2017 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 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 Massachusetts, New Hampshire, Vermont, 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.

The CT DEEP and IEC Long Island Sound (LIS) Water Quality Monitoring Programs are synoptic in nature and are intended to characterize water quality conditions over a broad area (the entire Sound). Both programs support long term monitoring databases designed to detect changes in hypoxia due to changing conditions *(e.g.*, management actions, climate change, productivity). Both programs also provide data (*e.g.* nutrients, BOD, TSS, chlorophyll a) not currently available from fixed station buoy applications. In addition, CTDEEP provides limited biological data (plankton communities).

The LISICOS water quality sensors are attached to fixed locations and provide a holistic view of the conditions over a more detailed span of time (*i.e.*, data measured every 15 minutes from one station as opposed to every two weeks). The LISICOS continuously recording buoys have shown instances where vertical mixing within the water column raises the DO concentrations above the hypoxic threshold of 3.0 milligrams per liter (mg/L) for extended periods of time (*e.g.*, days). These episodic conditions are not captured by CT DEEP or IEC surveys.

As such, 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.

What is 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).

The Connecticut Department of Energy & Environmental Protection (CTDEEP), the New York State Department of Environmental Conservation (NYSDEC), and the Interstate Environmental Commission (IEC) have water quality criteria for dissolved oxygen. These criteria, designed to protect the states' waters from degradation, define hypoxia as DO concentrations below 3.0 mg/L. Low oxygen levels can occur naturally in estuaries during the summer, when calm weather conditions prevent the mixing of the water column that replenishes bottom water oxygen during the rest of the year. However, excess nitrogen can exacerbate hypoxia beyond that which may be caused by natural conditions.

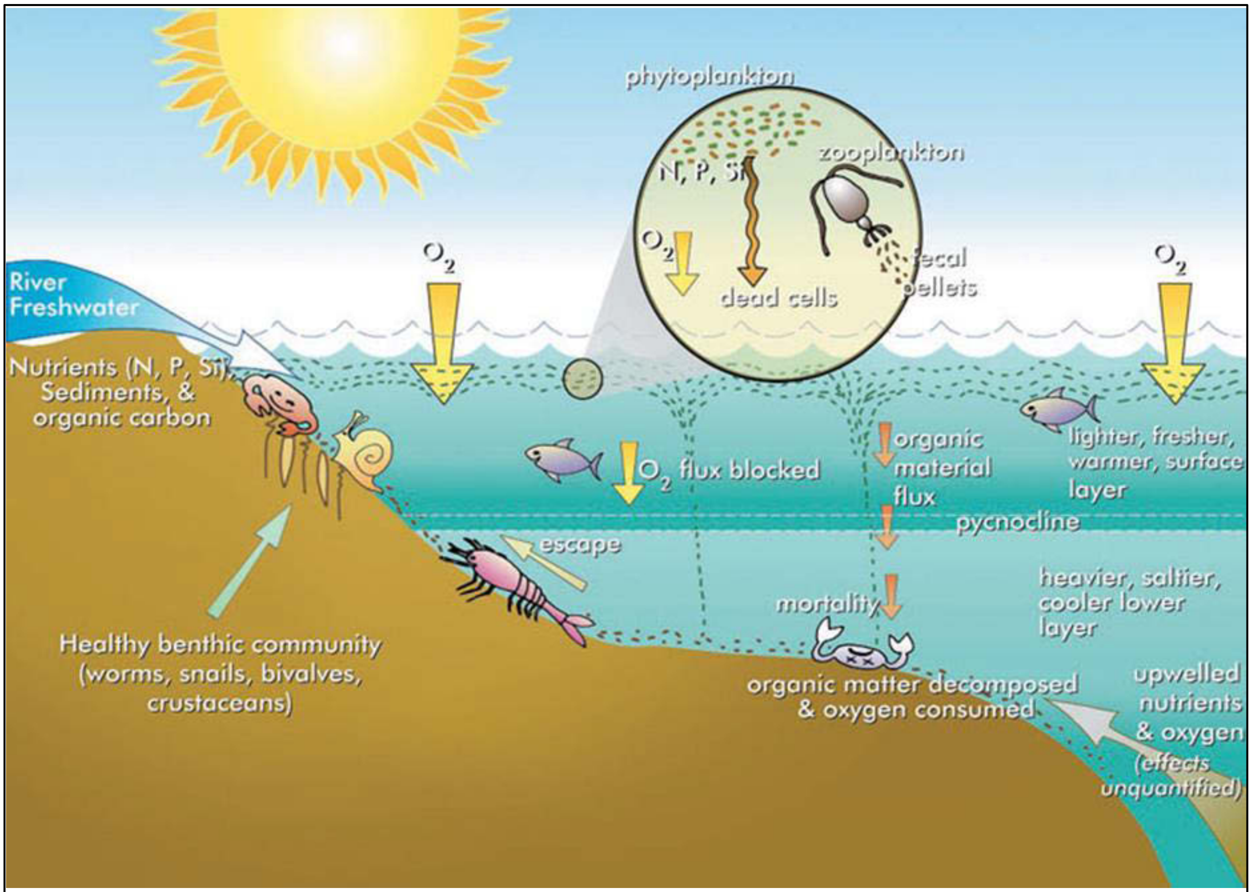
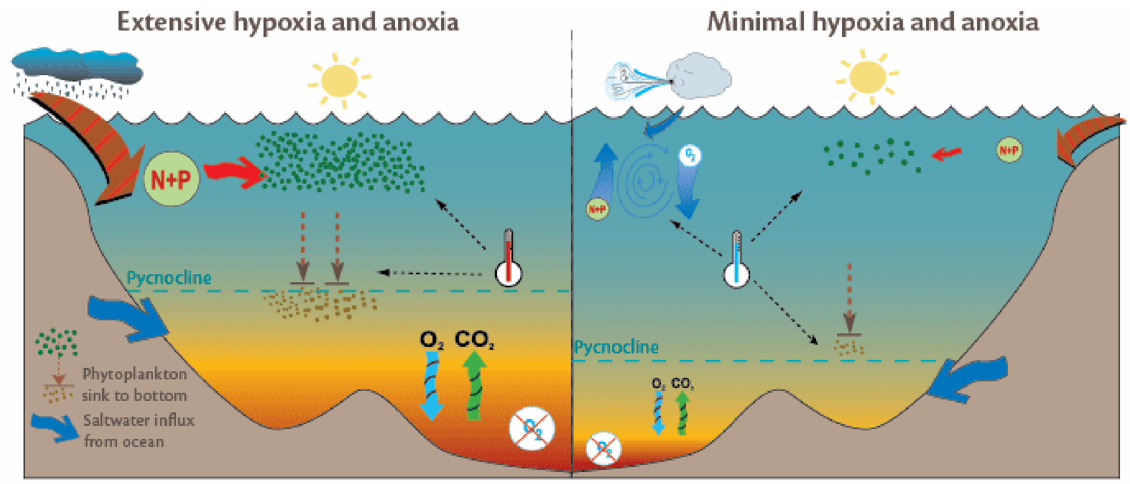


Figure 1: biogeochemical cycles in aquatic environments; from: https://www.epa.gov/sites/production/files/2015-03/eutro_big.jpg

Factors that May Influence Dissolved Oxygen in LIS

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. Data collected during IEC's weekly summer surveys and CT DEEP's hypoxia monitoring cruises are used to help estimate the extent of favorable conditions for the onset, extent, and end of the hypoxic event. The conceptual diagram below, while developed for Chesapeake Bay, applies to Long Island Sound. In LIS, there are two key contributors to hypoxia: nutrient enrichment and water column stratification due to temperature and salinity gradients. 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 nutrient 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.



	Loads	Phytoplankton	Decomposition	Temperature	Wind event
Large amount of low dissolved oxygen	Large nitrogen and phosphorus loads	Elevated nutrients cause large phytoplankton blooms	High oxygen consumption by decaying phytoplankton	Warm water a) Stimulates decomposition b) Stratifies water column c) Stimulates phytoplankton	No wind event: water column remains stratified
Little amount of low dissolved oxygen	Small nitrogen and phosphorus loads	Less nutrients lead to small phytoplankton blooms	Low oxygen consumption by decaying phytoplankton	Cool water: a) Slow decomposition b) Mixed water column c) Slow phytoplankton growth	Wind events destratifies water column: a) Bottom water aerated b) Nutrients move to surface

Conceptual diagram detailing the factors that determine the dissolved oxygen content of the tidal waters of Chesapeake Bay
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Ecocheck

Figure 2

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 concentrations 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 area typically occurs in early August.

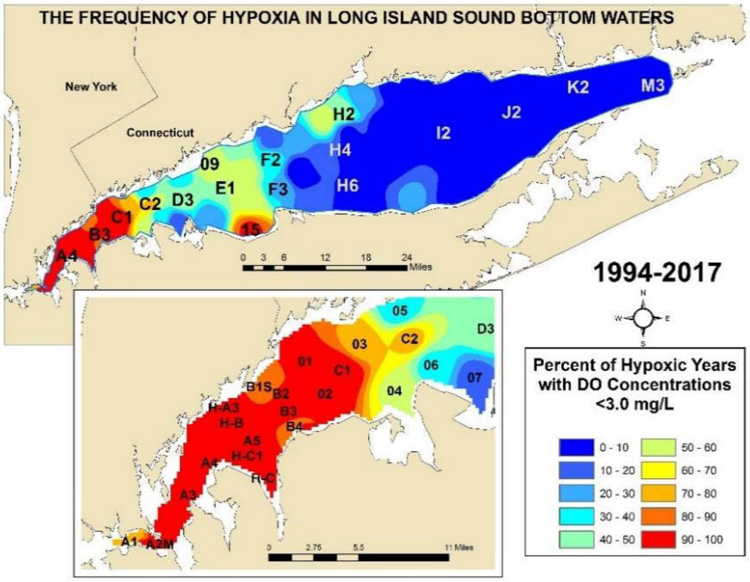


Figure 3

EPA, NY and CT implemented the *Total Maximum Daily Load to Achieve Water Quality Standards for Dissolved Oxygen in Long Island Sound (2000 TMDL)* which has resulted in significant progress in reducing open water Sound hypoxic conditions. Across Connecticut and New York, 106 wastewater treatment plants have been upgraded and 40 million fewer pounds of nitrogen have entered the Sound (51.5% reduction).

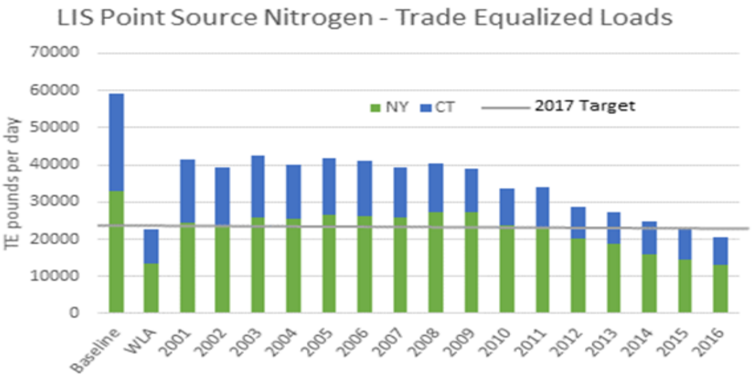
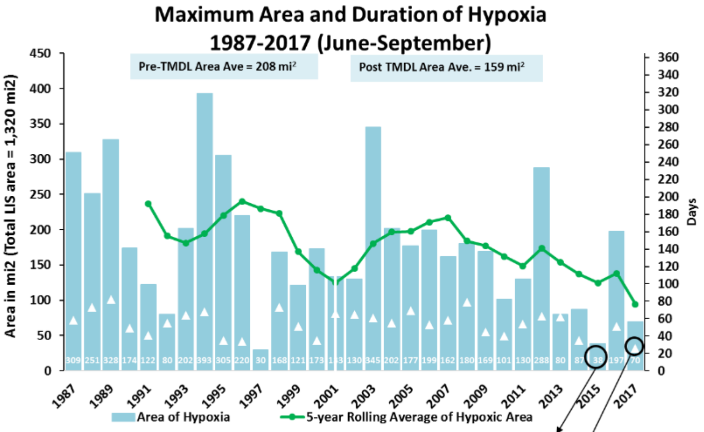


Figure 4: Nitrogen Loads, source: EPA, LISS, CTDEEP, NYSDEC

EPA estimates a 40% reduction in the five-year rolling average area of hypoxia across the Sound, compared to pre-TMDL levels (EPA 2015).



Second smallest area in 28 years

Shortest Duration

Figure 5: extent and duration of hypoxia

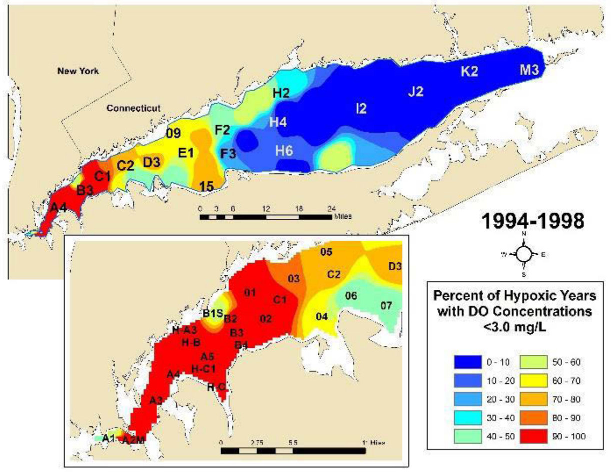


Figure 6

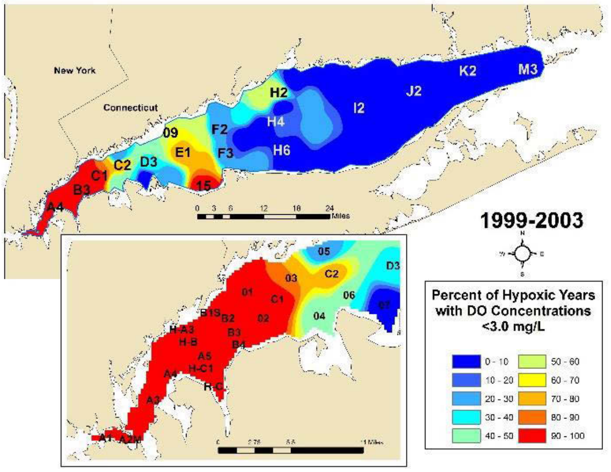


Figure 7

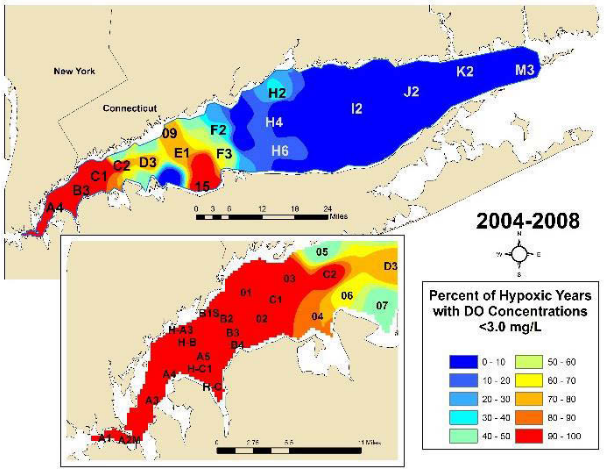


Figure 8

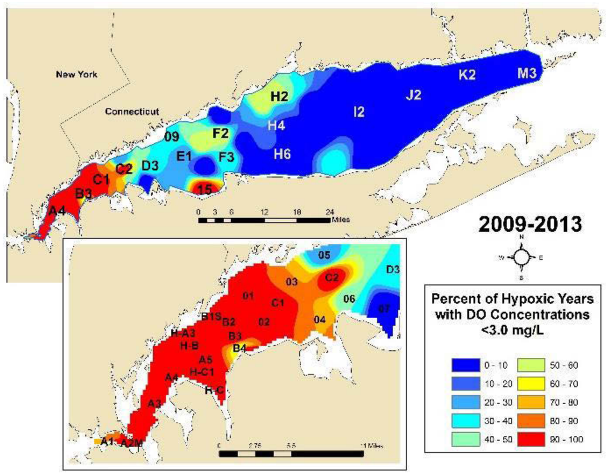


Figure 9

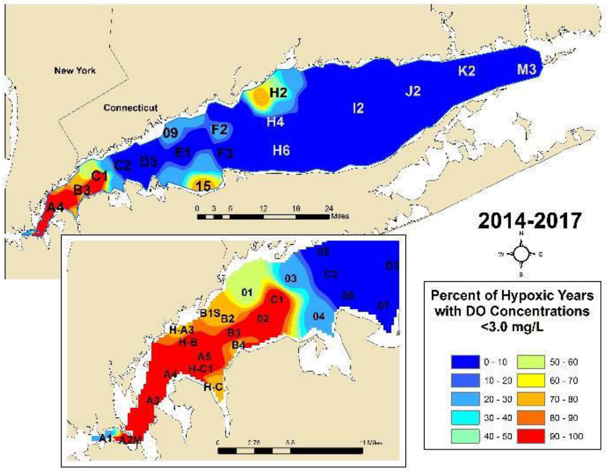


Figure 10

Figures 6-10 display the percentage of years when dissolved oxygen concentrations at each station were below 3.0 mg/L in the bottom waters of Long Island Sound in five-year intervals. The maps show the area of hypoxia reducing in the Western Sound (Stations 09, E1, D3). While hypoxia continues to persist in the Narrows (Stations A4, B3, C1) the inclusion of IEC data shows that hypoxia in the narrows is localized to specific stations.

Habitat Impairment Associated with Hypoxia

The following description of the "Biomass Area-Day Depletion (BADD) index of habitat impairment was excerpted from an article written by CT DEEP Marine Fisheries Biologist Penny Howell for the July/August 2014 edition of CT Wildlife Magazine.

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, DO can become limiting below 4.8 mg/L for sensitive fish species, such as whiting and scup, while more tolerant species, such as butterfish, bluefish, lobster and Atlantic herring, are not affected until DO falls below 2 mg/L (Simpson *et al,* 1995, 1996).

An index of habitat impairment, "Biomass Area-Day Depletion" (BADD) was developed by CT DEEP Marine Fisheries Division based on extensive sampling in the Sound from 1986-1993 (Simpson *et al,* 1995,1996). *Instead of individual species' responses to low oxygen, an aggregate response of 18 demersal (bottom-dwelling) finfish species was calculated as a general index of the impact on living resources to low oxygen conditions at or near the bottom of the Sound. The total weight, or biomass, of these demersal finfish species captured in samples taken at various levels of low DO was quantified and the percent reduction in biomass from that captured in fully oxygenated water was computed. These studies showed that the finfish biomass is reduced by 100% (total avoidance) in waters with DO less than 1.0 mg/L. In waters with 1.0-1.9 mg/L DO, biomass is reduced by 82%, while a 41% reduction occurs at 2.0-2.9 mg/L DO, and a 4% reduction occurs at 3.0-3.9 mg/L DO* (Simpson *et al,* 1995, 1996).

For each survey the total area of the Sound encompassing each 1-mg interval of DO is calculated and the depletion percentage applied. These area depletions are summed over the number of days they persist during the designated hypoxia season. The summed area-day depletion is then expressed as a percentage of the total available area (total sample area of 2,723 km^2*) multiplied times the total season (94 days). A maximum BADD index of 100% would result from severe hypoxia occurring over the entire study area for the entire hypoxia season.*

In an average year, hypoxic waters cover ~440 km^2 *(169 miles*^{2}*) for 55 days and result in a BADD impairment index of 2.5%. In the worst year (1994), hypoxia spread over 1,000 km*^{2} *(395 miles*^{2}*) for the entire season, resulting in a BADD index of almost 9%.* In 2017, the BADD index was 1.34% down from 3.05% in 2016.

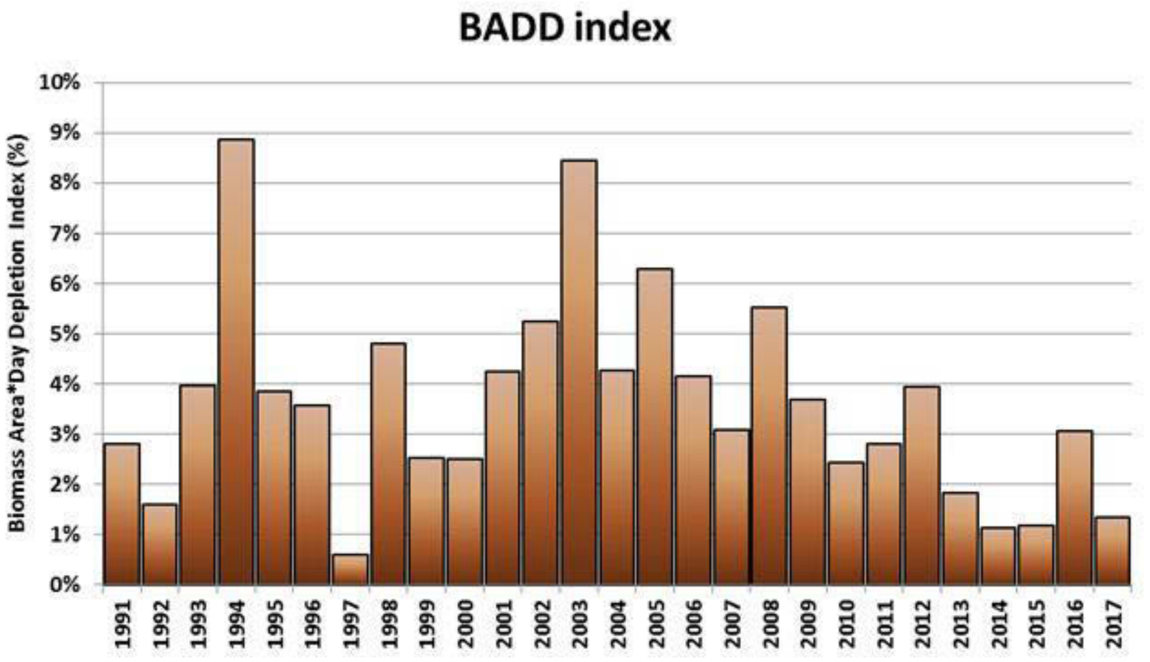


Figure 11

2017 Summer Weather Conditions

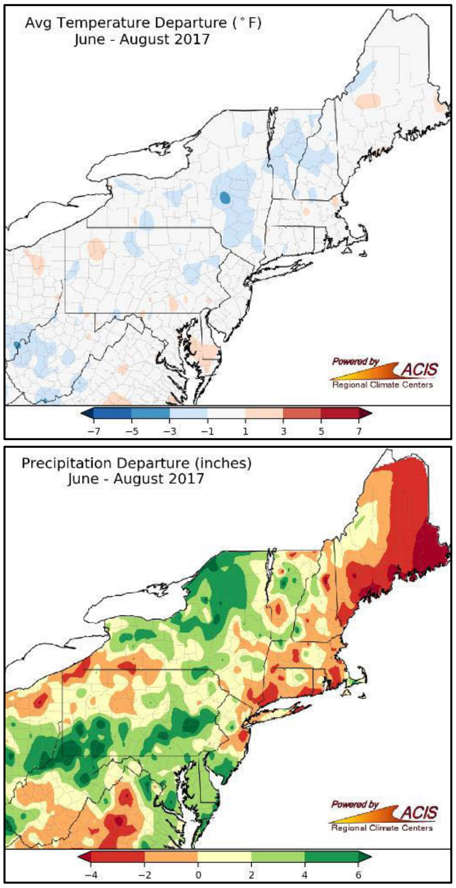


Figure 12

The Northeast Regional Climate Center (NRCC) at Cornell University is tasked with disseminating climate data and information for 12 states. This climate information is useful as physical processes influence the timing and duration of hypoxia. The summer of 2017 was variable. The season started out slightly warmer than normal with above average rainfall. August wrapped up the season on the dry side with below average temperatures. September brought cooler than normal temperatures this fall and shifted into October with some record setting warm days at multiple climate sites. June and July were 0.2°F above normal while August was 1.3ºF below normal, and September was 3.0ºF above normal. Consequently, the summer of 2017 (June-August) was 0.3°F above average. Warm temperatures continued into November where the region as a whole was 2.0ºF above normal. The average maximum summer (June-August) 2017 air temperatures at climate sites around Long Island Sound ranged from 81.1ºF in Bridgeport, CT to 82.8 ºF at LaGuardia Airport in Queens, NY and at Islip, NY on Long Island.

