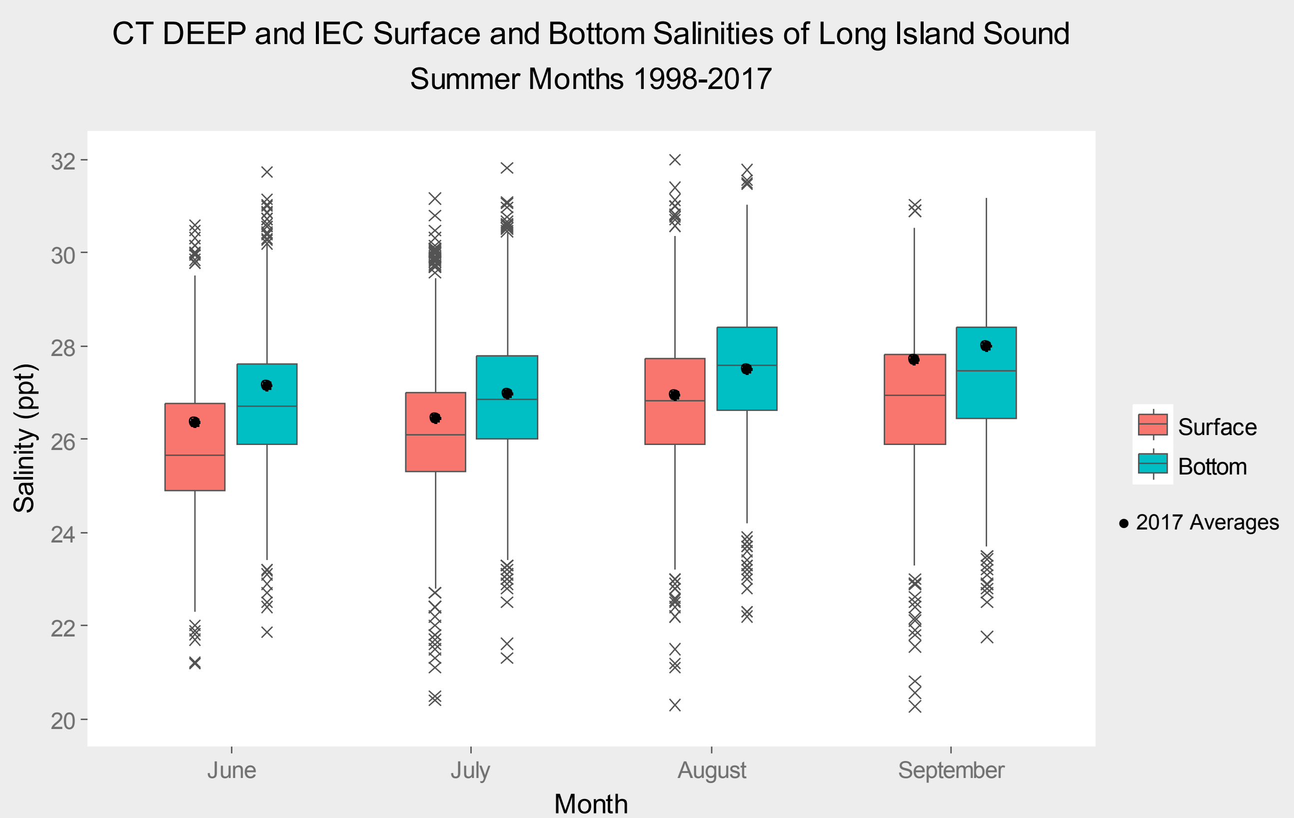


Figure 7

Water Clarity

Water clarity is measured by lowering a Secchi disk into LIS until it disappears. It is then raised until it reappears. The depth where the disk vanishes and reappears is the Secchi disk depth. The depth to disappearance is related to the transparency of the water. Water clarity in Long Island Sound follows a west to east gradient, with clarity improving as you move eastward. The graph below highlights this gradient present in Long Island Sound. In 2017, 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 Fisher's Island) had an average summer Secchi disk depth of 3.8 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 narrower 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.