The Northeast received 107% of its normal precipitation for June through August. At the beginning of June (week June 6, 2017), the U.S. Drought Monitor indicated that 100% (cumulative percent area) of the Northeast was not in any drought category with the region receiving over 100% of its precipitation in June and up to 122% of its precipitation in July. There were multiple record setting rainfall events which occurred in Maryland, Pennsylvania, New York, and New Jersey causing flooding and harmful algal blooms. A rare Nor'easter hit the region around July 27. By Mid-August ~10% of the region was abnormally dry. Transitioning into fall ~8% of the Northeast moved into moderate drought.

Comparatively, last year's summer season was considerably drier with extreme drought (category D3) covering over 5% of the region in September 2016 (figure 13, below). Across Long Island Sound, precipitation totals varied widely from site to site and month to month. Across the coastal areas of Connecticut and New York, summer rainfalls were slightly below normal ranging from 78%-97% of normal for June, 79%-75% of normal for July and 59%-93% of normal for August. However, as a whole Connecticut and New York had over 100% of their normal precipitation for June and July.

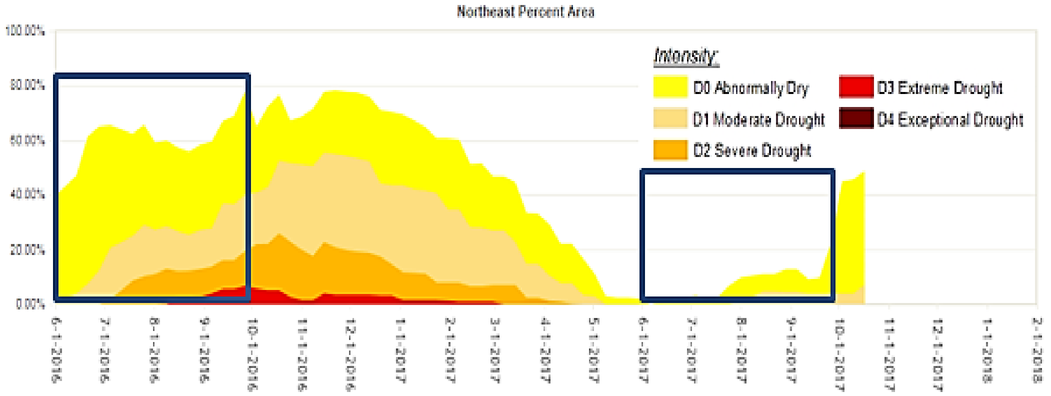


Figure 13 The Northeast drought monitor percent area of drought June 2016 through October 2017. Boxes define the approximate summer hypoxia monitoring seasons

CT DEEP Program Overview

Since 1991, the Connecticut Department of Energy & Environmental Protection (CT DEEP, formerly the Department of Environmental Protection, (CTDEP) has conducted 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), especially nutrients, temperature, and chlorophyll. These data are also used to evaluate the effectiveness of the management program to reduce nitrogen concentrations. During the summer (June -September) CT DEEP conducts additional summer hypoxia surveys at bi-weekly intervals to better define the areal extent and duration of hypoxia.

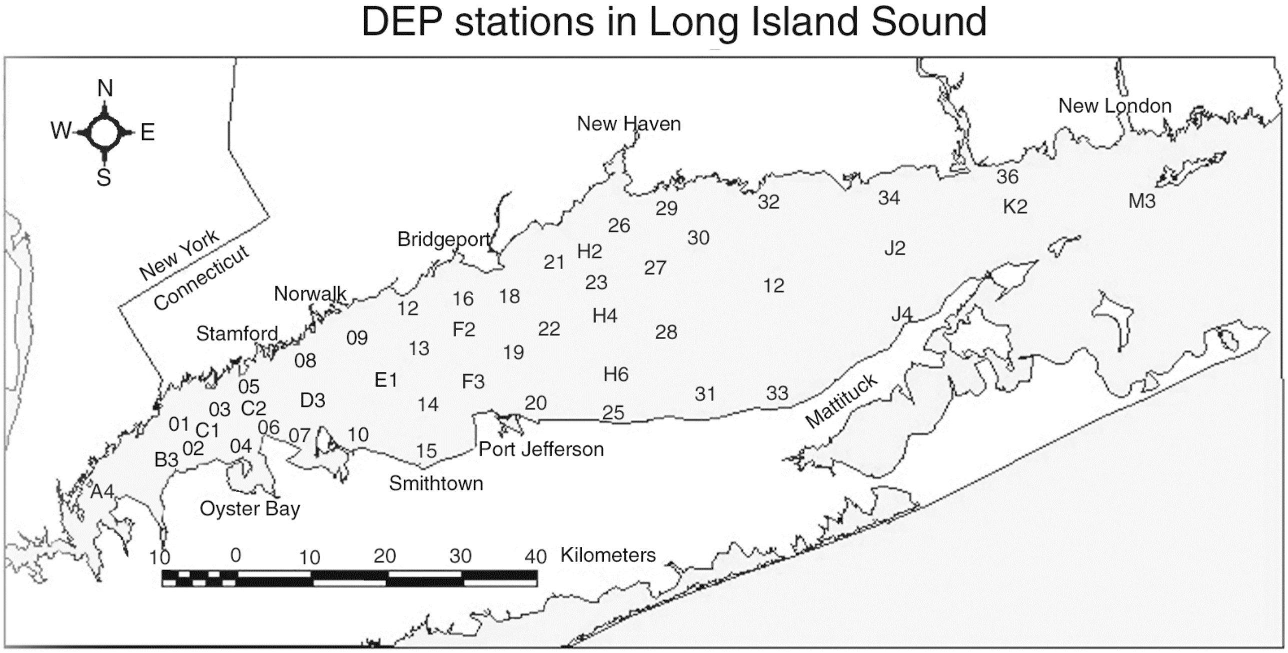
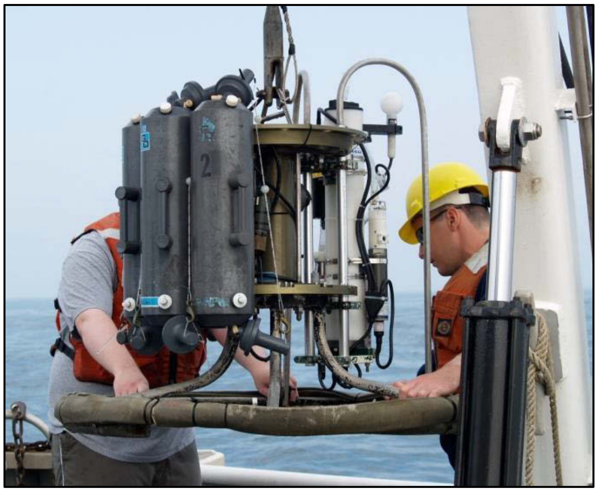


Figure 14: stations sampled by the CT DEEP LIS Water Quality Monitoring Program.

CT DEEP Methods

In situ data and nutrient samples are collected monthly year round from 17 sites. 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. All samples are collected and analyzed under EPA-approved Quality Assurance Project Plans.



Dissolved oxygen, temperature, pH, and salinity data are collected in situ (on site in the water column) using an electronic instrument called a Conductivity Temperature Depth recorder (CTD). 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. The Rosette is lowered off the stern of the R/V John Dempsey through the water column at a rate of approximately 0.2 meters per second, measurements are recorded every 0.5 seconds, creating a surface to bottom water column profile. In situ data are reviewed in real-time with measurements recorded on field data sheets at three distinct depths (near bottom = 1 m off the bottom, bottom= 5 m off the bottom, and surface = 2 m below the surface).

Water samples for nutrient analysis are collected using Niskin water sampling bottles that are attached to the Rosette Sampler. The bottles are remotely triggered from the shipboard lab, allowing a water sample to be collected from any specified depth. CT DEEP samples are collected as the Rosette is retrieved (i.e., on the upcast) from two depths- at 5 meters above the bottom (referred to as Bottom samples) and 2 meters below the surface (referred to as Surface samples). 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.

Samples are analyzed for dissolved silica, particulate silica, particulate carbon, dissolved organic carbon, dissolved nitrogen, particulate nitrogen, ammonia, nitrate + nitrite, particulate phosphorus, total dissolved phosphorus, orthophosphate, chlorophyll a, biochemical oxygen demand, and total suspended solids.

Since 2002, CT DEEP has collected zooplankton samples from six stations and phytoplankton from ten stations across Long Island Sound. The samples are sent to researchers at the University of Connecticut who identify species composition, abundance, community structure, and spatial and temporal distribution throughout the Sound.

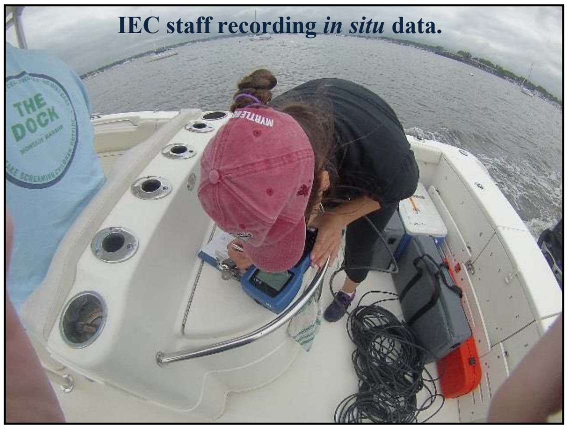
IEC Program Overview

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. The IEC's area of jurisdiction runs west from New Haven, CT, and Port Jefferson, NY, on Long Island Sound. As of 2012, IEC has been in a temporary host relationship with the New England Interstate Water Pollution Control Commission (NEIWPCC).

IEC has conducted monitoring in the far Western Long Island Sound 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. 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), such as dissolved oxygen and nutrients, which are important for understanding, and mitigating, hypoxia in the far western Long Island Sound. 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'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.

IEC collects *in situ* data from 22 stations in the far western (Narrows) portion of the Sound on a weekly basis (see figure 15). *In situ* parameters include water temperature, dissolved oxygen, salinity, pH, and water clarity (Secchi disk depth). In addition, IEC collects biweekly samples for chlorophyll a, biochemical oxygen demand (BOD), total suspended solids (TSS), and a suite of nutrient parameters. More information about IEC and its monitoring program can be found below or on the IEC website: (http://www.iec-nynjct.org).



IEC staff recording *in situ* data.

Dissolved oxygen data from 13 of IEC's 22 stations are incorporated into hypoxia maps and areal estimates that are presented in this report. These 13 stations (A1, A2M, A3, A4, HA3, HB, A5, HC1, HC, B1S, B2, B3M, B4) represent open water portions of the western Narrows. DO data collected from IEC's embayment stations were not utilized in areal estimates. Additionally, data collected from six IEC stations (A1, A2M, A3, A4, A5, B3) are presented along with data from seven of CT DEEP's stations (A4, B3, D3, F3, H4, I2, and M3) to examine the west to east spatial patterns of temperature, salinity, dissolved oxygen, and chlorophyll a concentrations across the Sound. These stations are along an axial transect that approximates the thalweg of the Sound. Supplemental IEC data from Little Neck Bay, Manhasset Bay and Hempstead Harbor appear in Appendix A of this report. Additional IEC data are available upon request and in IEC's weekly season summaries.

IEC Methods

Dissolved oxygen, temperature, salinity, and pH data are collected using a YSI EXO 1 Multiparameter Sonde at bottom, mid, and surface depths at all 22 stations on a weekly basis from June through September. For stations with a depth of less than 10 meters, only surface and bottom measurements are collected. In addition, 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.

Surface grab samples (within one meter of the surface) are collected on a biweekly basis June through September 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. Figure 15 highlights where sample collection takes place and for which parameters. Samples collected for chlorophyll a and TSS are collected directly into a clean, dry, 1000-mL polypropylene sample bottle and are stored in the dark. BOD and nutrient samples are collected using a clean, dry, 2000-mL polypropylene sample bottle. All samples are kept at ≤4°C during collection and transport to the IEC laboratory. The IEC laboratory is a National Environmental Laboratory Accreditation Program (NELAP) certified environmental testing laboratory.

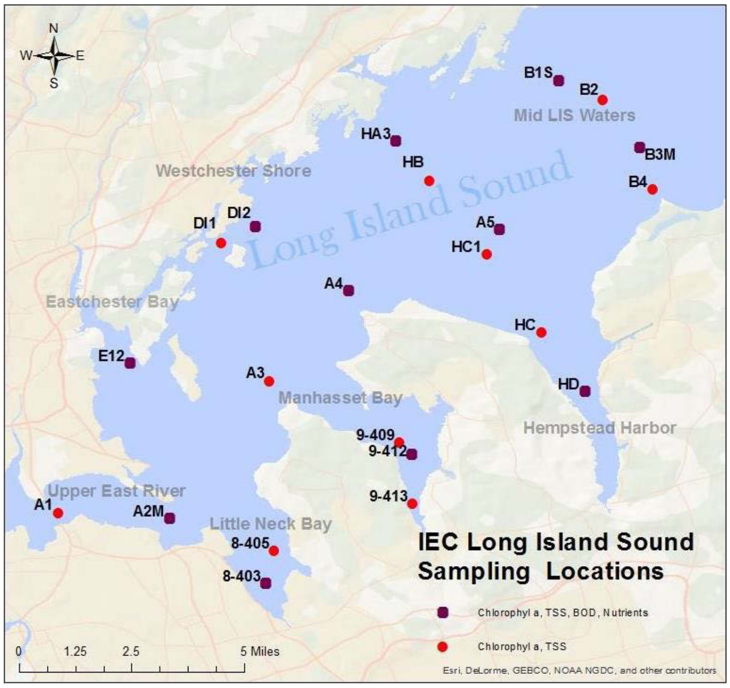


Figure 15: IEC's 22 monitoring stations in western Long Island Sound.

The 11 stations selected for BOD and nutrient sampling (added to the program in 2014) were chosen based on feedback and input from the Long Island Sound Study Water Quality Monitoring Workgroup.

The specific nutrient parameters that are analyzed include 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 and 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. Further information on sampling and analytical methods can be found in the EPA-approved QAPP *Ambient Water Quality Monitoring in Far Western Long Island Sound, version 3.0.*

LISICOS

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.

The initial goal was to develop "a capability to observe and understand the LIS ecosystem and predict its response to natural and anthropogenic changes."

Welcome to the Long Island Sound Coastal Observatory

NOTICE: Eastern Sound offline for repairs, expected redeployment when funding arrives.

QuickLinks:

- New London Ledge Light webcam
- Bottom Dissolved Oxygen Forecast for Western Sound Station
- Bottom Dissolved Oxygen Forecast for Execution Rocks Station

Choose a data product:

Or select a station from the map below:

LISICOS mobile access: lisicos.uconn.edu/m/

Funding provided by NOAA in support of the U.S. Integrated Ocean Observing System:

University of Connecticut · Dept. of Marine Sciences · 1080 Shennecossett Road · Groton, CT 06340

UConn Disclaimer & Copyrights : Data Disclaimer : Contact Us Monday, November 05, 2012 12:47:48 PM EST

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.

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.

Table 1: Extent and Duration of Hypoxia

Cruise*	Start Date	End Date	Number of stations sampled*	Number of hypoxic stations	Hypoxic Area (mi^2)	Min DO Observed	Station with Min DO
WQJUN17	6/5/2017	6/8/2017	17	0	0.00	6.67	A4
HYJUN17	6/20/2017	6/21/2017	23	0	0.00	4.65	A4
IEC Run #1	6/27/2017	6/27/2017	13	2		0.86	A4
WQJUL17	7/5/2017	7/7/2017	34	0	0.00	3.65	A4
IEC Run #2	7/5/2017	7/5/2017	13	0		2.36	H-C
IEC Run #3	7/11/2017	7/11/2017	14	0		3.35	A4
HYJUL17	7/18/2017	7/20/2017	40	6	**69.9**	2.14	02
IEC Run #4	7/18/2017	7/18/2017	13	1		2.97	B2
IEC Run #5	7/26/2017	7/26/2017	13	0		3.86	A1
WQAUG17	7/31/2017	8/2/2017	43	0	0.00	3.37	F3
IEC Run #6	8/1/2017	8/1/2017	13	0		3.69	H-C1
IEC Run #7	8/8/2017	8/8/2017	13	4		2.45	A3
IEC Run #8	8/15/2017	8/15/2017	13	13		1.53	A5
HYAUG17	8/14/2017	8/16/2017	40	5	44.13	**1.11**	**A4**
IEC Run #9	8/22/2017	8/22/2017	13	8		1.90	A4
WQSEP17	8/28/2017	9/1/2017	40	3	42.39	2.46	A4
IEC Run #10	8/31/2017	8/31/2017	13	0		4.56	A2M
IEC Run #11	09/05/2017	9/05/2017	13	0		3.00	A4
HYSEP17	No Survey	No Survey	-	-	-	-	-
IEC Run #12	9/11/2017	9/11/2017	13	0		5.56	A2M

NC= Not calculated
Bold= highest area of hypoxia
*IEC samples 22 stations, however only 13 stations are included

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 16 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.

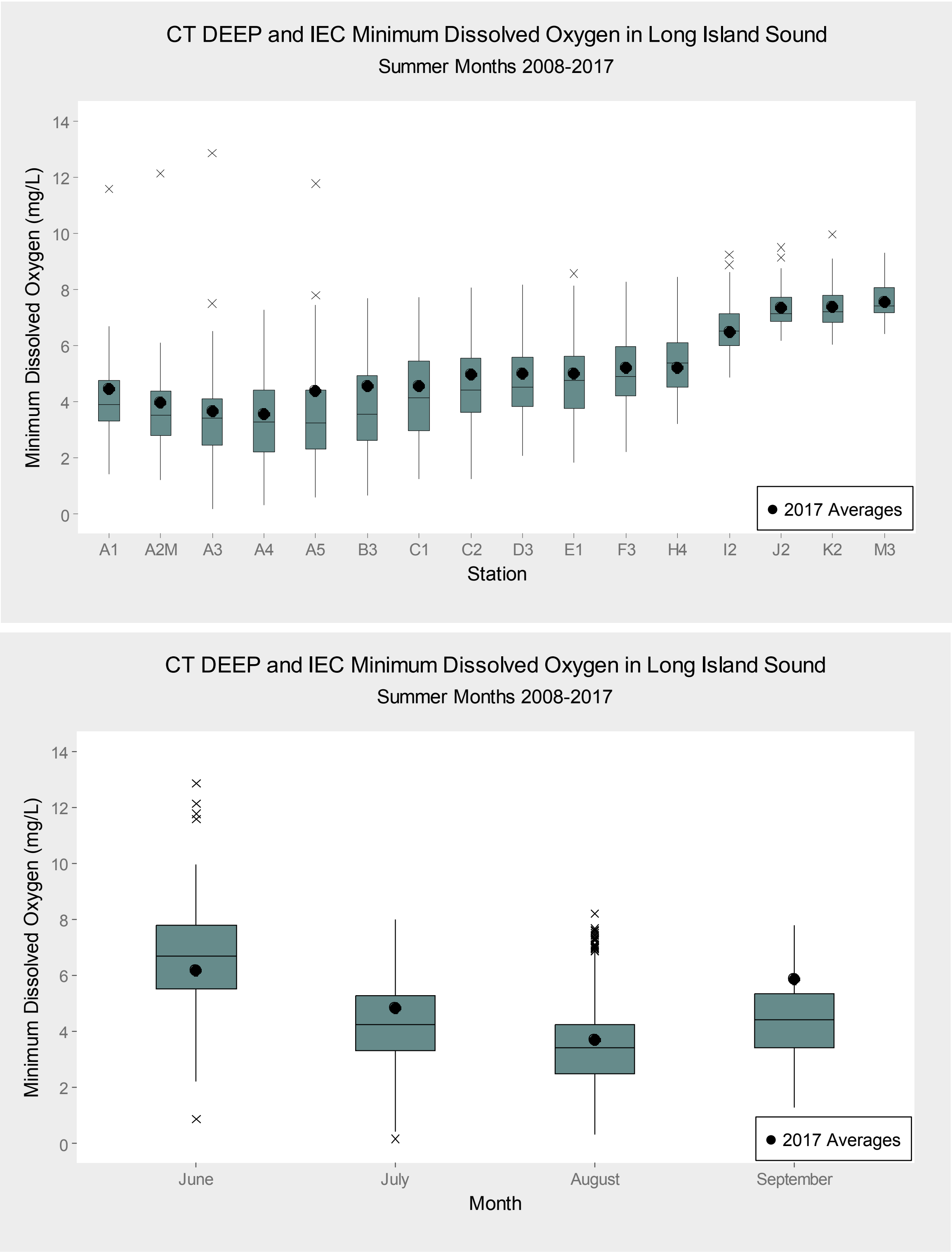


Figure 16: Spatial and temporal distribution of minimum dissolved oxygen in Long Island Sound; 2008-2017. Summer is defined as June-September.

Timing and Duration of Hypoxia: 1991 – 2017

Start dates and end dates for the hypoxic events are estimated by plotting CT DEEP and IEC data from stations A4 and B3 in an Excel spreadsheet and then using a line with markers chart to interpolate when the DO concentration drops below/rises above 3.0 mg/L. 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 (Figures 18-20). 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.

Table 2: 2017 Duration Estimates

	Estimated Start Date	Estimated End Date	Duration (days)
Event #1	7/18/2017	7/20/2017	3
Event #2	8/7/2017	8/29/2017	23
Total			26

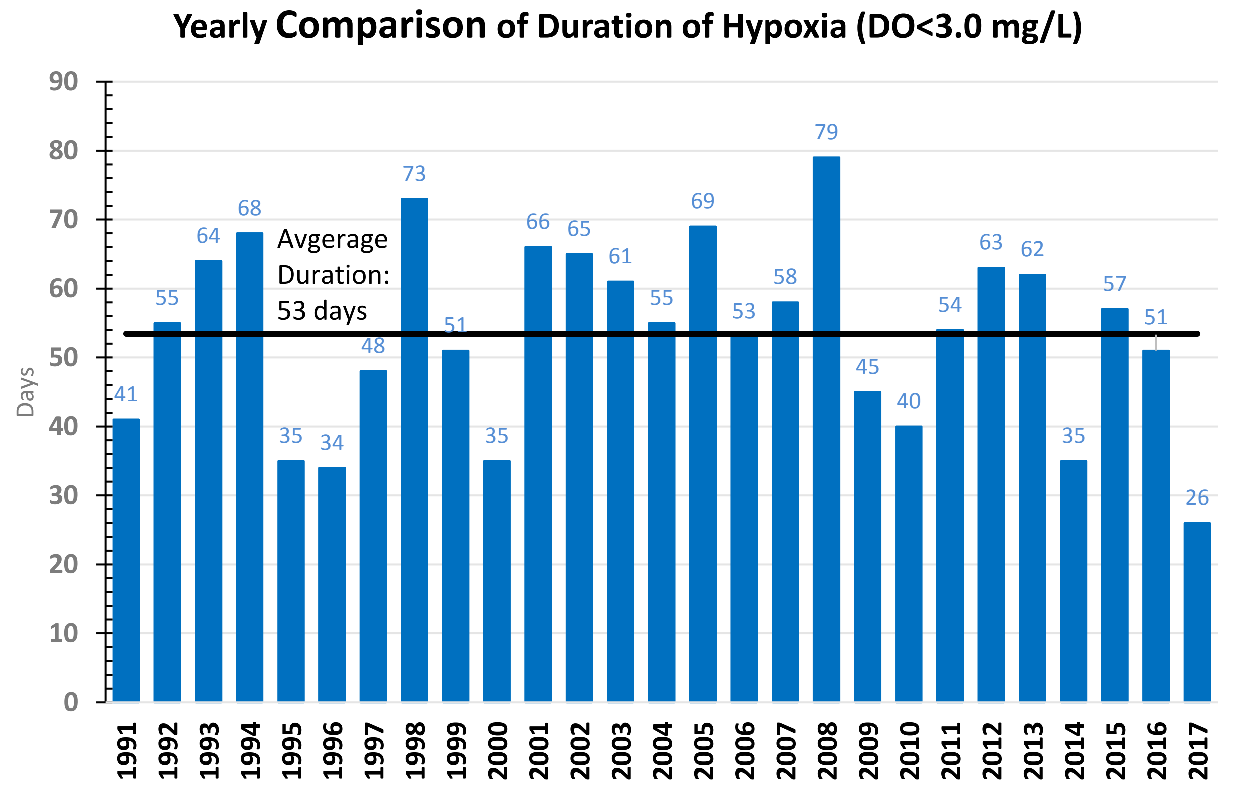


Figure 17

Table 3: Onset and Duration of Hypoxia, 1991-2017 (CT DEEP data only)

Year	Estimated Start Date	Estimated End Date	Maximum Area mi^2	Duration (days)
1991	July 19	Aug 28	122	41
1992	July 7	Aug 30	80	55
1993	July 9	Sept 10	202	64
1994	July 1	Sept 6	393	68
1995	July 12	Aug 16	305	35
1996	Aug 10	Sept 12	220	34
1997	July 27	Sept 12	30	48
1998	July 5	Sept 16	168	73
1999	July 2	Aug 21	121	51
2000	July 2	Aug 6	173	35
2001	July 10	Sept 14	133	66
2002	June 25	Aug 28	130	65
2003	July 5	Sept 3	345	61
2004	July 20	Sept 12	202	55
2005	July 14	Sept 20	177	69
2006	July 6	Aug 27	199	53
2007	July 16	Sept 11	162	58
2008	July 3	Sept 19	180.1	79
2009	July 19	Sept 1	169.1	45
2010	July 5	August 13	101.1	40
2011	July 6	August 28	130.3	54
2012	July 10	Sept 10	288.5	63
2013	July 8	Sept 7	80.7	62
2014*	July 24	Sept 9	87.1	35
2015	July 16	Sept 10	38.3	57
2016*	July 8	Sept 3	197.5	51
2017*	July 18	Aug 29	69.9	**26**
Average	July 12	Sept 4	166.8 mi^2	53
Deviation	±10 days	±11 days	± 88.3 mi^2	± 14 days

Table 3 displays the onset, duration, and end of the hypoxic events from 1991 through 2017 based on CT DEEP data only. This table will be updated in the future once historic (1991-2015) hypoxia maps are updated to include IEC data.

Using the LISS dissolved oxygen standard of 3.0 mg/L, the average date of onset was July 12 (±10 days), the average end date was September 4 (±12 days), and the average duration was 55 days (±13 days).
The earliest onset of hypoxia (red text) occurred on June 25, 2002 and the latest end date (green text) occurred on September 20, 2005.

The maximum area of hypoxia was 393 square miles (blue text) and occurred in 1994. The longest hypoxic event occurred in 2008 (magenta text) and lasted 79 days. The shortest hypoxic event occurred in 2017 and lasted **26** days (orange text).

* In 2014, 2016, and 2017 there were clear periods where the DO concentration rose above the 3.0 mg/L threshold in the early/middle part of August before dipping again during late August and early September.

Continuous Dissolved Oxygen Data

LISICOS Buoys 2017

Real-time bottom dissolved oxygen data collected by the LISICOS buoys in Western Long Island Sound are depicted in Figures 19 and 20. While real-time data were not available from the buoys in 2017, the sensors still logged the data internally. Data were periodically uploaded by UConn staff during maintenance cruises. The data show the clear period in late July/early August when dissolved oxygen concentrations rose above the 3.0 mg/L threshold. This is partly a result of a summertime Nor'easter that swept through the area. Figure 18 shows the wind speeds and wave heights recorded by the buoys during this storm event.

The climatology from both the Execution Rocks buoy and the Western Sound buoy are also presented in the Figures 19-20. The continuous data are represented by a blue line on the Execution graph and an orange line on the Western Sound graph. The average of the 10-year dataset is represented by a black line and the variability observed over the historical station record is the gray shading.

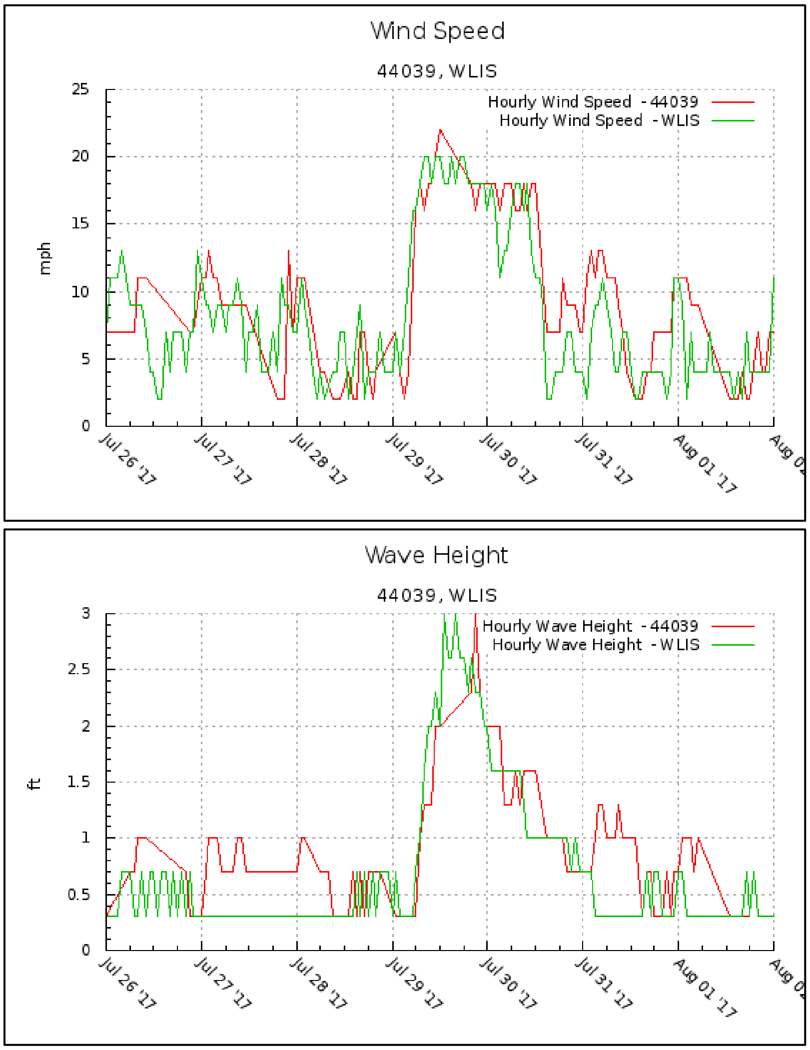


Figure 18 Wind speed data (a) and wave height data (b) from Central LIS (44039) and Western LIS during summer 2017 Nor'easter. Downloaded from NERACOOS website 1/9/2018.

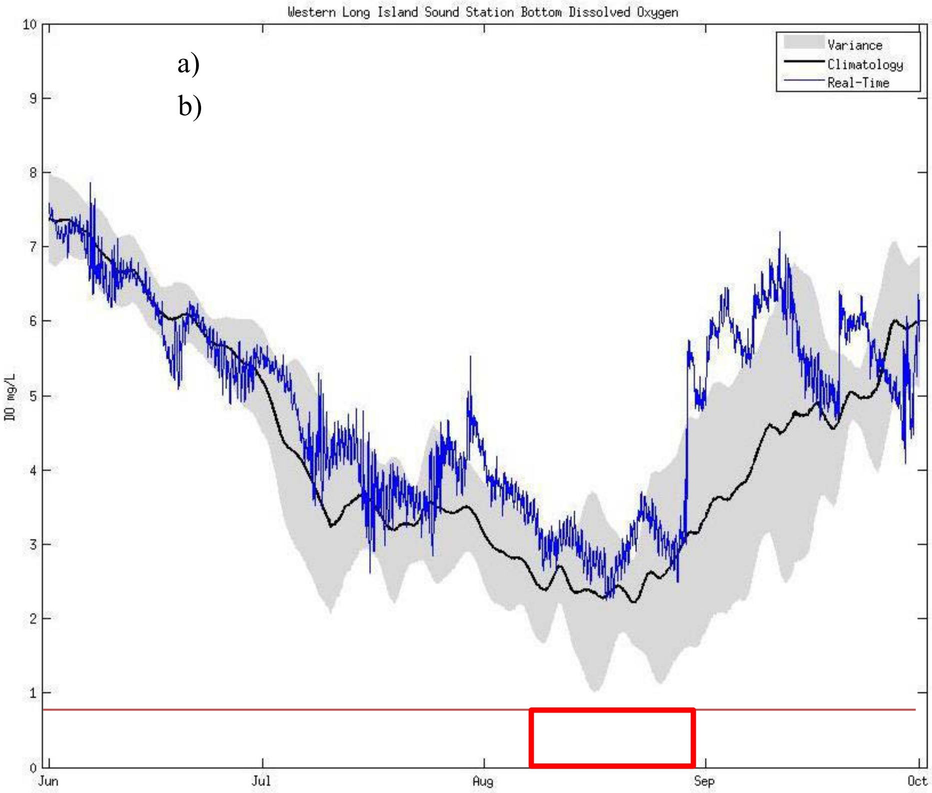


Figure 19

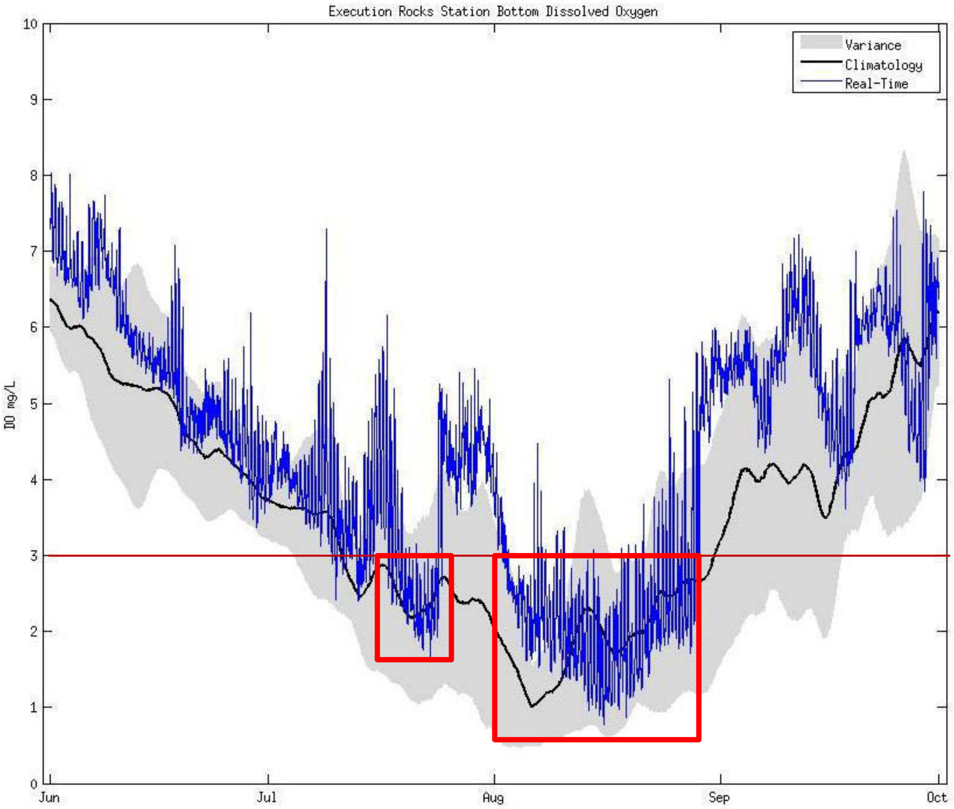


Figure 20

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

(See Red Box Figure 19)

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

(See Red Boxes Figure 20)

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)

Data obtained from T. Fake, UCONN, 12/21/17. Duration is calculated by LISICOS by summing the time (in days) of the number of samples where DO was below the specified value (T. Fake, pers comm. 18 October 2012). ***Data are provisional and subject to change.***

Area Estimates

The peak hypoxic event occurred during **IEC Run #8 and the HYJUL17** cruises between 18 and 20 July. Based on the *traditional CT DEEP stations only interpolation*, the **maximum area was 69.9 square miles**. Compared to the previous 24-year average, 2017 was below average in area (see figure below). The lowest dissolved oxygen concentration (1.11 mg/L) documented by CT DEEP during 2017 occurred on 7/18/17 at Station A4. The lowest dissolved oxygen concentration documented by IEC during 2017 (excluding embayment stations and A4 in early June) occurred on 7/15/17 was 1.53 mg/L at Station A5. The Execution Rock Buoy recorded its' lowest reading, 0.78 mg/L, on 8/16/17.

The maximum areal estimate (figure 21) is still based on the traditional CT DEEP only data to maintain the continuity of the long-term data set and because the entire previous 24-year dataset has not been re-interpolated using both the CT DEEP and IEC stations.

Table 4 demonstrates the differences in the areal estimates between using CT DEEP data alone and CT DEEP data combined with IEC data. Differences in areal estimates are attributed to the increase in spatial coverage in the Western Sound. By increasing the spatial coverage, the map interpolation software used to create the maps places less emphasis (weighting) on stations A4 and B3. For example, if one looks at the areal estimates for the WQAUG17/IEC Run 8 event, CT DEEP only data provides an estimate of 4.8 square miles of the bottom water with DO concentrations less than 2.0 mg/L. Adding in the IEC data increases the estimate to 18.4 square miles. Looking at the maps from the HYAUG17 and Survey #8 helps to further illustrate this. On the IEC only map (top left) one can see that there are 3 stations with concentrations in the 1-1.99 mg/L range. The CT DEEP only map (top right) uses data from only two stations, A4 and B3, to interpolate that area in the 1-1.99 mg/L range.

Table 4 demonstrates the differences in the areal estimates between using CT DEEP data alone and CT DEEP data combined with IEC data.

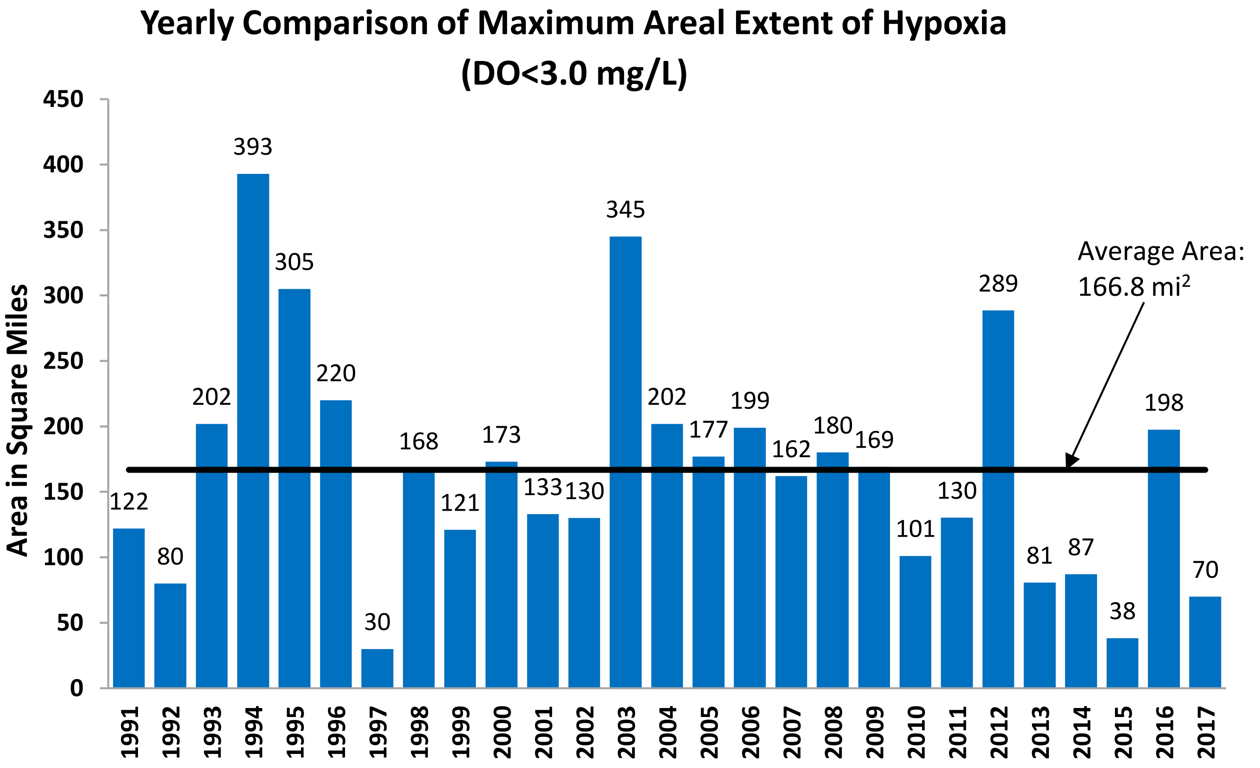


Figure 21

Table 4: CT DEEP and IEC Hypoxia Areal Extent (mi^2)

Survey	Area <1.0 mg/L		Area <2.0 mg/L		Area <3.0 mg/L		Area <4.8 mg/L	
	DEEP	IEC & DEEP	DEEP	IEC & DEEP	DEEP	IEC & DEEP	DEEP	IEC & DEEP
WQJUN17	0	--	0	--	0	--	0	--
HYJUN17	0	--	0	--	0	0	15.64	--
WQJUL17 & IEC Survey #2	0	0	0	0	0	2.20	85.95	79.42
HYJUL17 & IEC Survey #4	0	0	0	0	69.9	42.55	504.3	508.77
WQAUG17 & IEC Survey #6	0	0	0	0	0	0	475.68	453.28
HYAUG17 & IEC Survey #8	0	0	4.8	18.42	44.13	63.71	484.17	502.28
WQSEP17 & IEC Survey #10	0	0	0	0	42.39	5.67	218.50	194.60
HYSEP17	No DEEP Survey							

Hypoxia Maps

The following maps depict the development of hypoxia based on CT DEEP and IEC data through the 2017 season. Data for all surveys are available upon request.

A combination of maps has been created for each IEC and CT DEEP survey; this includes combined maps for overlapping surveys. The following 13 IEC stations were incorporated in the combined maps: A1, A2M, A3, A4, A5, B1S, B2, B3M, B4, H-A3, H-B, H-C, H-C1. As IEC and DEEP share two stations (A4 and B3), the data from these stations were averaged together to create the new combined maps. IEC stations in embayments (*i.e.,* DI1, DI2, 9-409, 9-412, 9-413, E-12, 8-405, 8-403, and H-D) were not included in the combined maps. While areal estimates were calculated using these combined hypoxia maps and are presented in this report, they are to be considered for informational purposes only. It is inappropriate to utilize the combined areal estimates as the official hypoxic area for 2017 as they are not comparable to the previous 23 years of estimates. DEEP is in the process of updating all the areal estimates from 1991 to the present utilizing historical datasets from IEC. Once completed the datasets would again be comparable. During the WQJUN17 survey conducted June 5-8, all CT DEEP stations had DO concentrations above 4.8 mg/L; therefore, no maps were produced.

HYJUN17

CT DEEP sampled 23 stations during the HYJUN17 survey that was conducted 20-21 July 2017. 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.

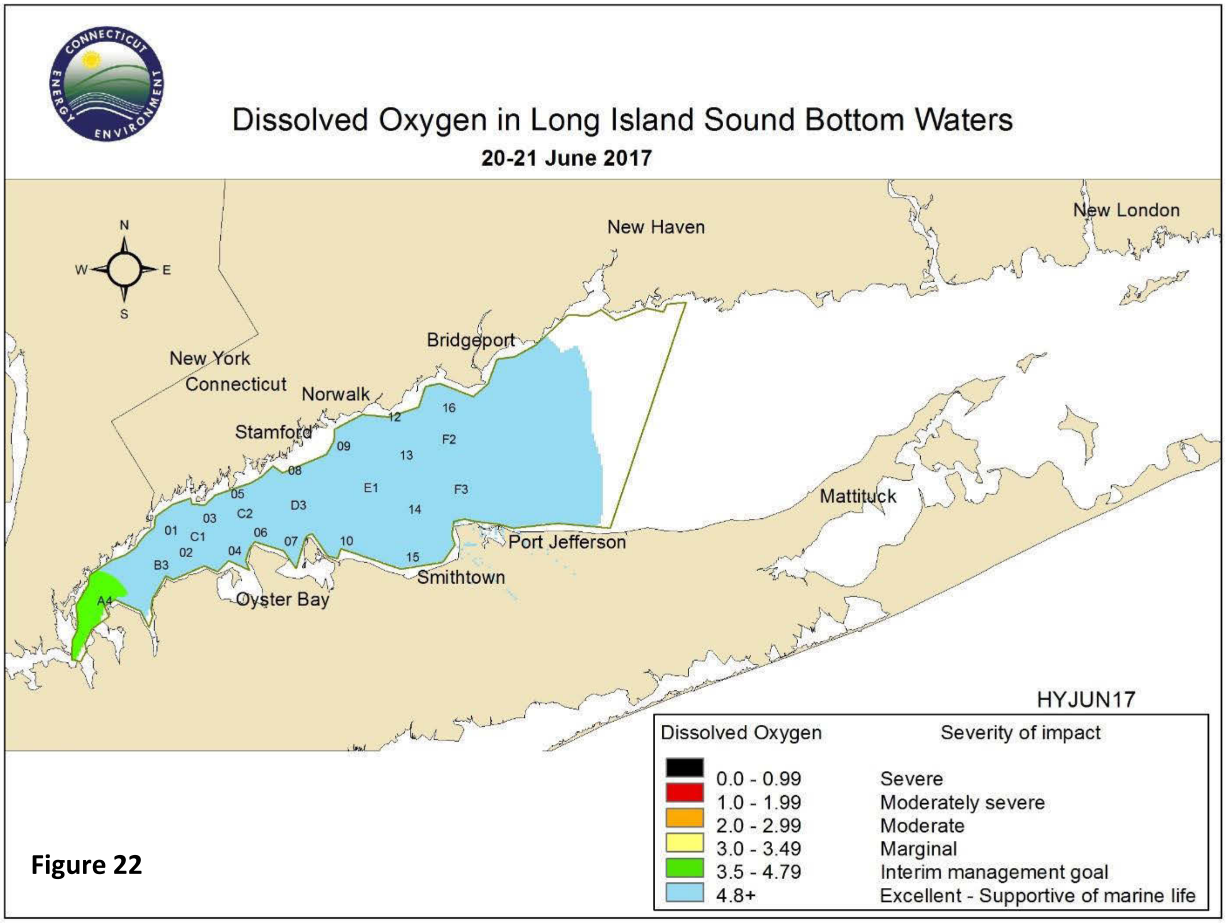


Figure 22

IEC Run #1

IEC conducted its first survey on June 28th, 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.