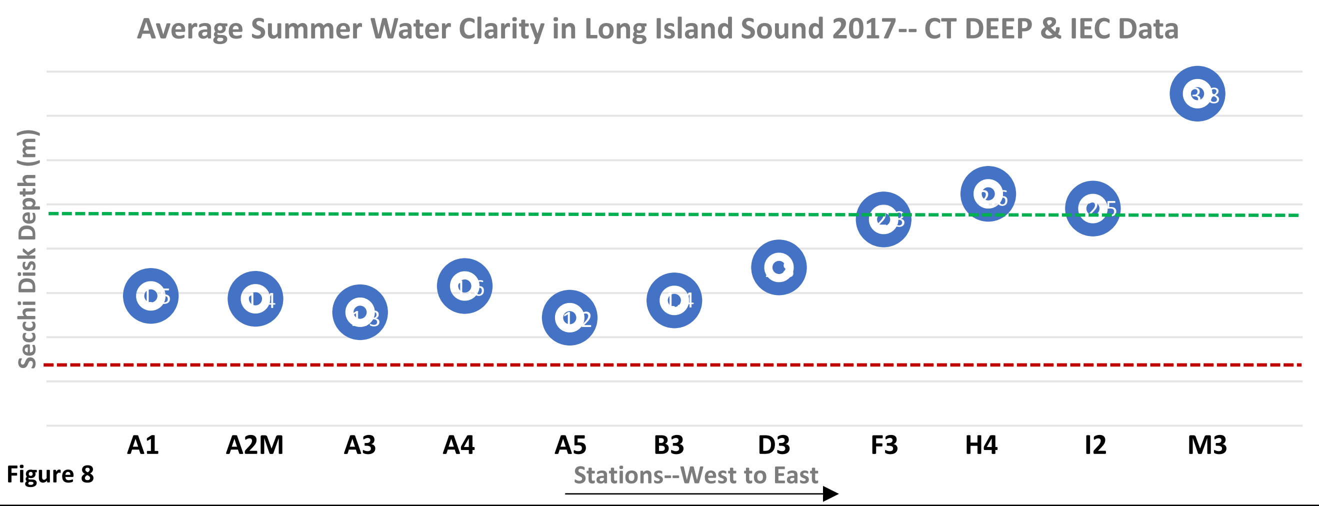


Figure 8

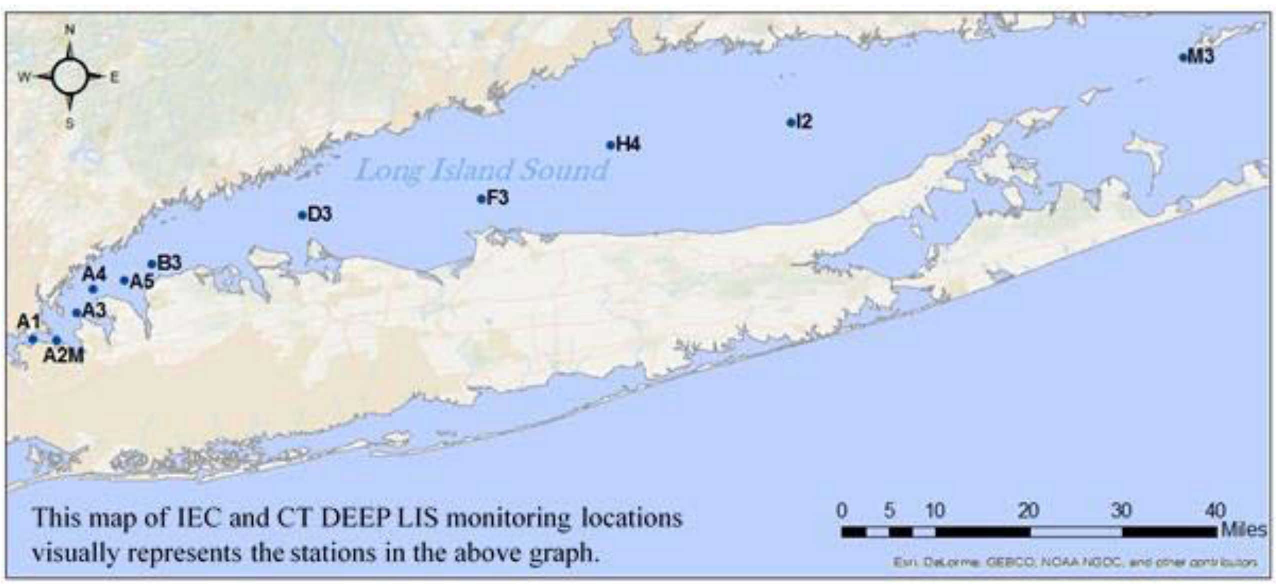
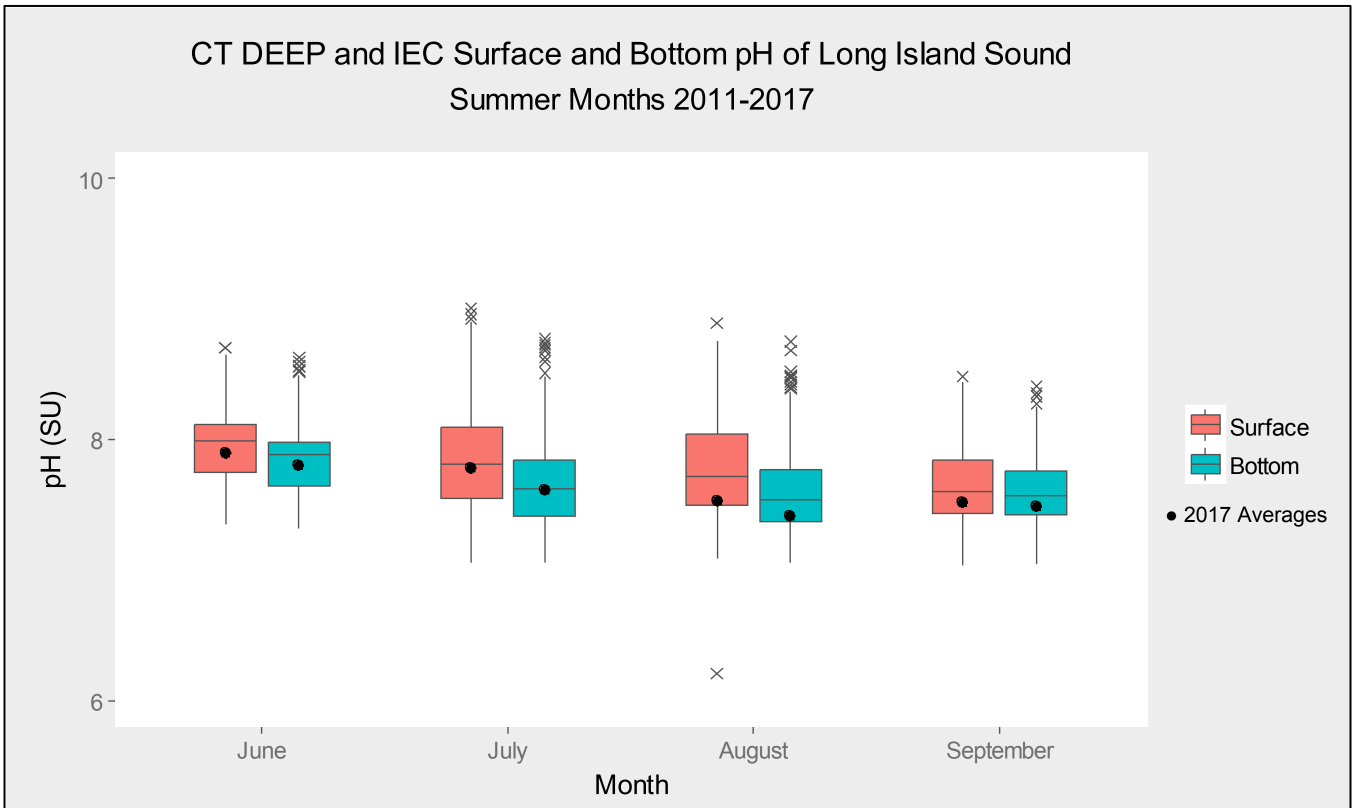


Figure 9

pH and Ocean Acidification

Human activities have resulted in increases in atmospheric carbon dioxide (CO_2). The ocean absorbs CO_2, greatly reducing greenhouse gas levels in the atmosphere and minimizing the impact on climate. When CO_2 dissolves in seawater, carbonic acid is formed. This acid formation reduces the pH of seawater and reduces the availability of carbonate ions. This process is depicted in the image below from NOAA. Carbonate ions are utilized by marine organisms in shell and skeletal formation. According to the NOAA Pacific Marine Environmental Laboratory Ocean Acidification, the pH of the ocean surface waters has already decreased from an average of 8.21 Standard Units (SU) to 8.10 SU since the beginning of the industrial revolution. The Intergovernmental Panel on Climate Change predicts a decrease of an additional 0.3 SU by 2100. Additional information specific to the Northeast region is available on the North East Coastal Acidification Network's website (http://www.necan.org/).

Data from the 2011-2017 monitoring seasons, depicted in Figure 10 show that the pH of bottom waters is lower than the pH of surface waters. Surface and bottom waters followed a similar pattern in 2017 becoming increasingly less acidic at the end of the summer, when compared to the start of summer.