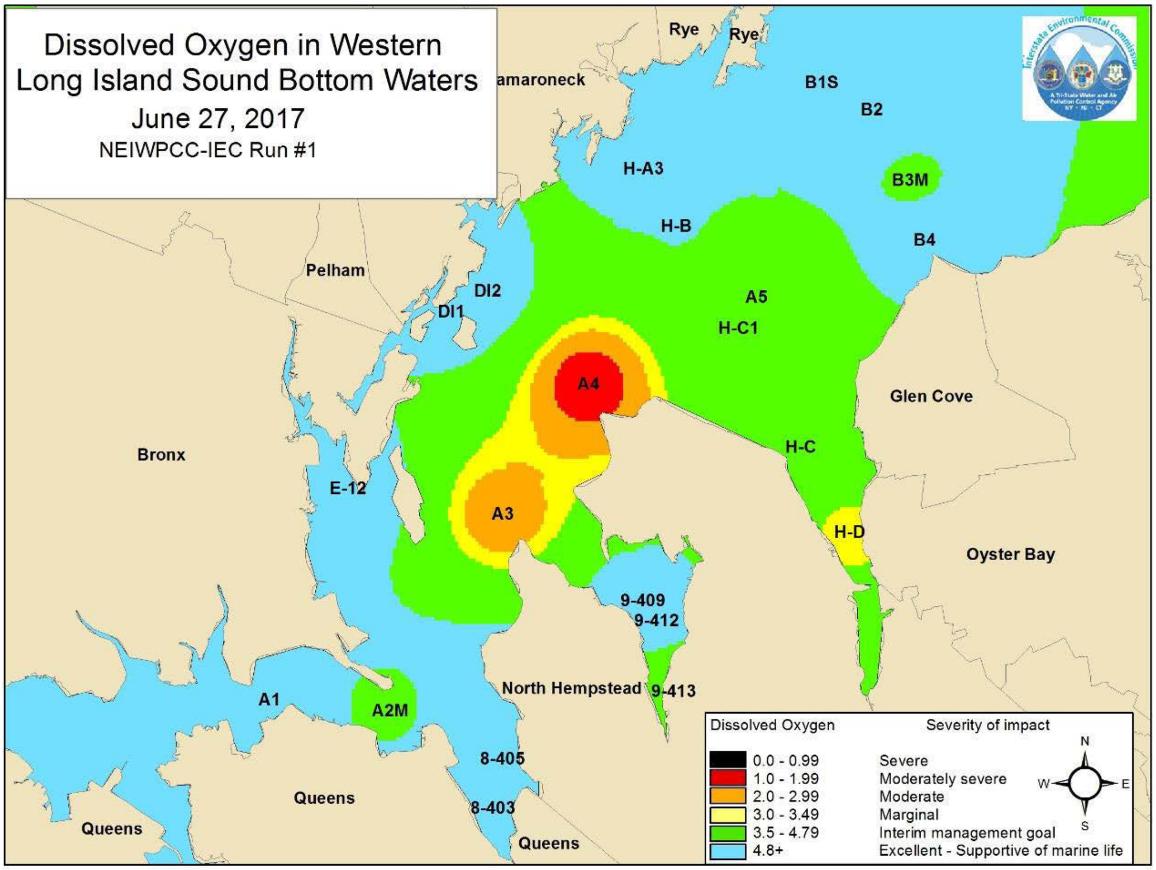


Figure 23

CT DEEP WQJUL17 and IEC Run #2

During the WQJUL17 and IEC Run #2 surveys 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.

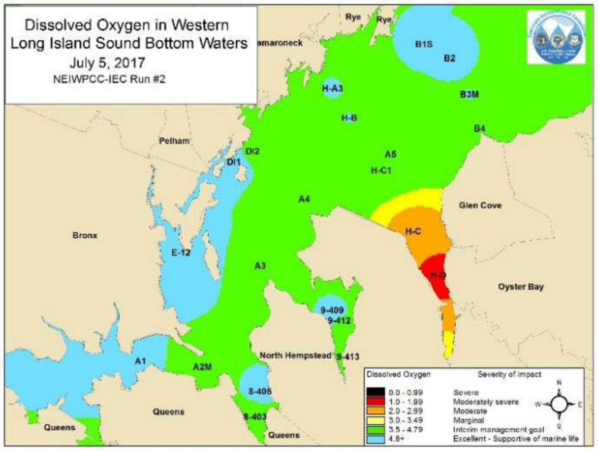


Figure 24

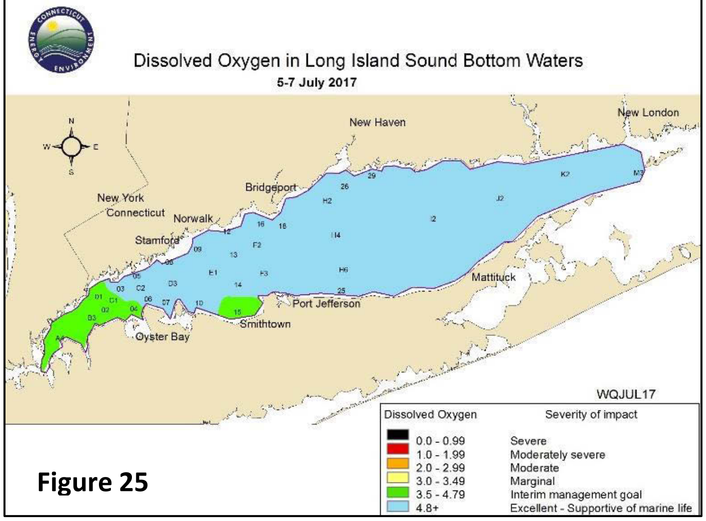


Figure 25

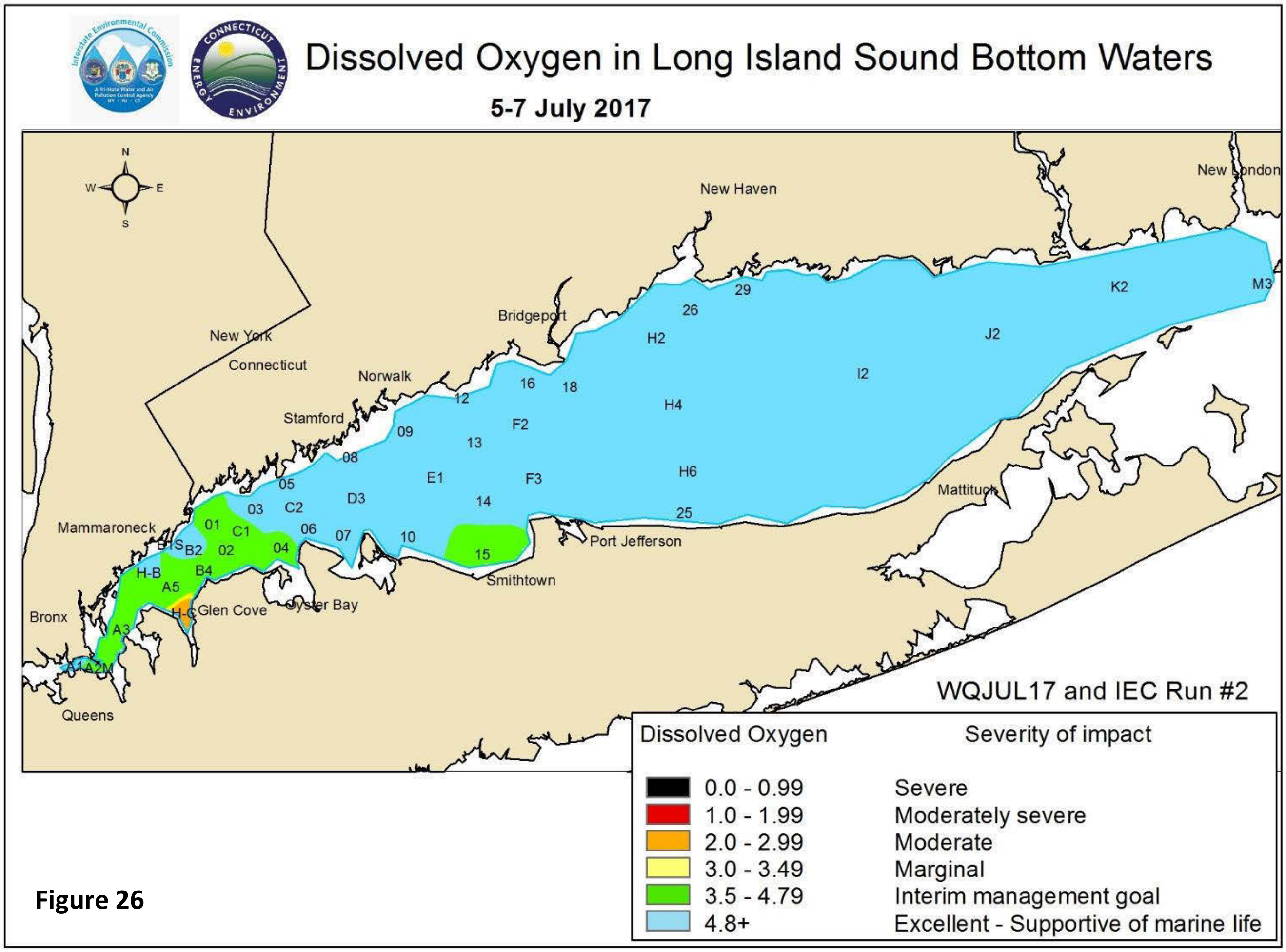


Figure 26

IEC Run #3

IEC conducted its third survey (Run #3) on July 11th. 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.

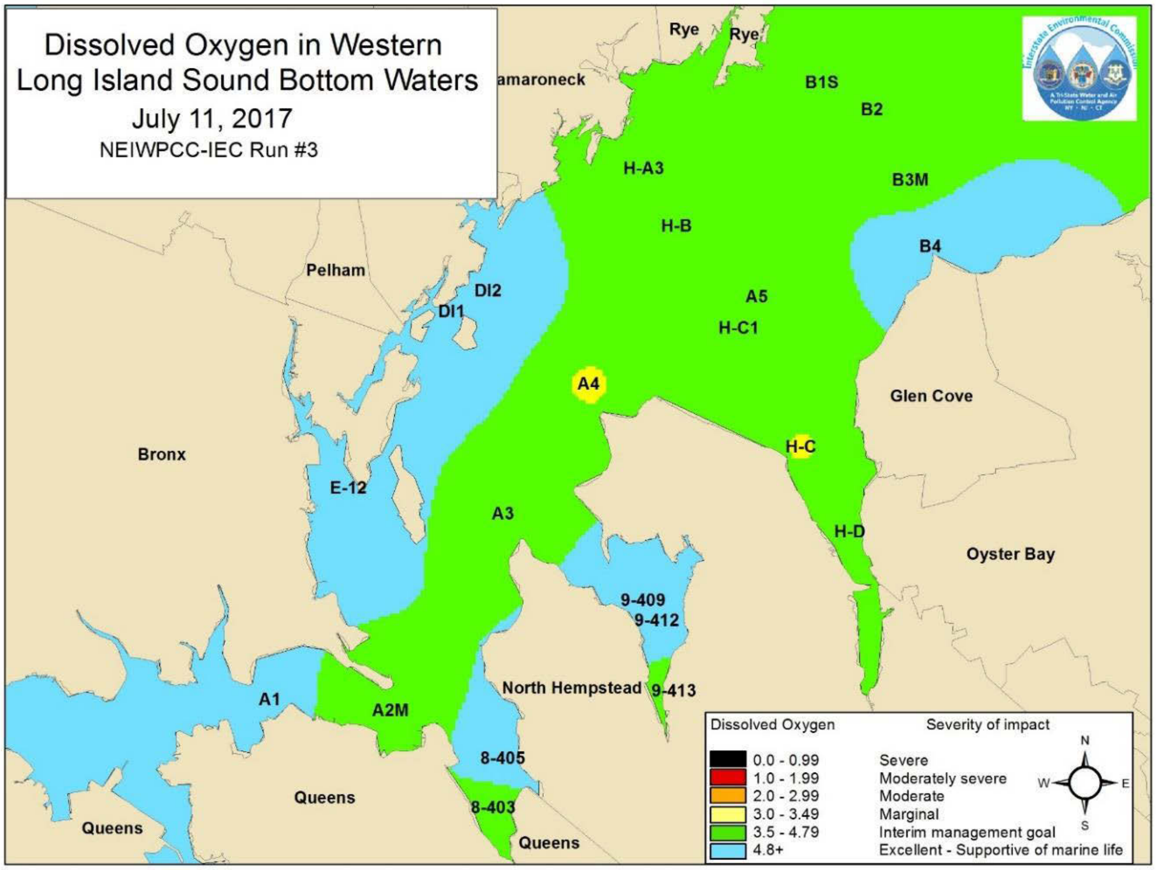


Figure 27

CT DEEP HYJUL17 and IEC Run #4

During IEC's fourth survey (Run #4) on 18 July, only four stations exhibited DO concentrations above 4.8 mg/L (Figure 28). 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.

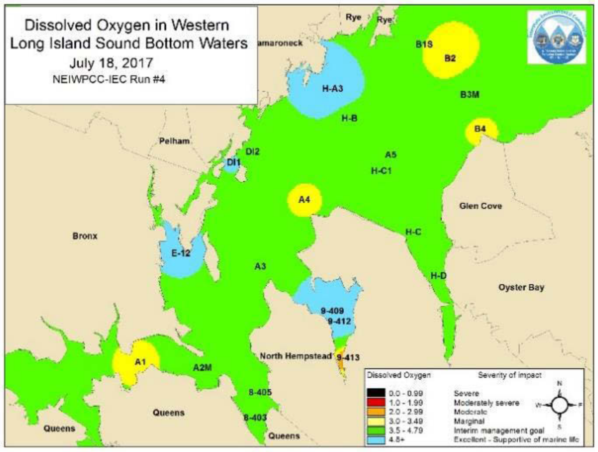


Figure 28

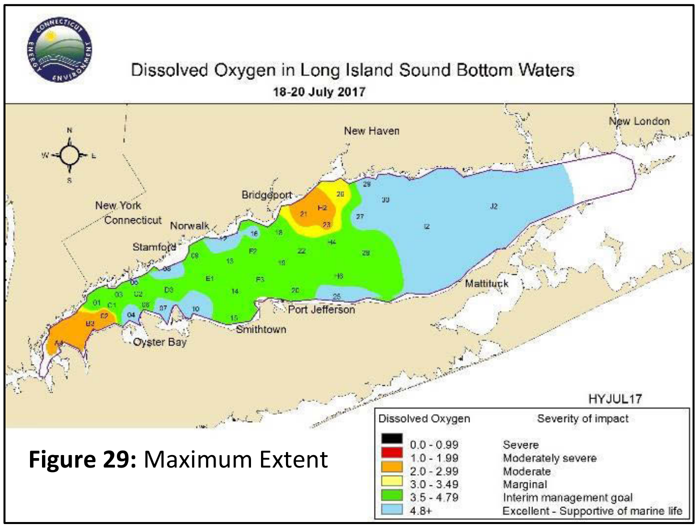


Figure 29: Maximum Extent

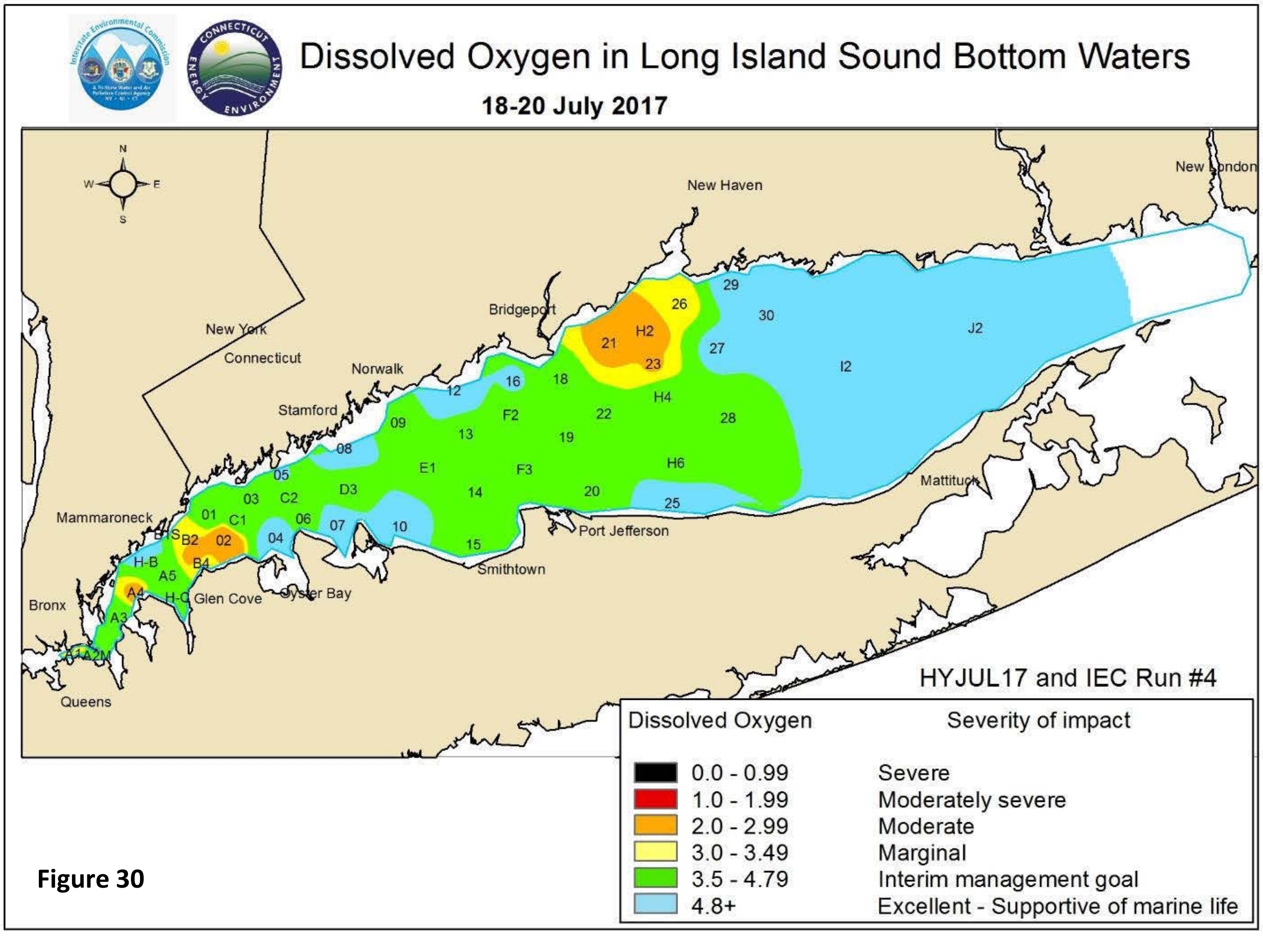


Figure 30

IEC Run #5

IEC conducted its fifth survey on July 26th. 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.

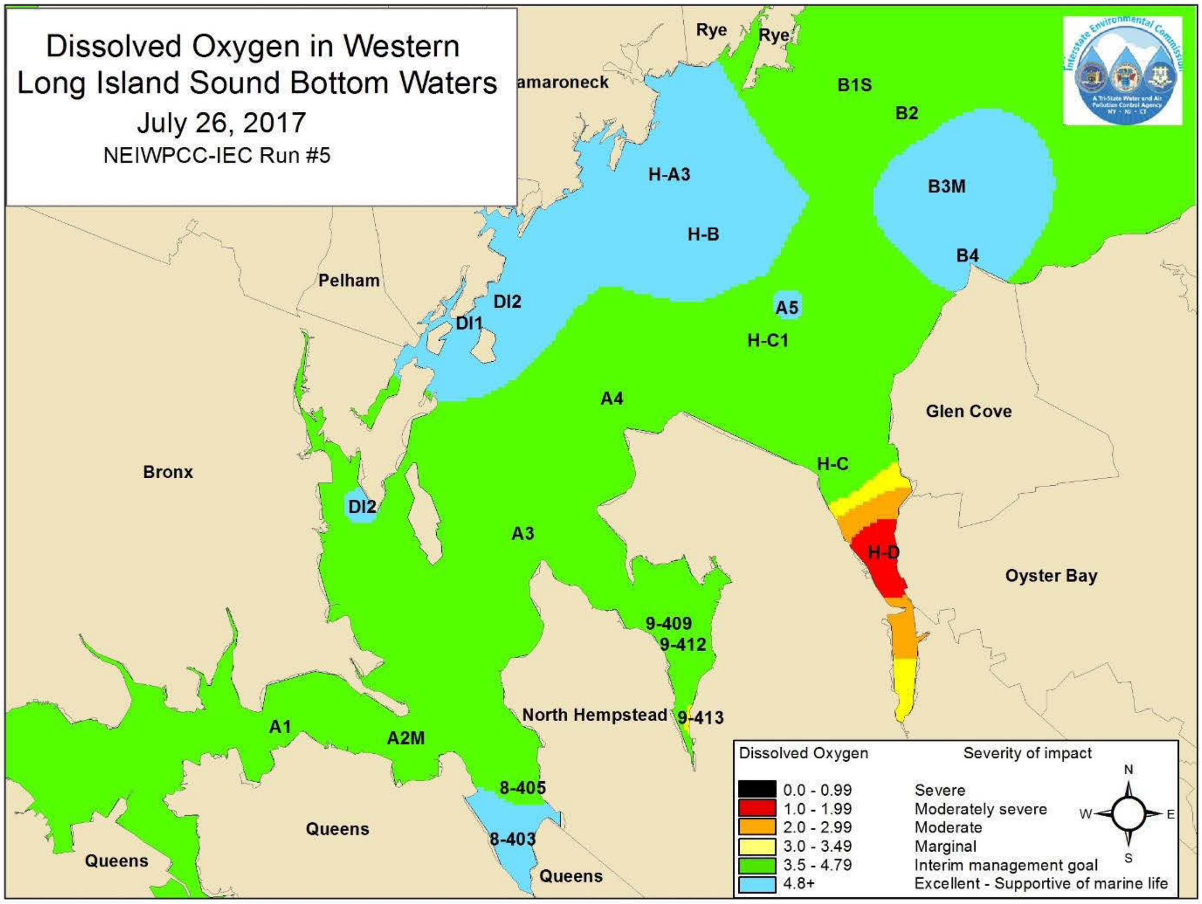


Figure 31

CT DEEP WQAUG17 and IEC Run #6

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.

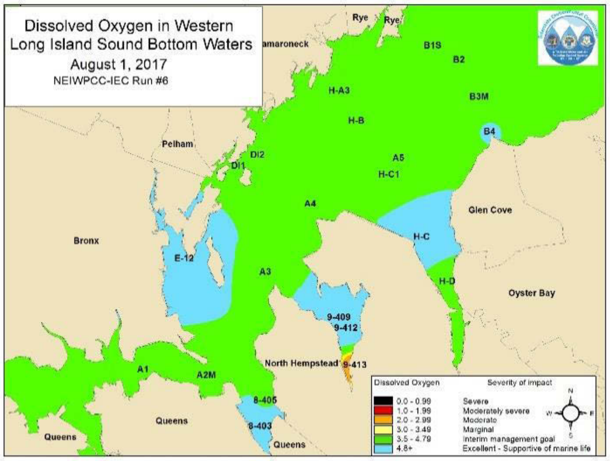


Figure 32

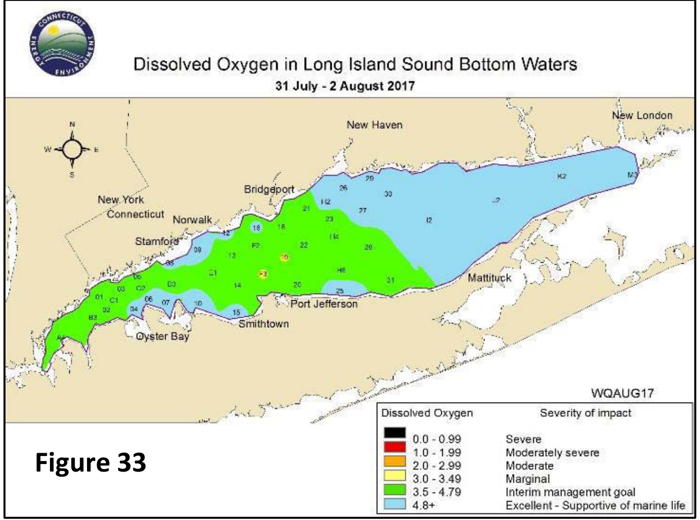


Figure 33

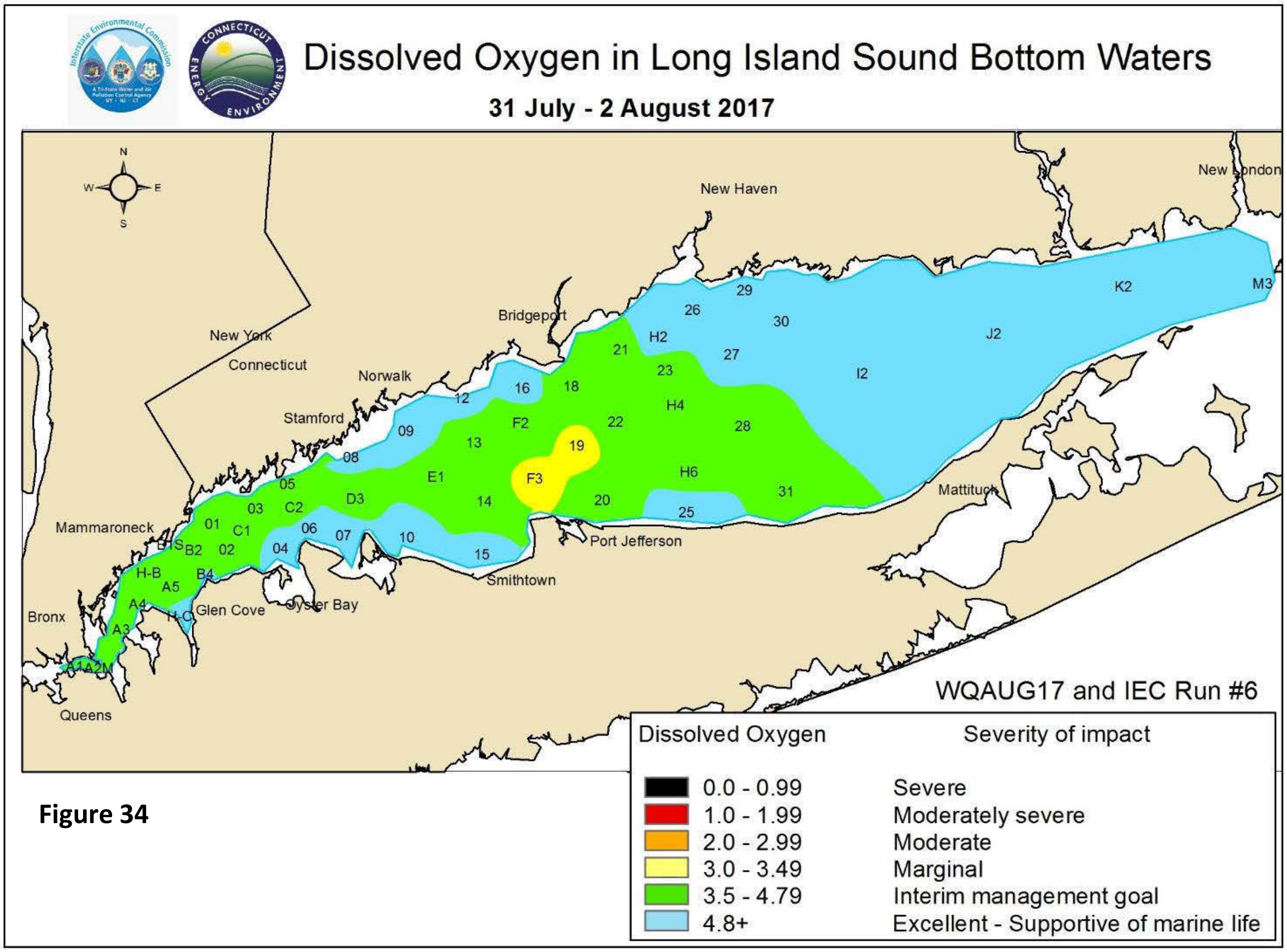


Figure 34

IEC Run #7

IEC conducted its seventh survey (Run #7) on August 8th. 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.

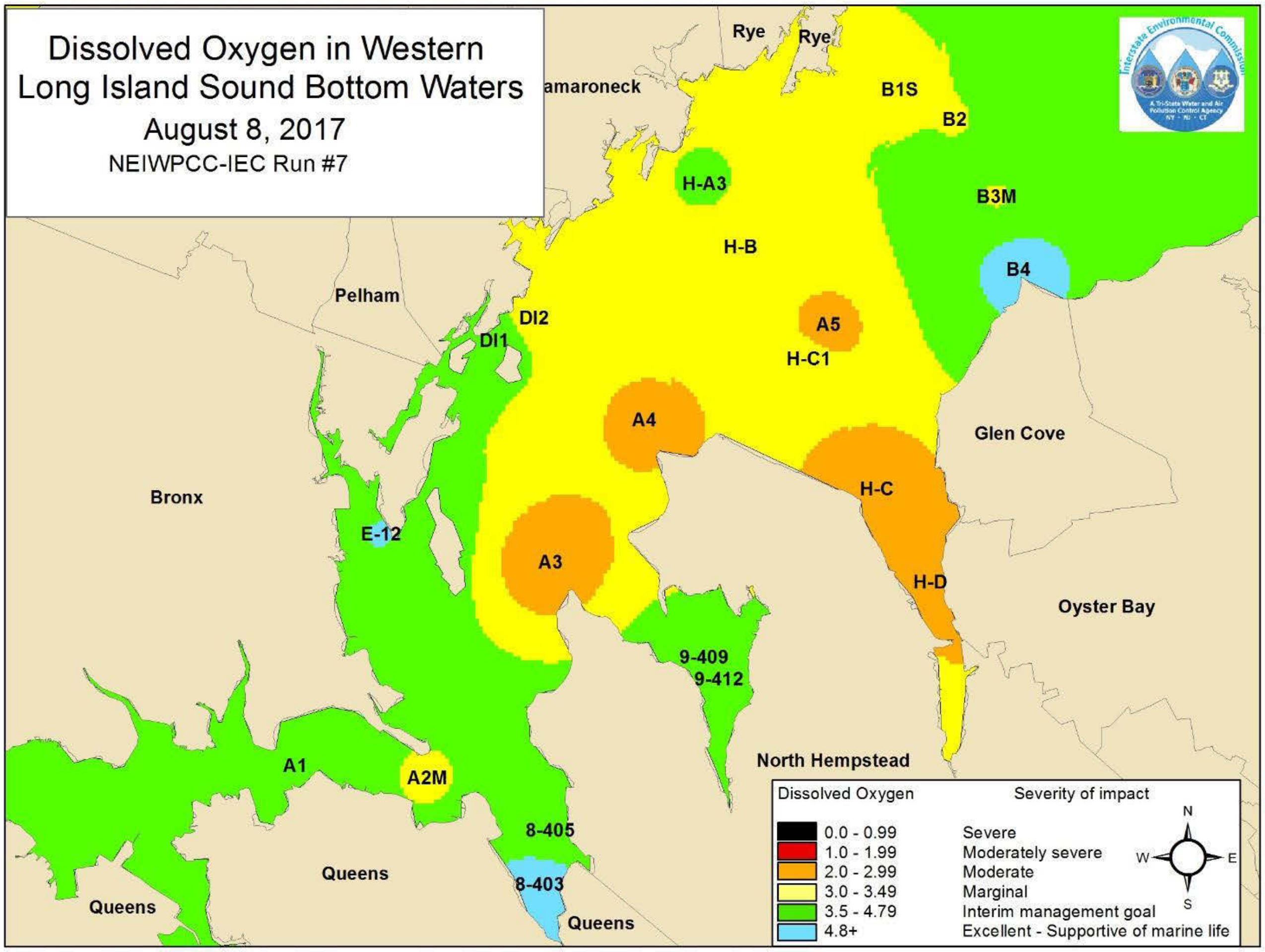


Figure 35

CT DEEP HYAUG17 and IEC Run #8

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.

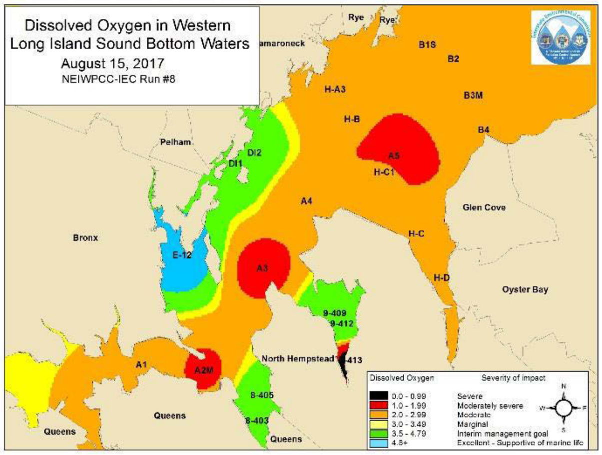


Figure 36

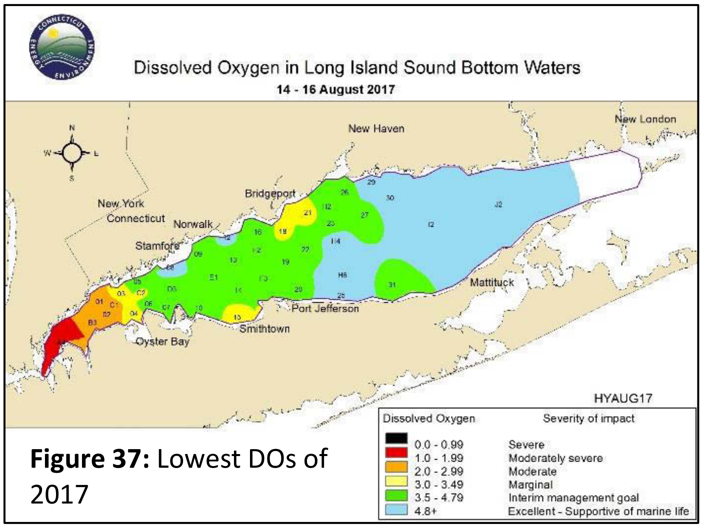


Figure 37: Lowest DOs of 2017

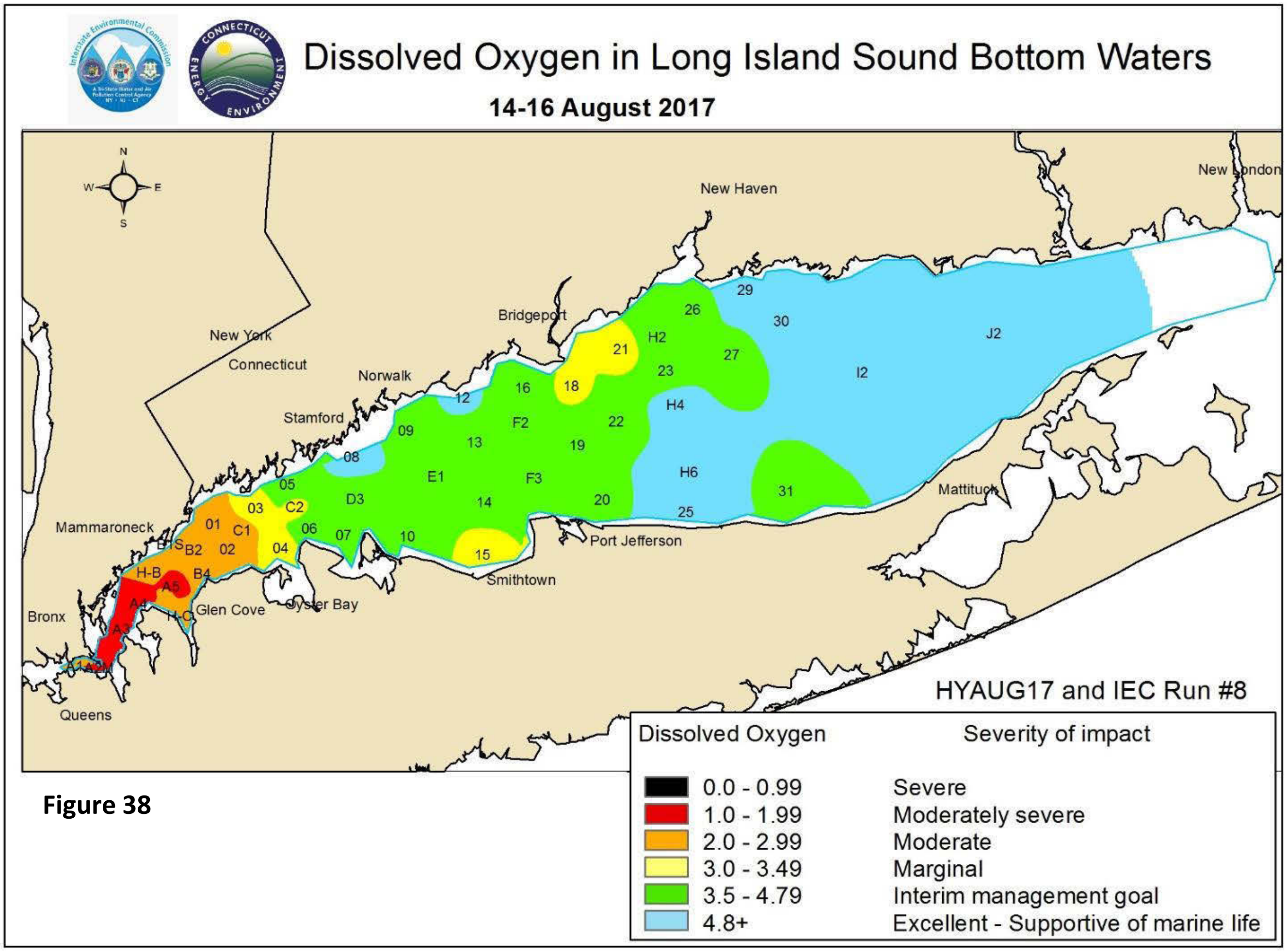


Figure 38

IEC Run #9

IEC conducted its ninth survey on August 22nd. 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.

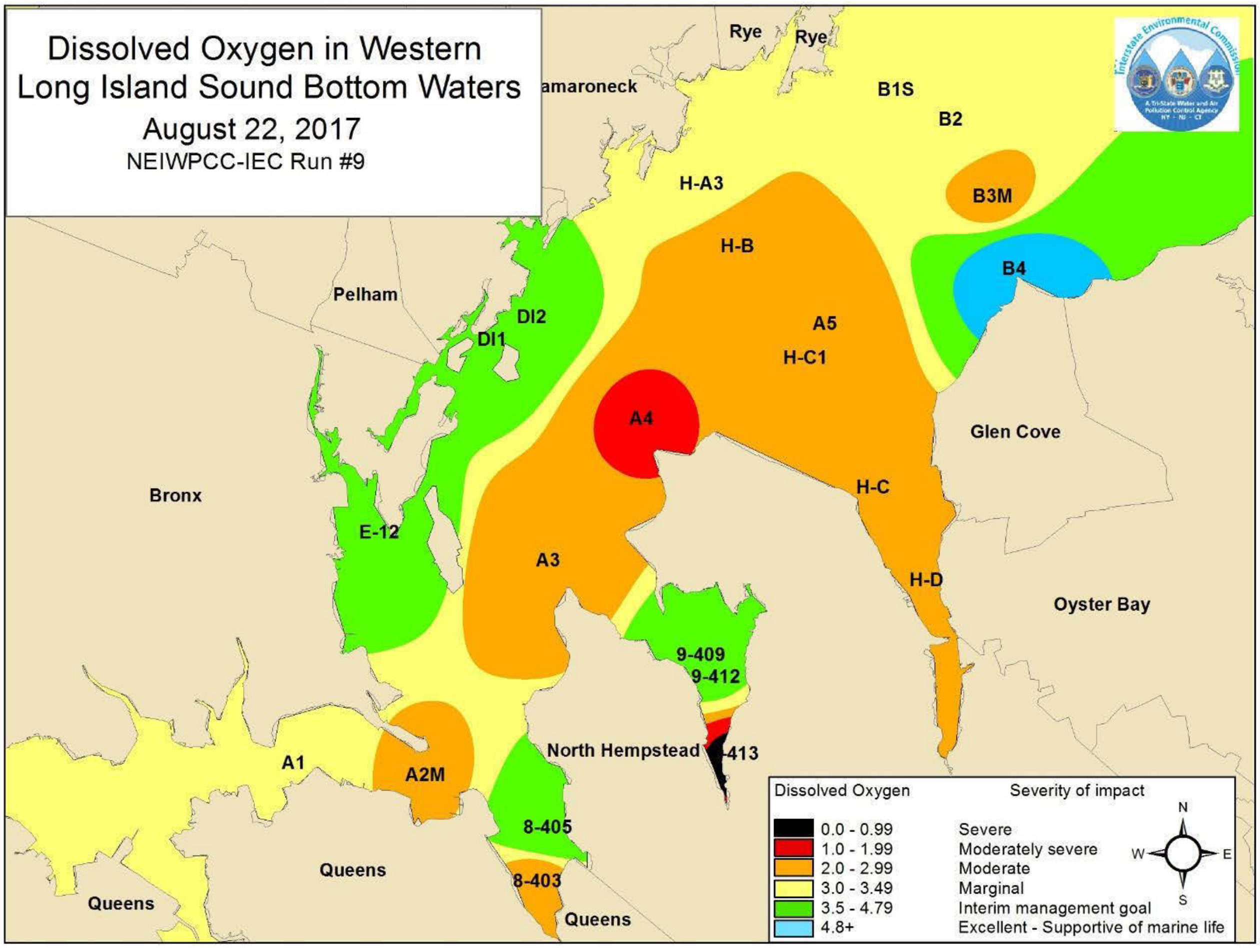


Figure 39

CT DEEP WQSEP17 and IEC Run #10

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.

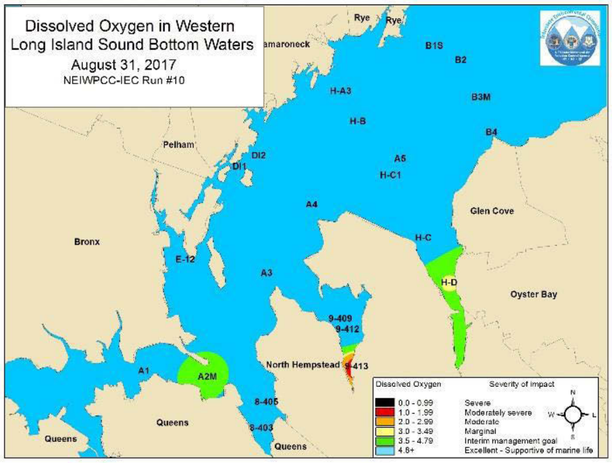


Figure 40

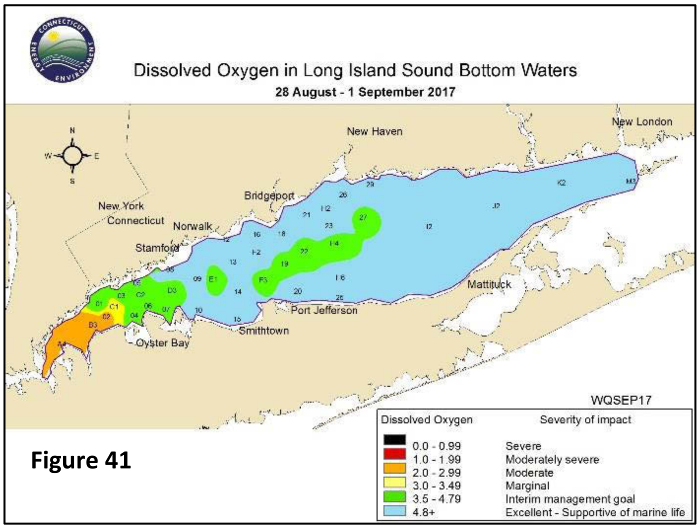


Figure 41

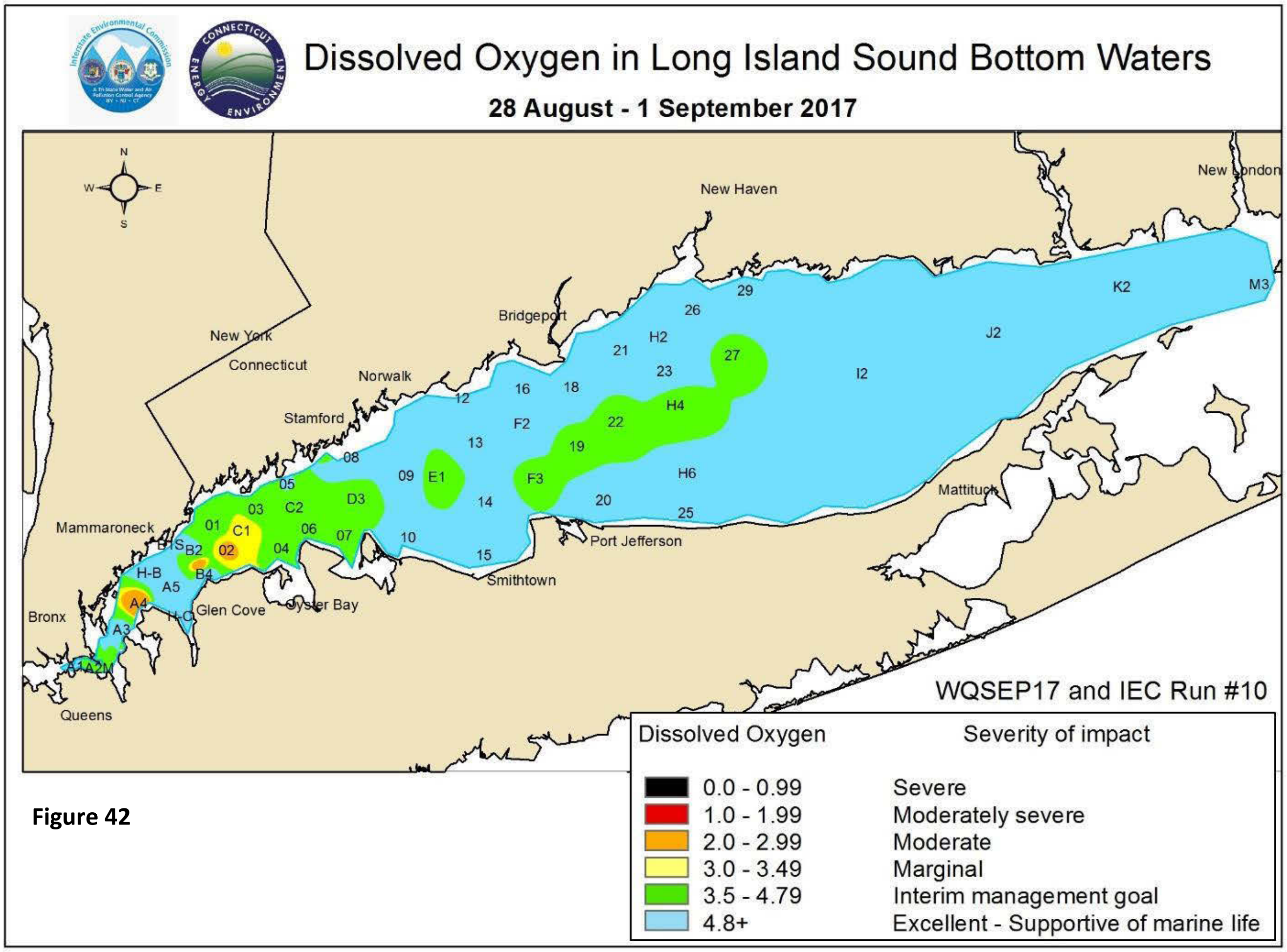


Figure 42

IEC Run #11

IEC conducted its eleventh survey on September 5th. The bottom waters of Western Long Island Sound showed marked improvement; only three 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.