DEEP began collecting pH data in December 2010

Figure 10

Chlorophyll a

Chlorophyll is a pigment found in plants that gives them their green color. It allows plants to absorb light from the sun and convert it to chemical energy during photosynthesis. In photosynthesis, carbon dioxide and water are combined to produce sugar giving off oxygen as a byproduct. Microscopic plants, called phytoplankton, form the basis of the food web in Long Island Sound. Water temperature, nutrient concentrations, and light availability all factor into the amount of phytoplankton biomass found in the Sound. The concentration of chlorophyll a is used as a measure to estimate the quantity of phytoplankton biomass suspended in the surface waters. It is most commonly used because it is easy to measure and because photosynthetic production is directly proportional to the amount of chlorophyll present.

The Integration and Application Network at the University of Maryland Center for Environmental Science released the first report card for Long Island Sound to the public in 2015. Chlorophyll-a thresholds were set at 5 ug/L and 20 ug/L. The National Coastal Condition Report also uses these thresholds and ranks data in three categories: poor, fair, and good. Chlorophyll a concentrations less than 5 ug/L are good; concentrations between 5 and 20 ug/L are fair; and concentrations greater than 20 ug/L are poor.

Chlorophyll-a concentrations are measured year- round by CT DEEP using the CTD fluorometer for measurement as well as through the collection of grab samples using Niskin bottles. The grab samples are brought back into the onboard laboratory, filtered, and then sent to University of Connecticut for analysis. IEC collects grab samples during the summer months and analyzes them for chlorophyll a content in their laboratory.

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.

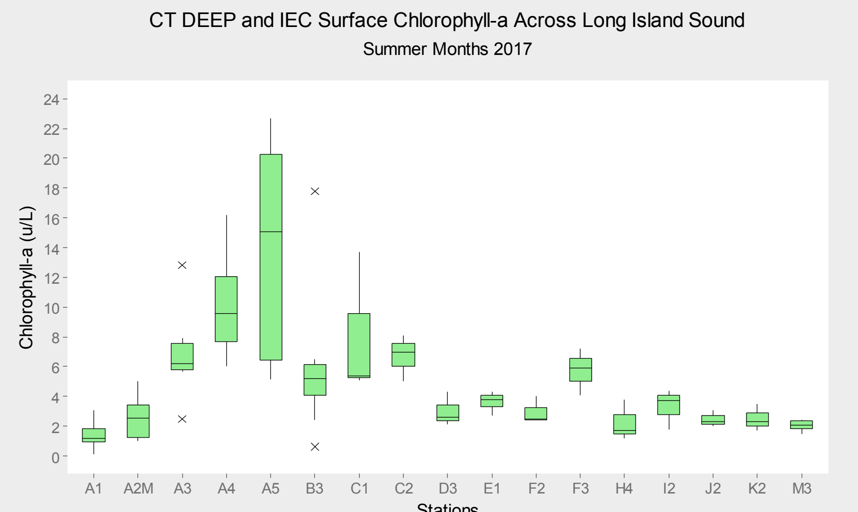


Figure 11

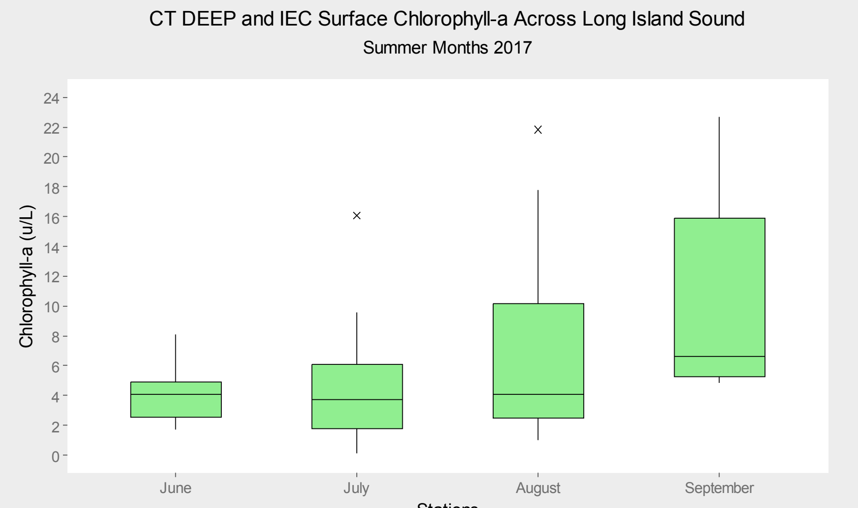


Figure 12

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Photos taken by Lloyd Langevin for CT DEEP, June 2007 and Jessica Haley, IEC, 2016 and 2017.

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