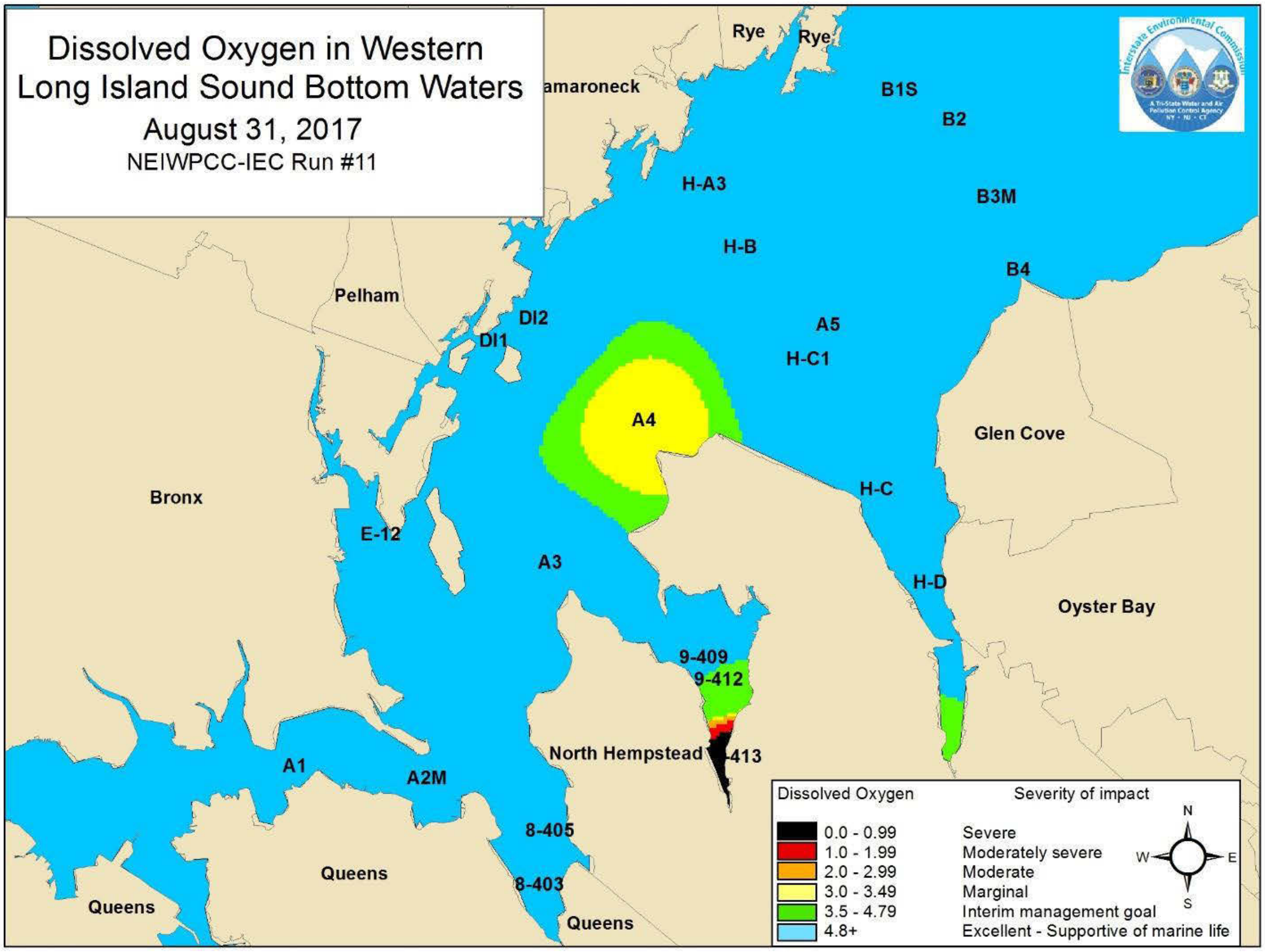


Figure 43

IEC Run #12

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.

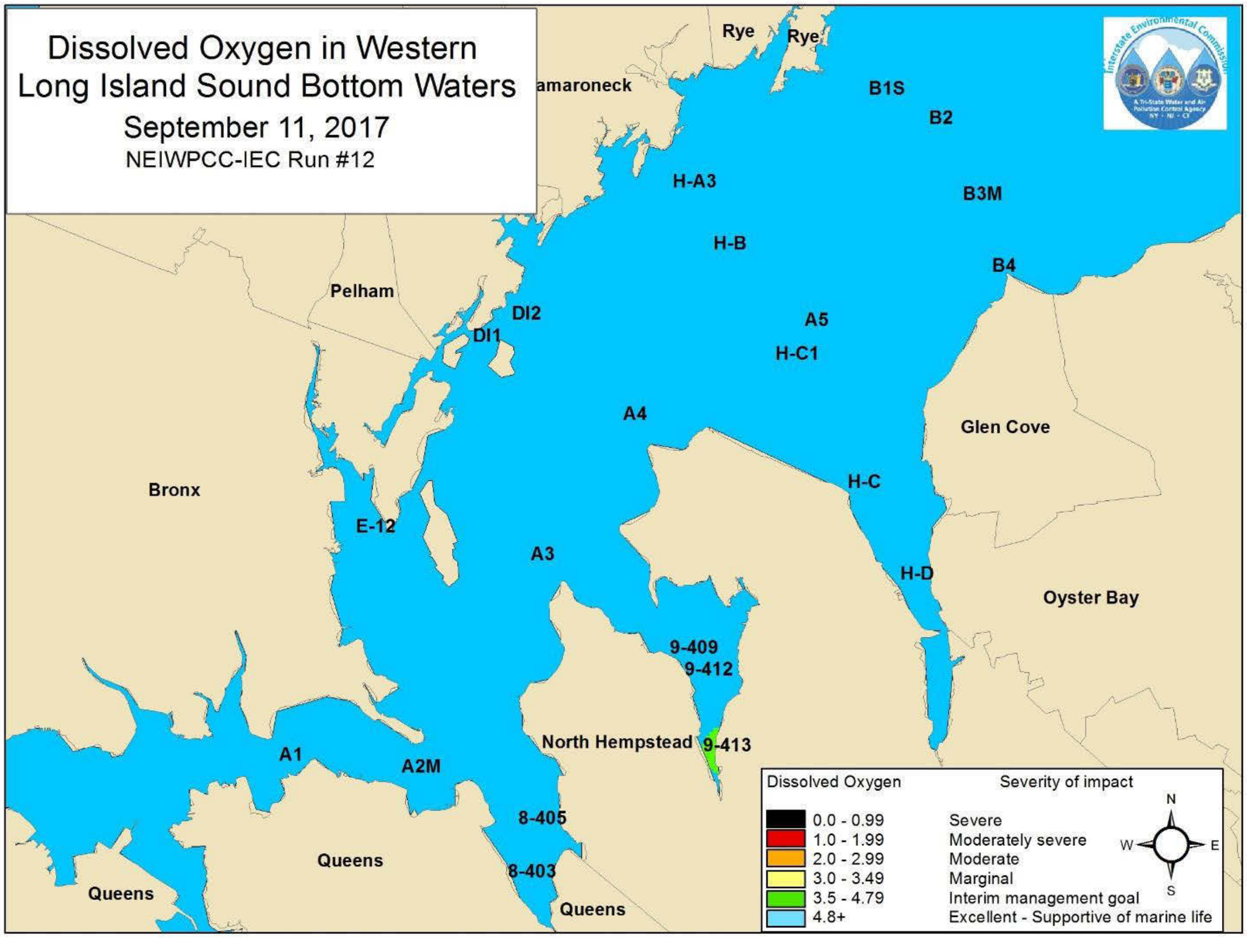


Figure 44

Area of Dissolved Oxygen Below the Chronic Criterion for Growth and Protection of Aquatic Life for LIS

Aquatic organisms can be impacted by a combination of low dissolved oxygen concentrations, exposure, and extended duration of low DO events (See Habitat Impairment Associated with Hypoxia, Page 7 and USEPA 2000). CT DEEP and NYS DEC have each established Dissolved Oxygen Chronic Exposure Criteria for the protection of aquatic life (CT DEEP 2015 and NYS DEC 2008). DO concentrations greater than or equal to 4.8 mg/L meets the chronic criterion for growth and protection of aquatic life. Organisms can tolerate DO concentrations less than 4.8 mg/L for short periods of time, without significant impacts.

Figure 45 illustrates the maximum area of bottom waters within Long Island Sound with DO concentrations between 3.0 and 4.8 mg/L based on biweekly sampling by CT DEEP. (This graph will be updated in the future once historic (1991-2015) hypoxia maps are updated to include IEC data.) This figure is intended to highlight that large areas of LIS bottom waters have concentrations of dissolved oxygen that, while not hypoxic, are less than optimal to protect the growth and development of exposed organisms. It is not intended for use is assessing if the bottom waters of LIS meet the states' chronic DO criteria.

In 2017, the maximum area of LIS bottom waters between 3.0 and 4.8 mg/L occurred during the WQAUG17 survey and was estimated at 476 square miles. From 1991-2017, the area affected by concentrations between 3.0 and 4.8 mg/L averages 493 square miles and varies slightly from 398 to 601 square miles.

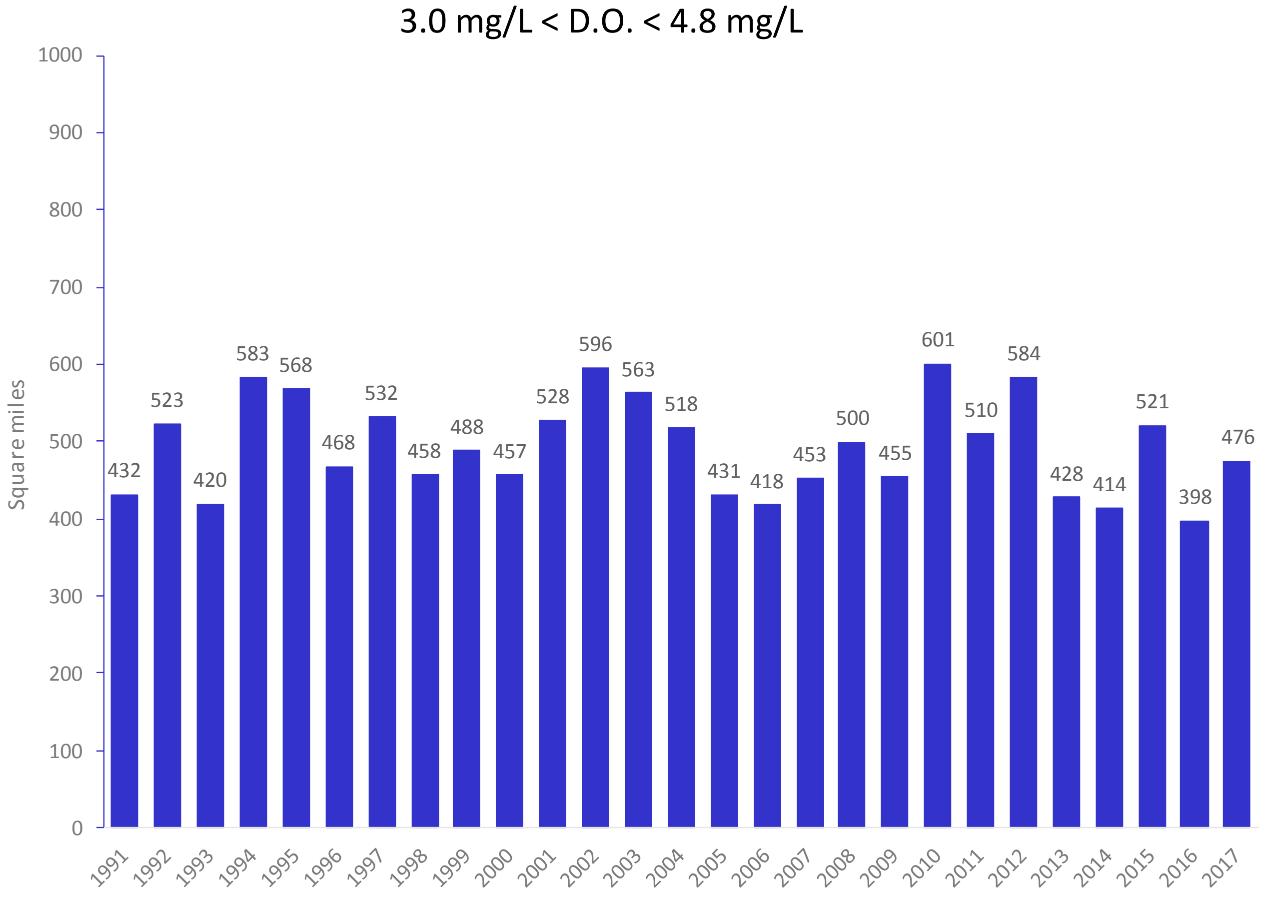


Figure 45

Severe Hypoxia

The Long Island Sound Study provides information on LIS hypoxia for inclusion in EPA's *Report on the Environment* (ROE, EPA 2017). The ROE reports on "the best available indicators of information on national conditions and trends in air, water, land, human health, and ecological systems…" The *Report on the Environment* tracks trends in the Gulf of Mexico and LIS as examples of coastal areas experiencing hypoxia. The ROE uses 2.0 mg/L as a benchmark to liken conditions in the Gulf of Mexico to LIS. In this report, the term severe hypoxia is used to describe DO < 2.0 mg/L and is discussed below.

Figure 46 illustrates the maximum area of bottom waters of Long Island Sound with DO concentrations less than 2.0 mg/L. Based on CT DEEP data, in 2017, bottom water dissolved oxygen concentrations were less than 2.0 mg/L over 4.8 square miles. This is a decrease over last year when concentrations in the bottom waters dropped below 2.0 mg/L across 40 square miles. (DEEP data). The average area with concentrations less than 2.0 mg/L, calculated from 1991-2017, is 51.23 mi^2. In 2017, based on CT DEEP estimates, there were 10 days with DO <2.0 mg/L. At the LISICOS Execution Rocks buoy, there were 12.45 cumulative days below 2.0 mg/L.

In LIS, 1994 and 2003 appear to be years when severe hypoxia (DO <2.0 mg/L) was especially prevalent. 1994 had cold winter bottom water temperatures and an unusually warm June which led to strong stratification. The highest average Delta T in July 1994 was 8.54°C. 2003 was the second hottest summer since 1895 and the 28th wettest which also led to the Sound being strongly stratified. Strong stratification (Delta T greater than 4°C) lasted for four months in 1994 (May-August) and only one month (July) in 2003.

In comparison, the 31-year average size of the hypoxic zone in the northern Gulf of Mexico is roughly 5,424 mi^2 (larger than the State of Connecticut). The 2017 hypoxic zone covered 8,776 mi^2 and was the largest size measured since the standardized mapping cruises began in July 1985. For additional information on the Gulf of Mexico hypoxic zone please visit their website at http://www.gulfhypoxia.net. The 2017 hypoxia forecast for the Gulf of Mexico released in June predicted the hypoxic zone would cover 10,089 mi^2 (Turner and Rabalais, 2017).

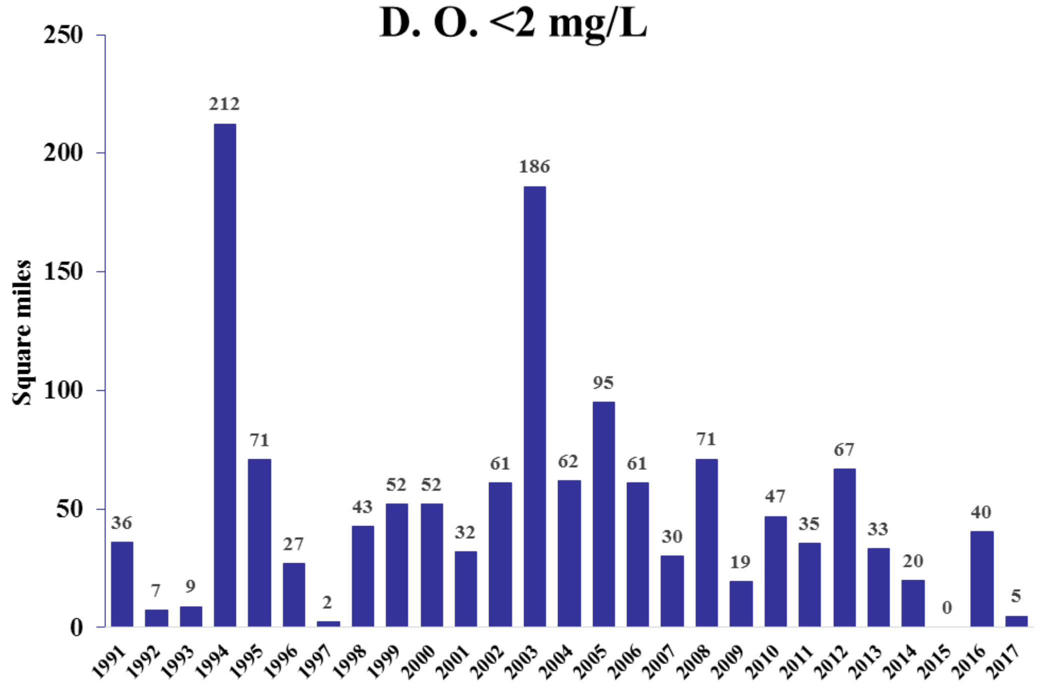


Figure 46

Anoxia

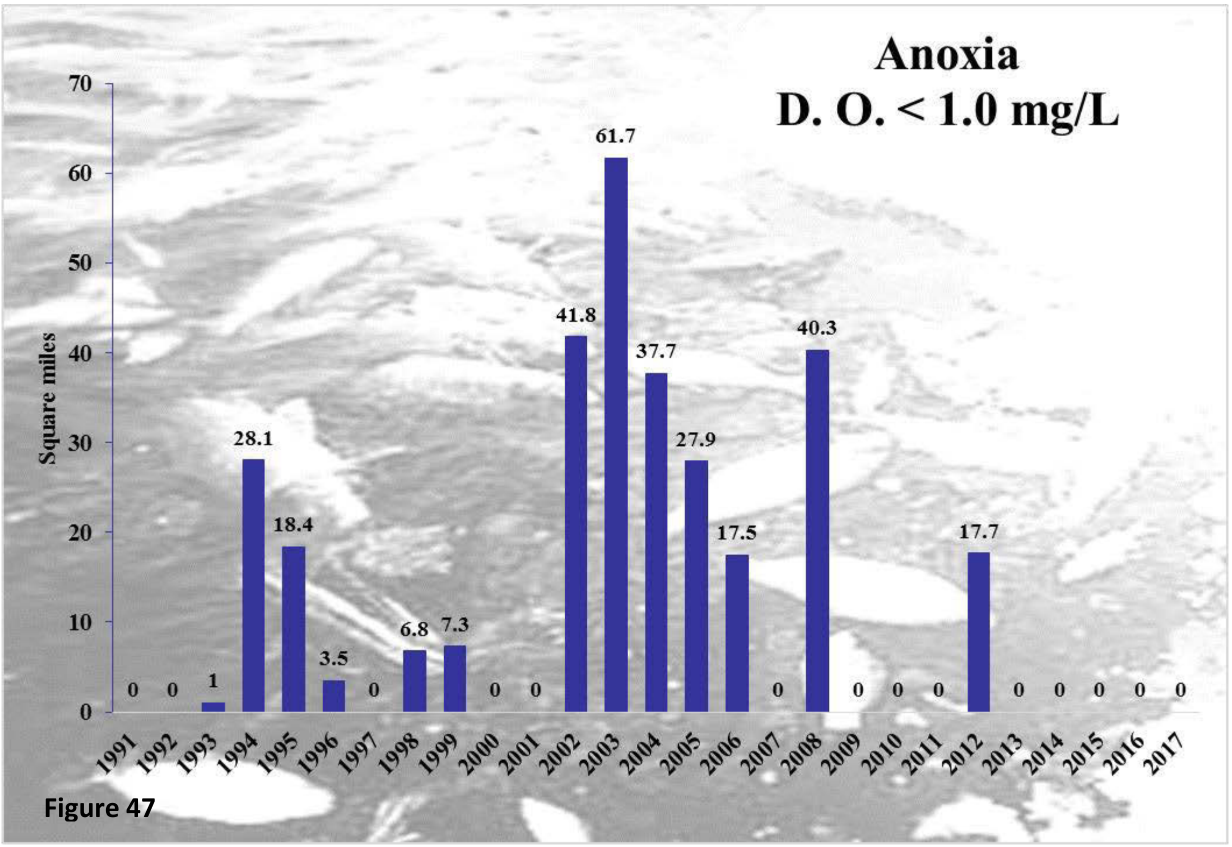


Figure 47

For management purposes, the Long Island Sound Study defines anoxia as DO concentrations less than 1 mg/L. This chart illustrates the maximum area of bottom waters in LIS with DO concentrations less than 1.0 mg/L based on biweekly sampling by CT DEEP.

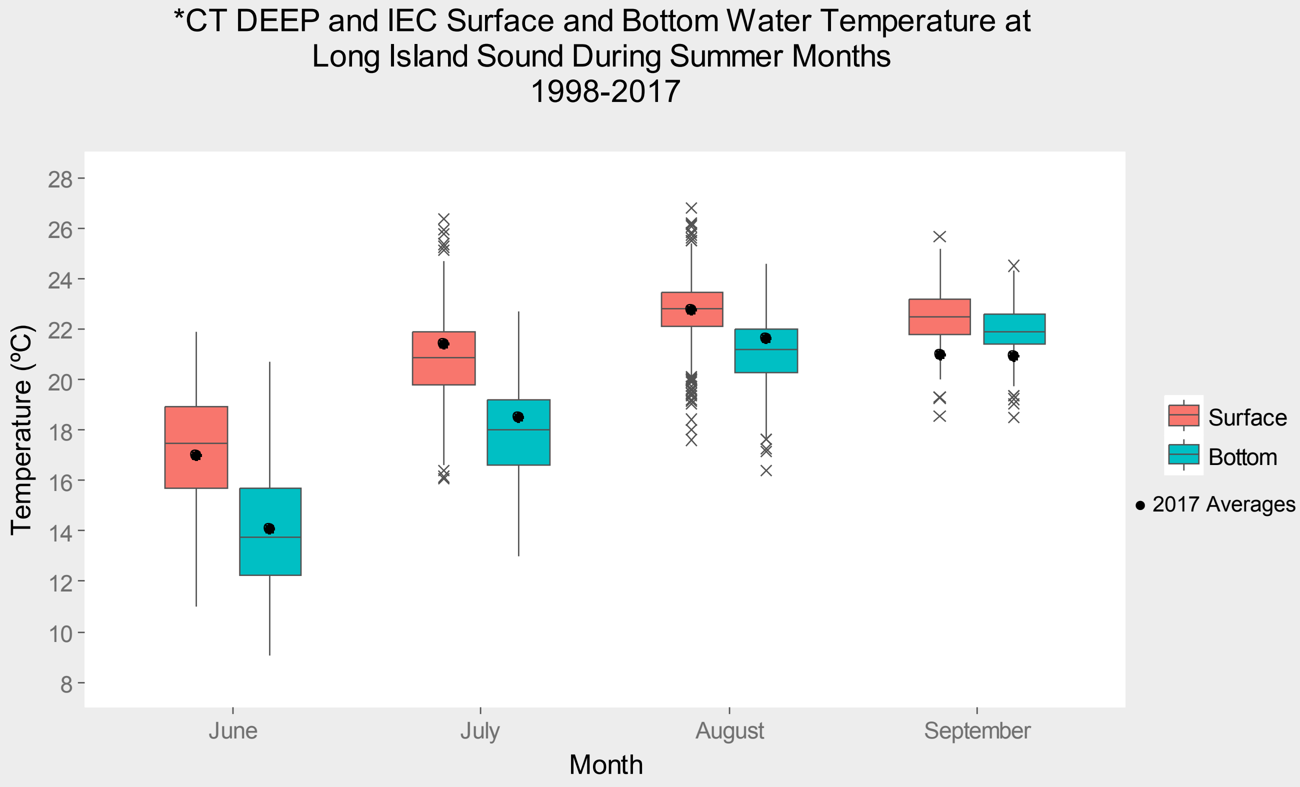
In 14 of the past 27 years, there was no anoxia reported by CT DEEP. It is important to note that IEC and LISICOS have documented anoxic conditions during years when CTDEEP has not. In 2009 and 2010, IEC documented two stations that were anoxic (Stations B3 and B2 in 2009, and in 2010 Stations B3 and H-D). In 2011, the LISICOS Execution Rocks buoy (Station A4) captured a minimum DO of 0.61 mg/L. This year (2017), the LISICOS Execution Rocks buoy (Station A4) documented a minimum DO of 0.78 mg/L.

Prior to 2002, the average area of bottom waters affected by anoxia was 5.9 mi^2. From 2002-2008 the average area affected was 32.4 mi^2. From 2009 to 2017, the average area affected was 1.97 mi^2. The overall average area affected from 1991-2016 is 11.47 mi^2. The greatest area with DO below 1 mg/L (62 square miles) was during the summer of 2003.

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.

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 48. The water column is usually already stratified by June and remains that way until late August/early September.



*Axial Stations

Figure 48

Looking at LIS summer surface temperature data spatially reveals there is only about a 1.5ºC difference between the mean temperatures across the Western and Central Sound (Stations A1-I2). The average summer temperatures at Stations J2, K2, and M3 are up to 4.8ºC cooler, showing the influence of mixing with cooler offshore Atlantic water. Over the 10-year period, Station A5 exhibited the warmest mean temperature while Station M3 was the coolest. The maximum temperature recorded was almost 27ºC at Station A5, while the coolest was 11ºC at station M3.

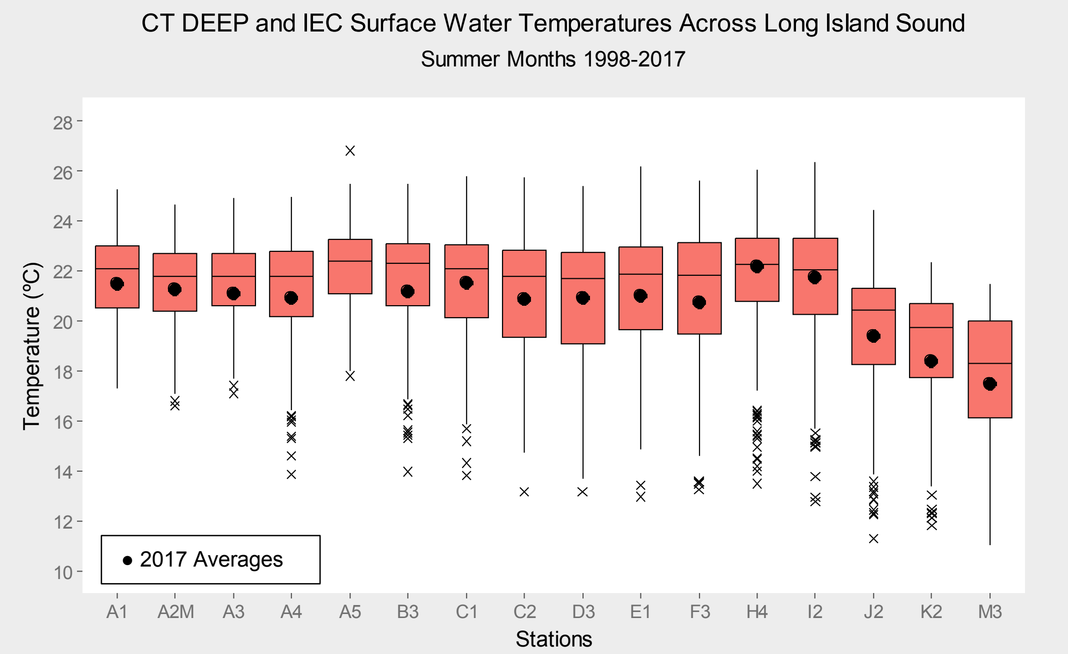


Figure 49

Average summer bottom water temperatures across the Sound are a bit more variable, but generally are warmer in the Western Sound and cooler in the Eastern Sound. The maximum bottom temperature was 24.6º at Station A1. The minimum bottom water temperature was 8.6 ºC at Station M3.

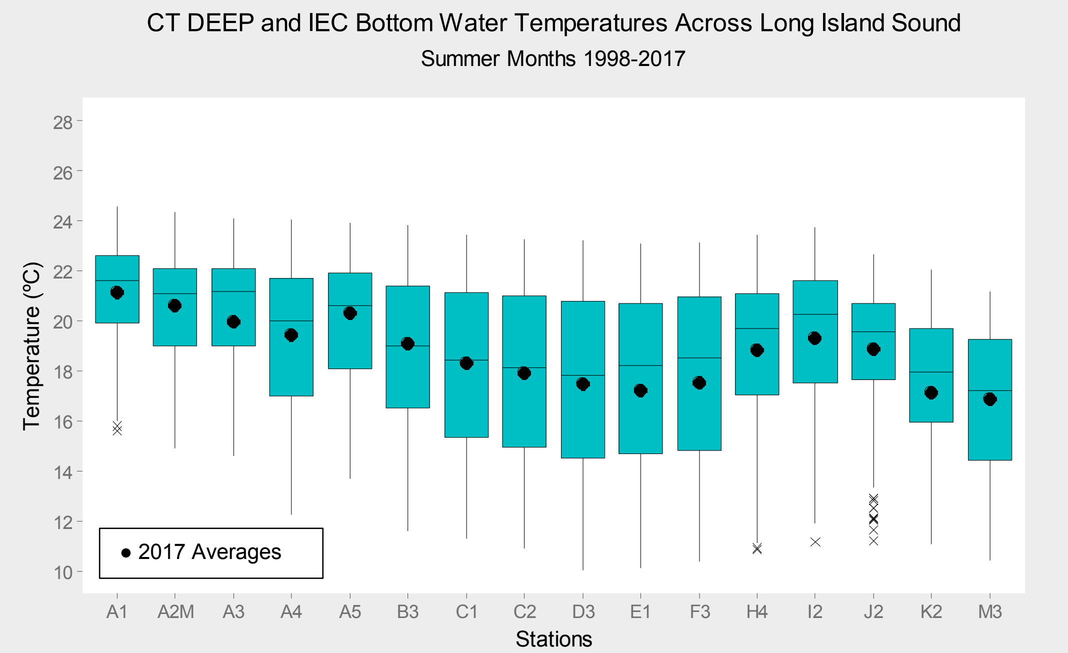


Figure 50

The average surface temperatures of Long Island Sound during the summer months were also examined in 5-year blocks. The average surface temperature of Long Island Sound between Western and Central Long Island Sound (Station A1 to I2) appears to have increased by about 1°C.

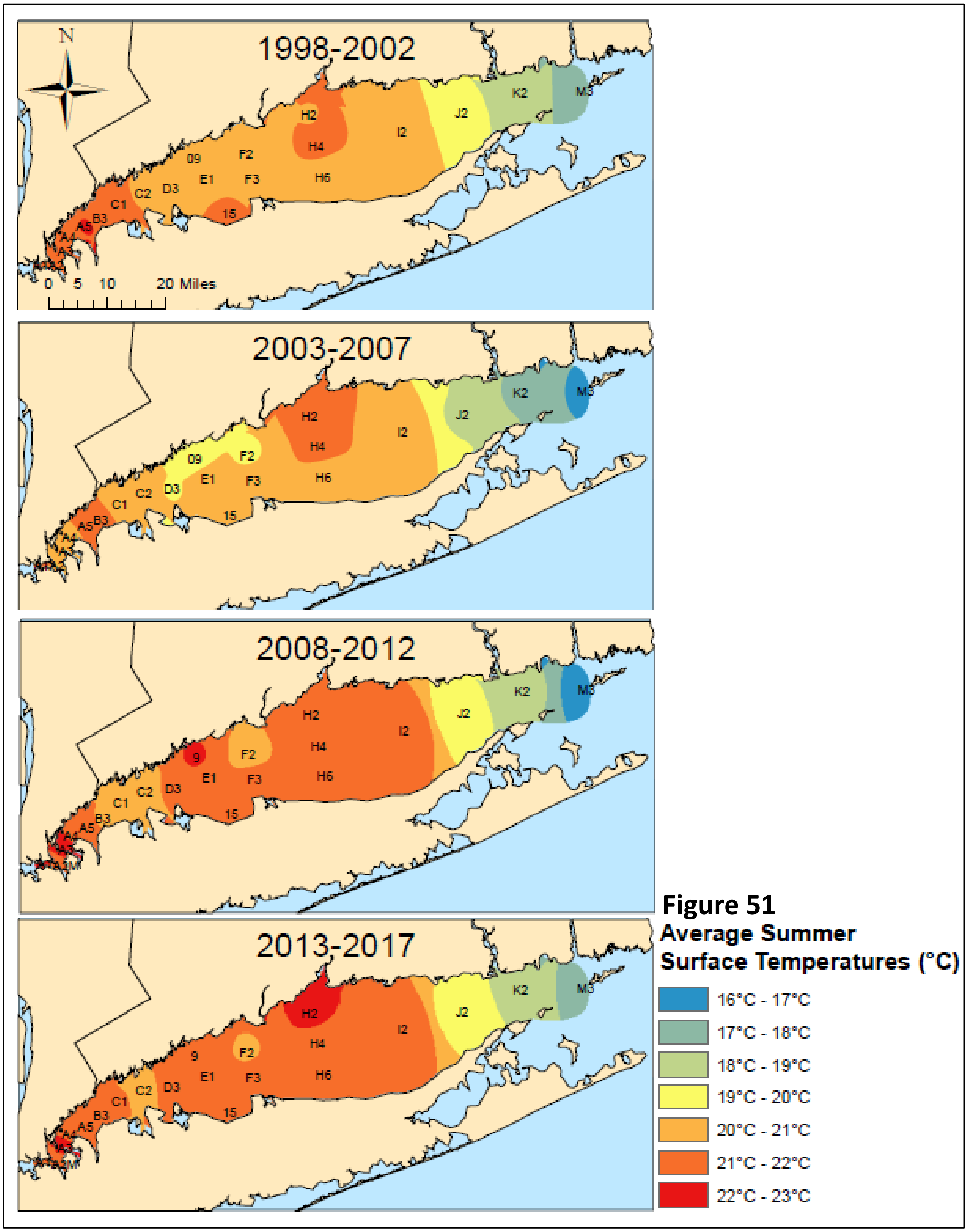
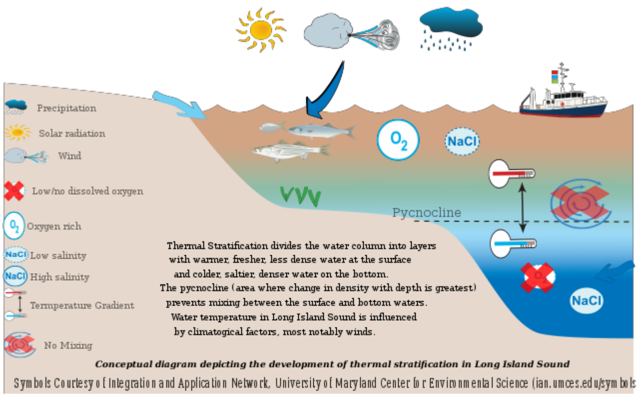


Figure 51
Average Summer Surface Temperatures (°C)

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.



Thermal Stratification divides the water column into layers with warmer, fresher, less dense water at the surface and colder, saltier, denser water on the bottom. The pycnocline (area where change in density with depth is greatest) prevents mixing between the surface and bottom waters. Water temperature in Long Island Sound is influenced by climatogical factors, most notably winds.

Conceptual diagram depicting the development of thermal stratification in Long Island Sound

Symbols Courtesy of Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols

Figure 52

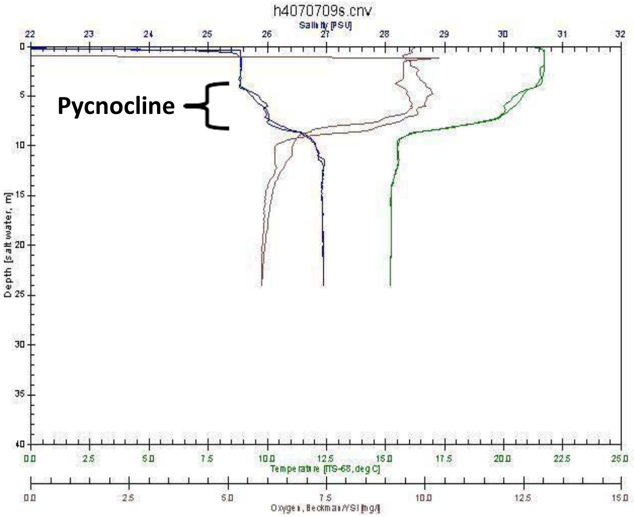


Figure 53

Figures 54-55 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.

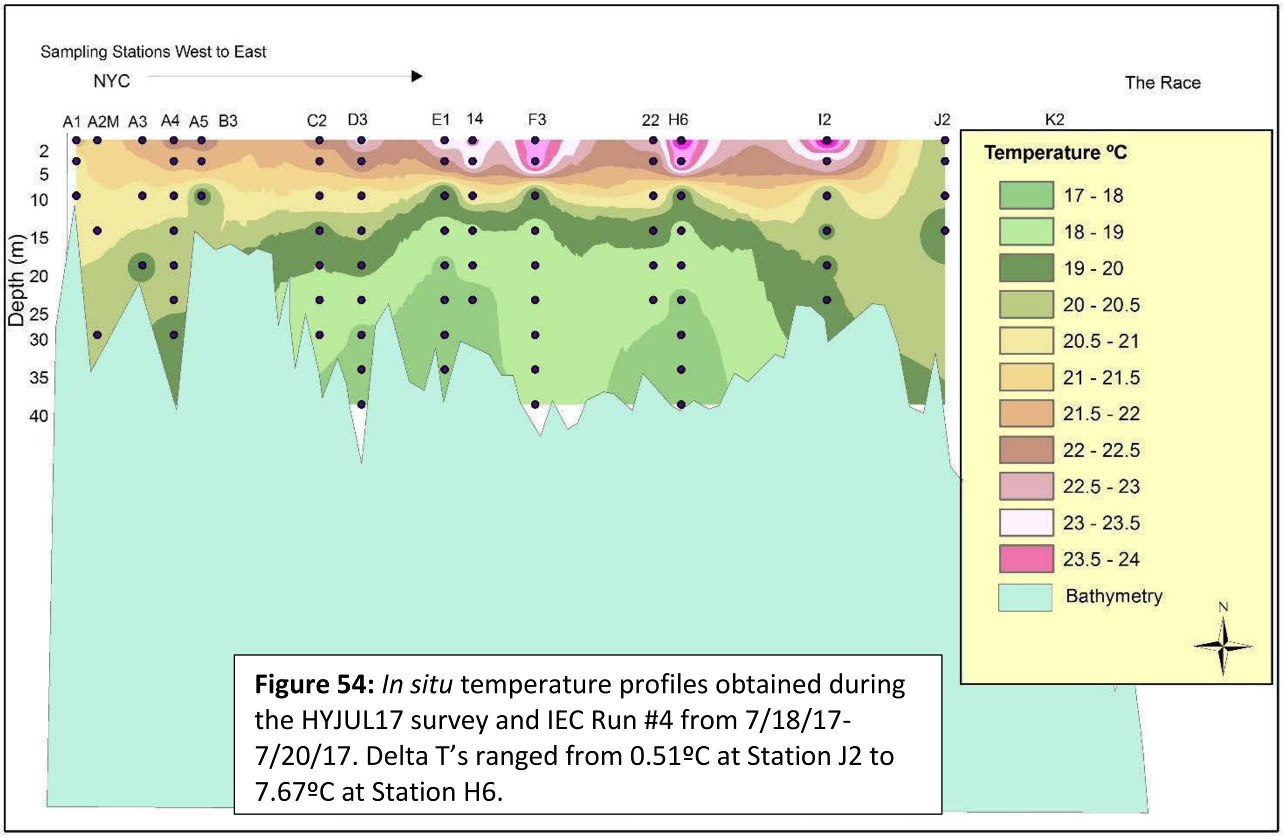


Figure 54: *In situ* temperature profiles obtained during the HYJUL17 survey and IEC Run #4 from 7/18/17-7/20/17. Delta T's ranged from 0.51ºC at Station J2 to 7.67ºC at Station H6.

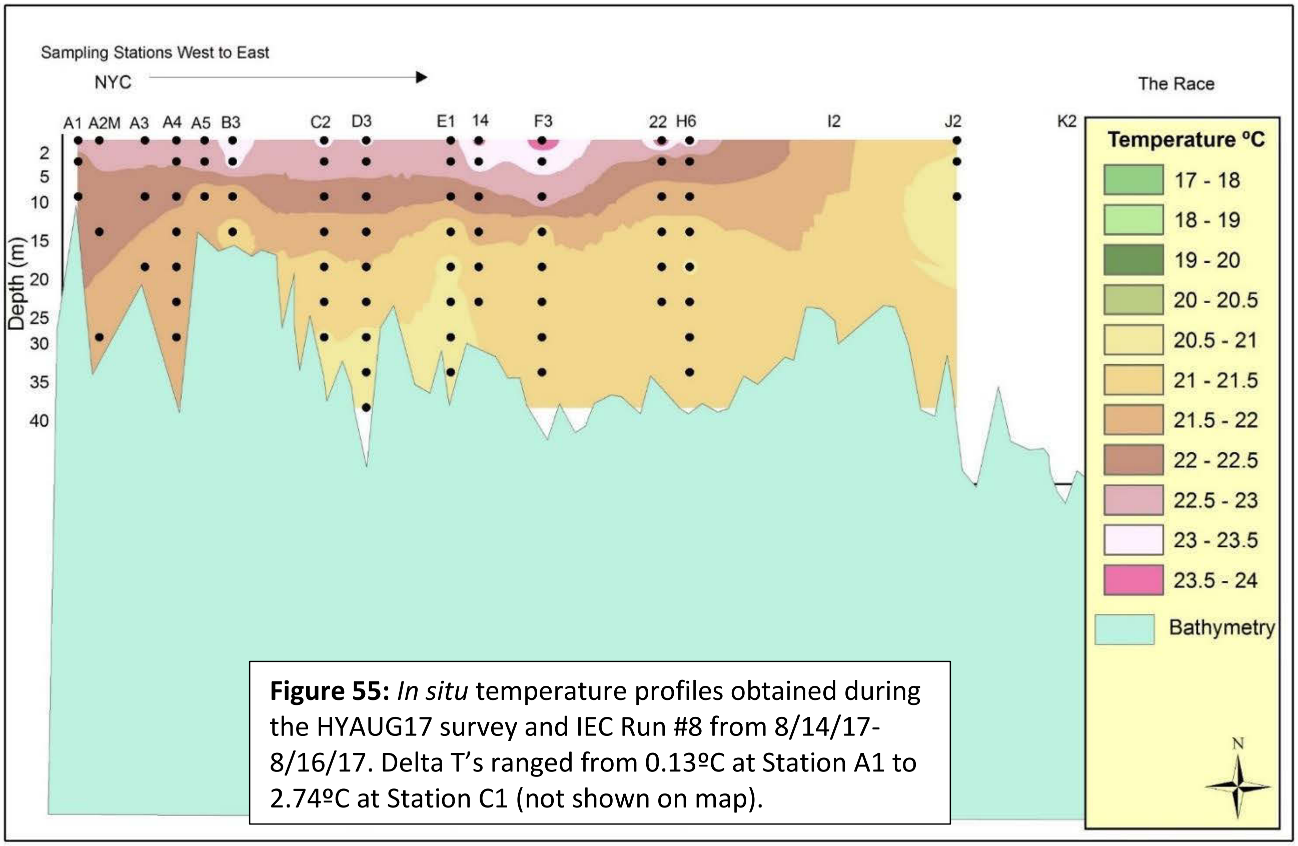


Figure 55: *In situ* temperature profiles obtained during the HYAUG17 survey and IEC Run #8 from 8/14/17-8/16/17. Delta T's ranged from 0.13ºC at Station A1 to 2.74ºC at Station C1 (not shown on map).

CTDEEP data collected between 1998 and 2017 are utilized to illustrate the seasonal warming cycle of the Sound. The water column is well mixed during January, February, and March. In April, the surface water temperature begins to warm at a greater rate than the bottom water, leading to the development of the pycnocline and setting up stratification. In later August/early September, meteorological events (e.g., storms) often result in the dissolution of the pycnocline and the return to a well-mixed estuary.

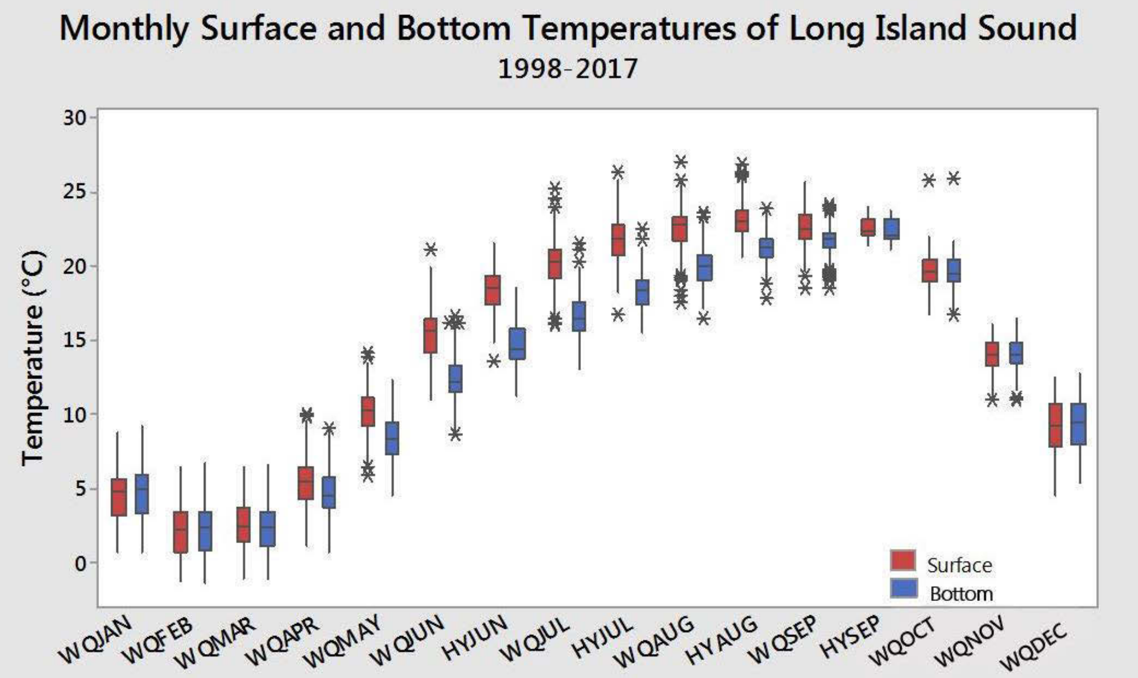


Figure 56

DEEP Did Not Conduct a HYSEP17 Survey

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. Stratification hinders the oxygenated surface waters from circulating downward and mixing with the oxygen starved bottom waters, exacerbating hypoxia. Salinity data collected by IEC and DEEP during the summer months are shown in Figure 57. The salinity (both surface and bottom) tends to drop from January until late June, then in early July the salinities start to increase again.

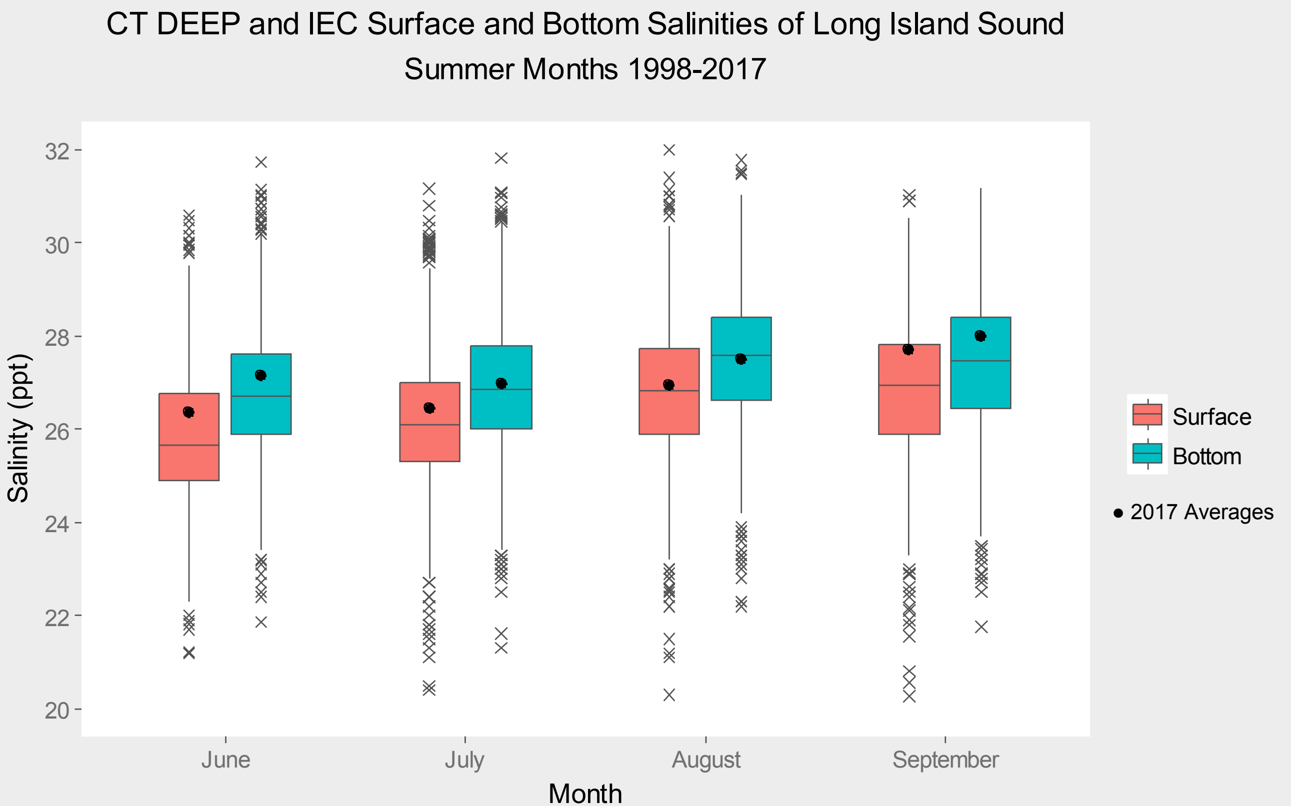


Figure 57

Salinity levels across Long Island Sound vary from 27 PSU in the Western Sound to 31 PSU in the Eastern Sound. The Thames, Connecticut, and Housatonic rivers are the major sources of freshwater entering the Sound.

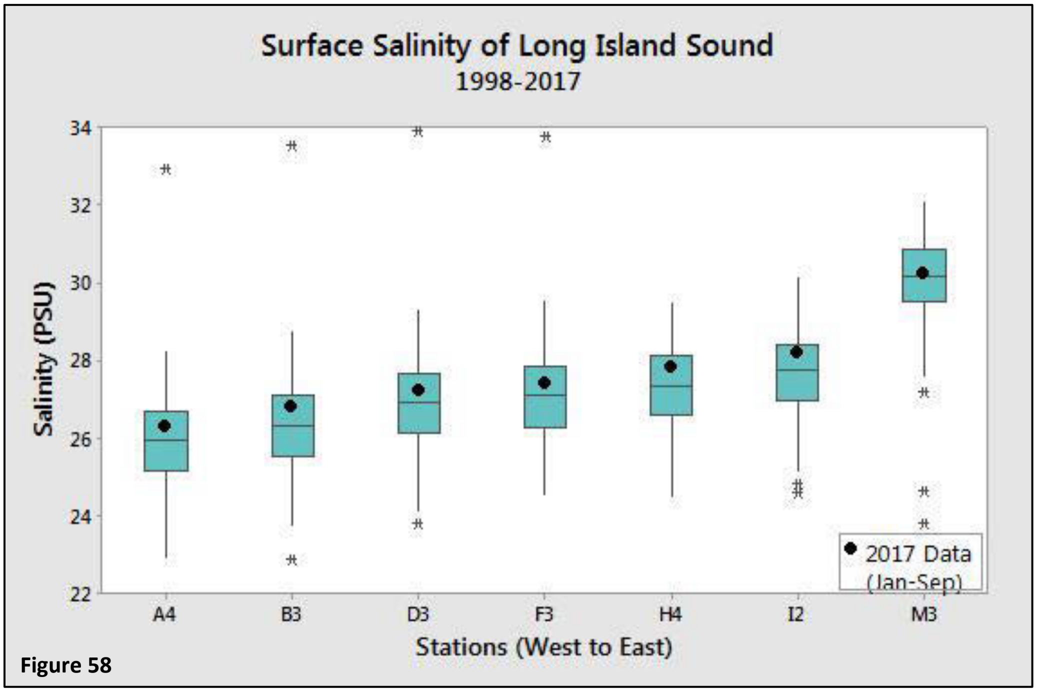


Figure 58

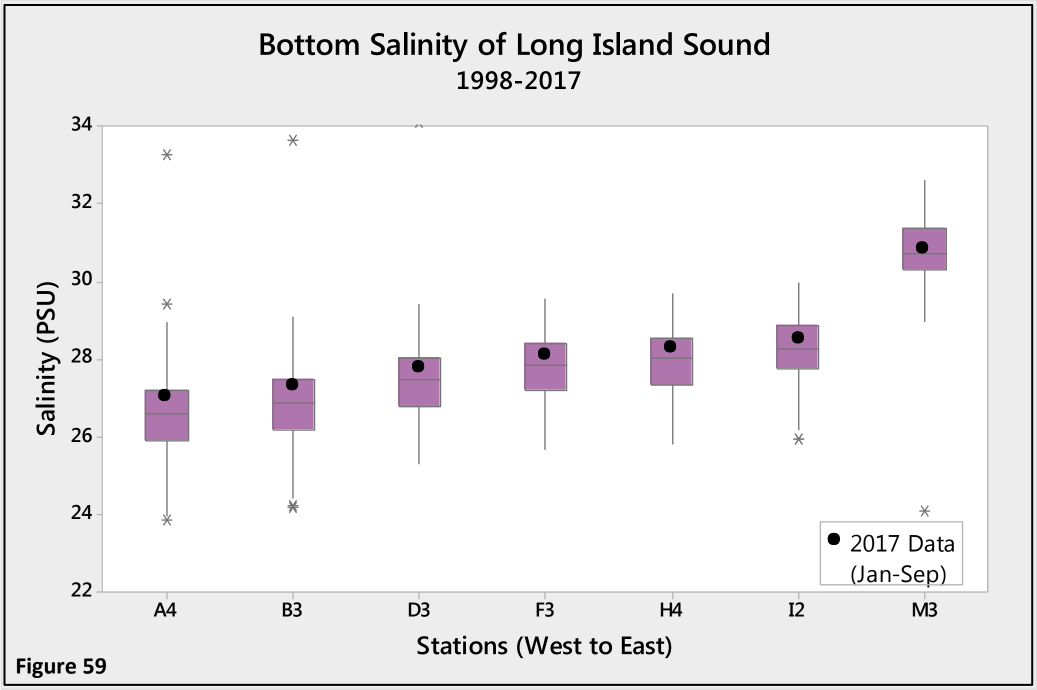


Figure 59

Figures 58 and 59 are based upon data collected during CT DEEP surveys from January 1998 – September 2017 and show the median surface salinity, range, interquartile range, and outliers by station. Surface in this case refers to data collected two meters below the air/water interface. Bottom in this case refers to data collected five meters above the sediment/water interface. The bottom waters are generally saltier than the surface waters. Salinity increases from west to east across the Sound.

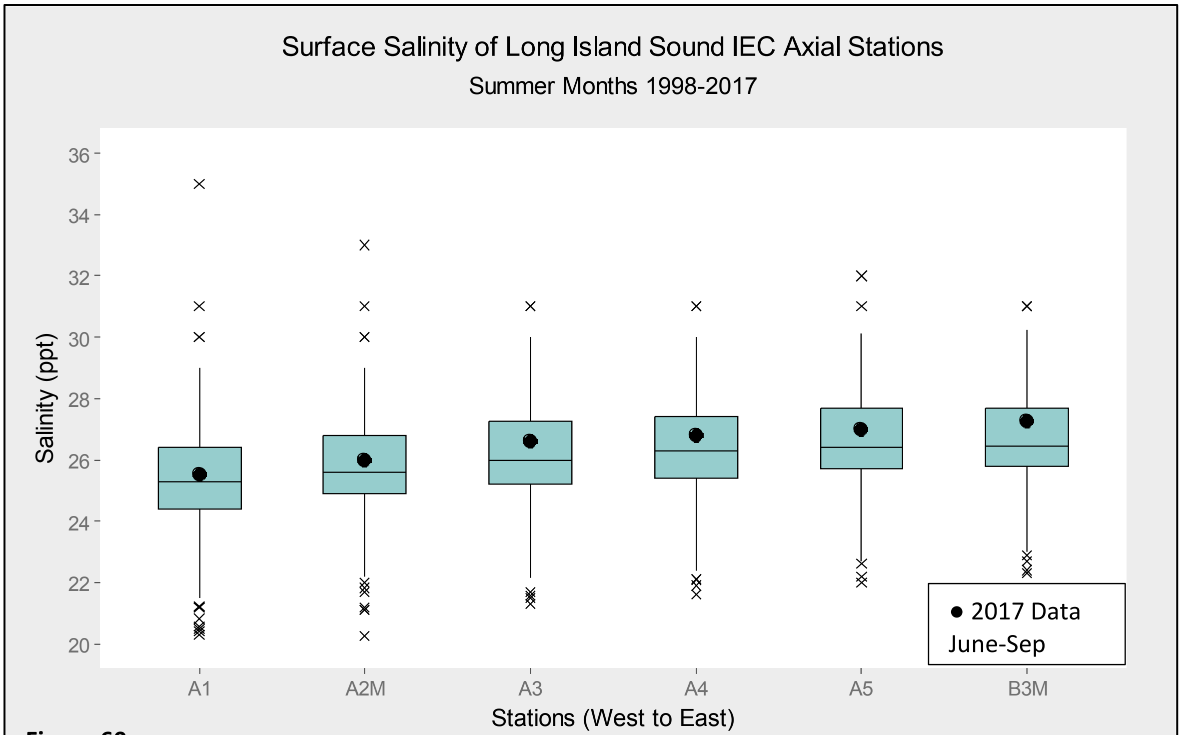


Figure 60

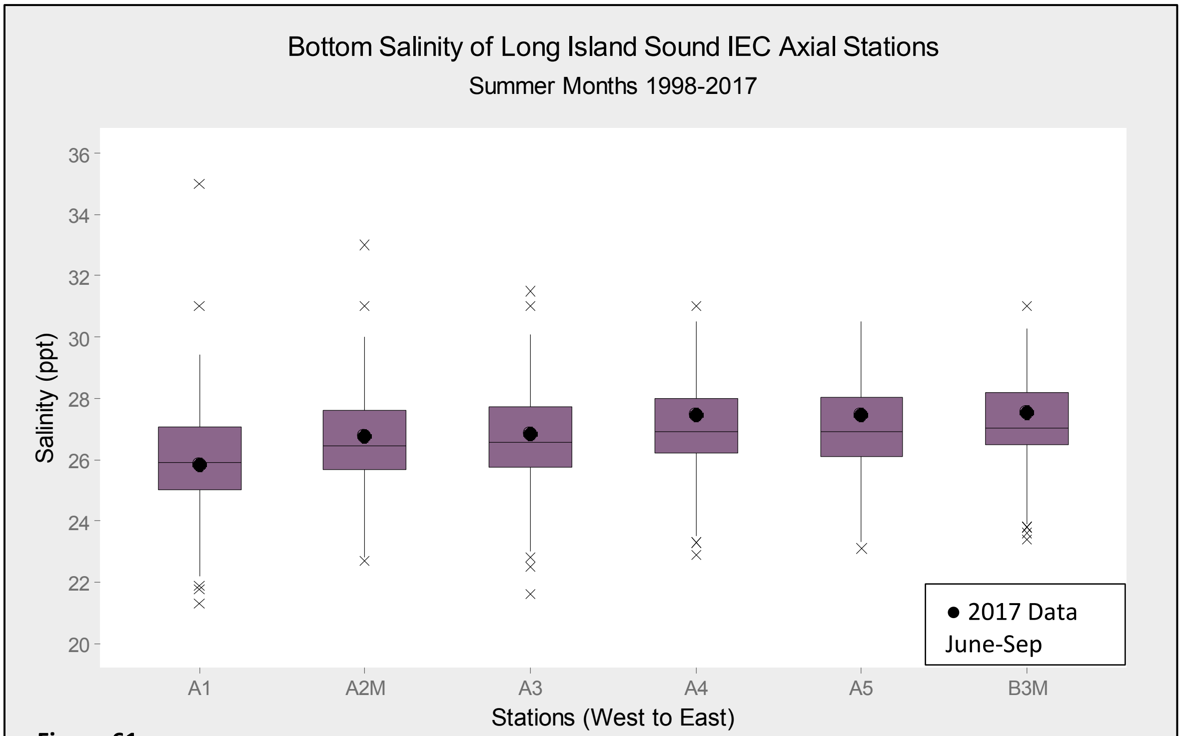


Figure 61

Figures 60 and 61 are based on data collected during IEC surveys from June – September between 1997 and 2017 and show the median surface salinity, range, interquartile range, and outliers by station. Surface in this case refers to data collected 0.5 meters below the air/water interface. Bottom in this case refers to data collected 0.5-1 meters above the sediment/water interface.

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 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.

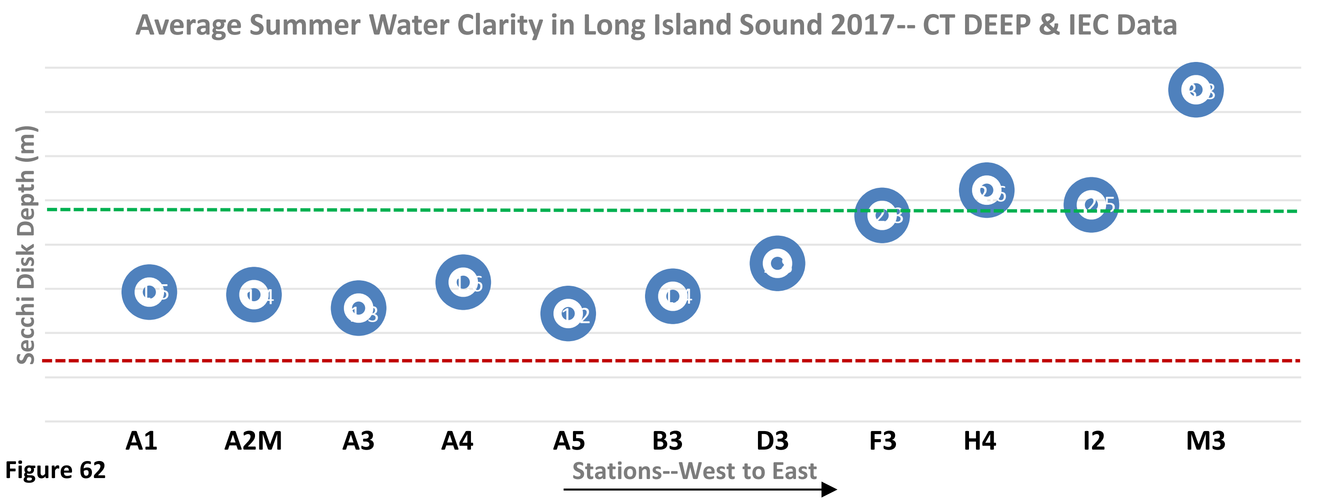
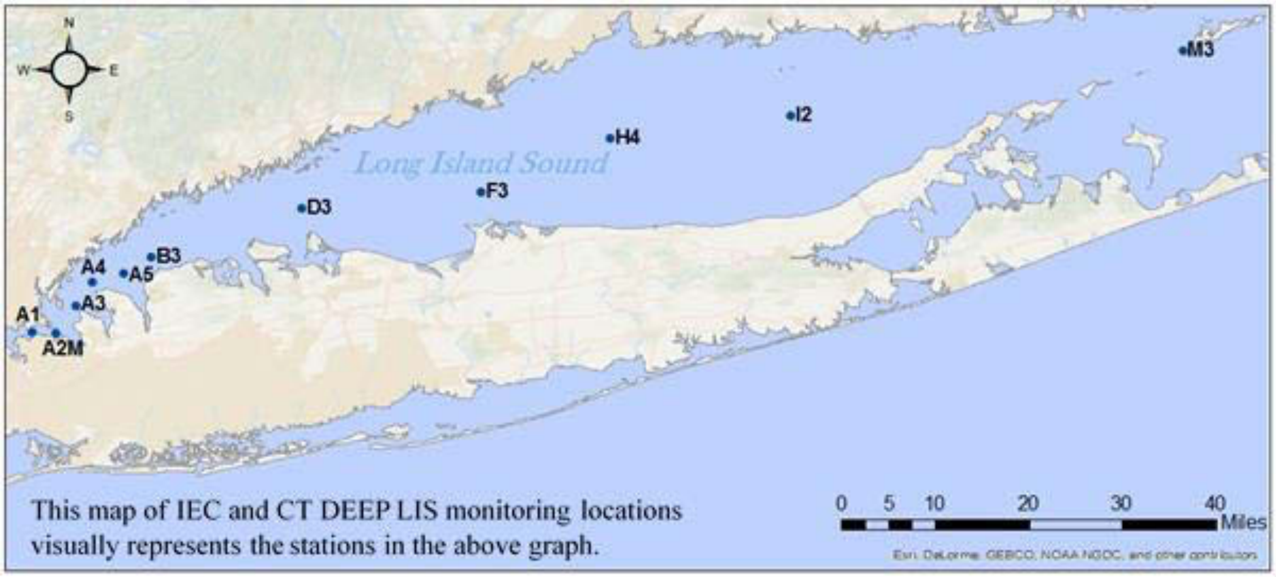
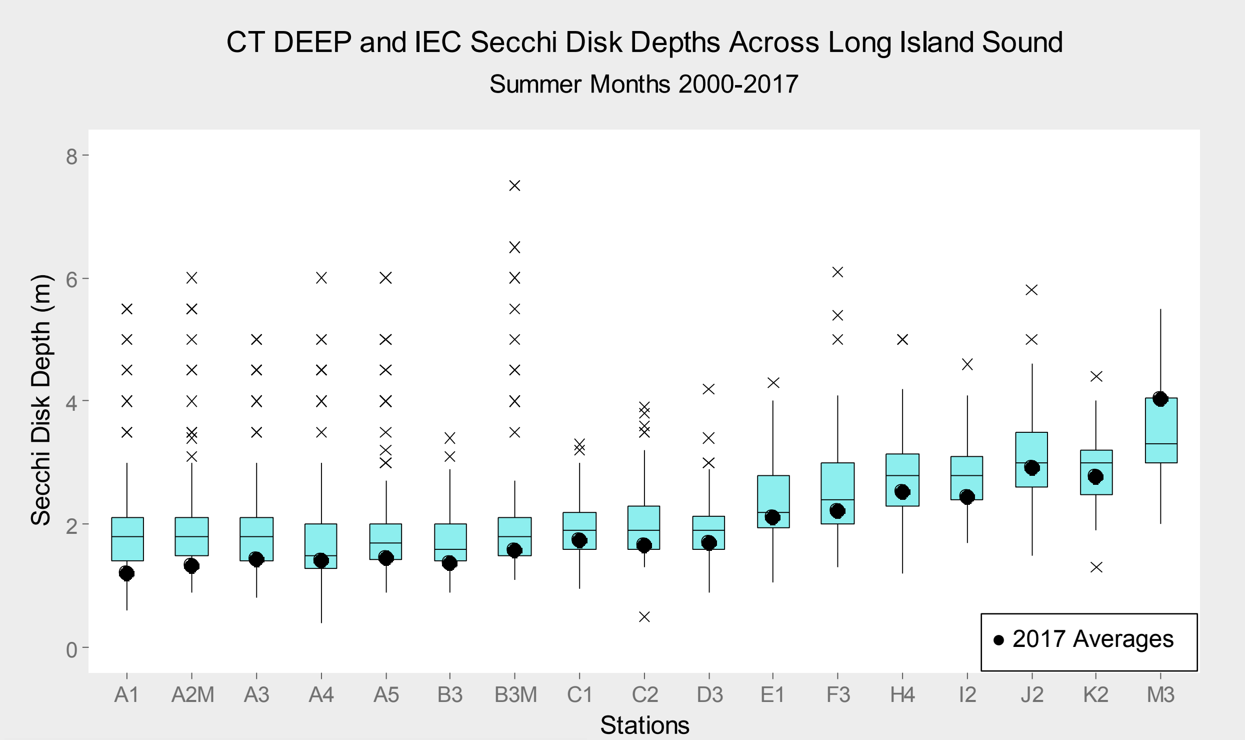


Figure 62



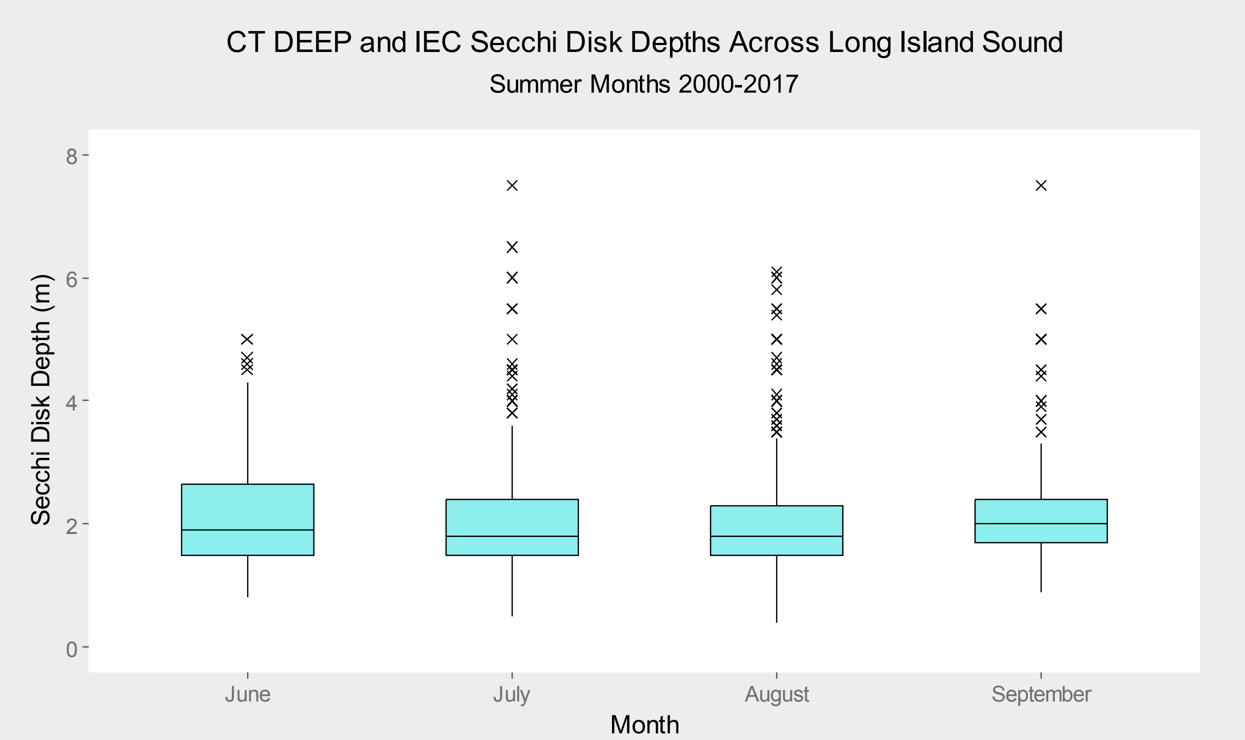
This map of IEC and CT DEEP LIS monitoring locations visually represents the stations in the above graph.

Figure 63



CT DEEP began collecting Secchi disk data in 2000

Figure 64



CT DEEP began collecting Secchi disk data in 2000

Figure 65

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/).

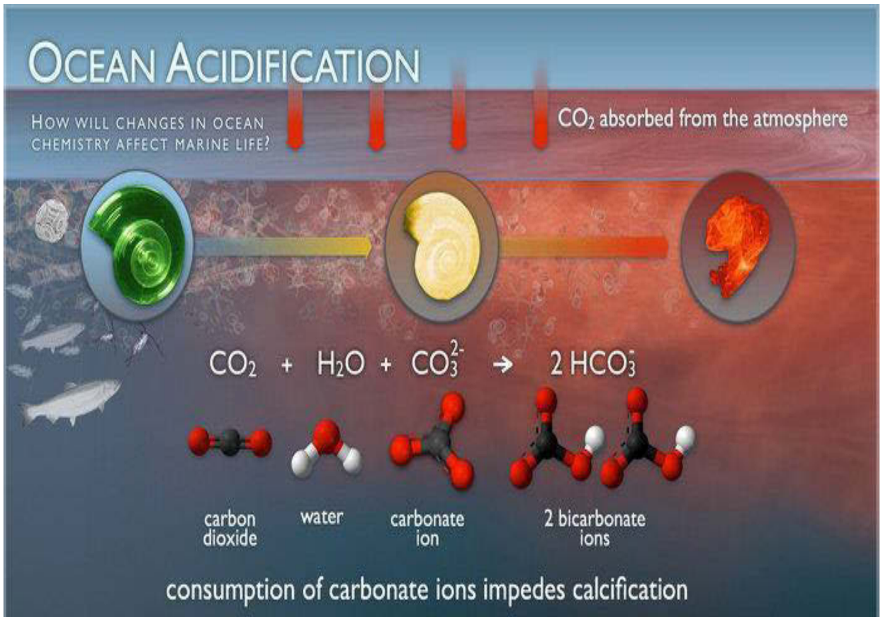
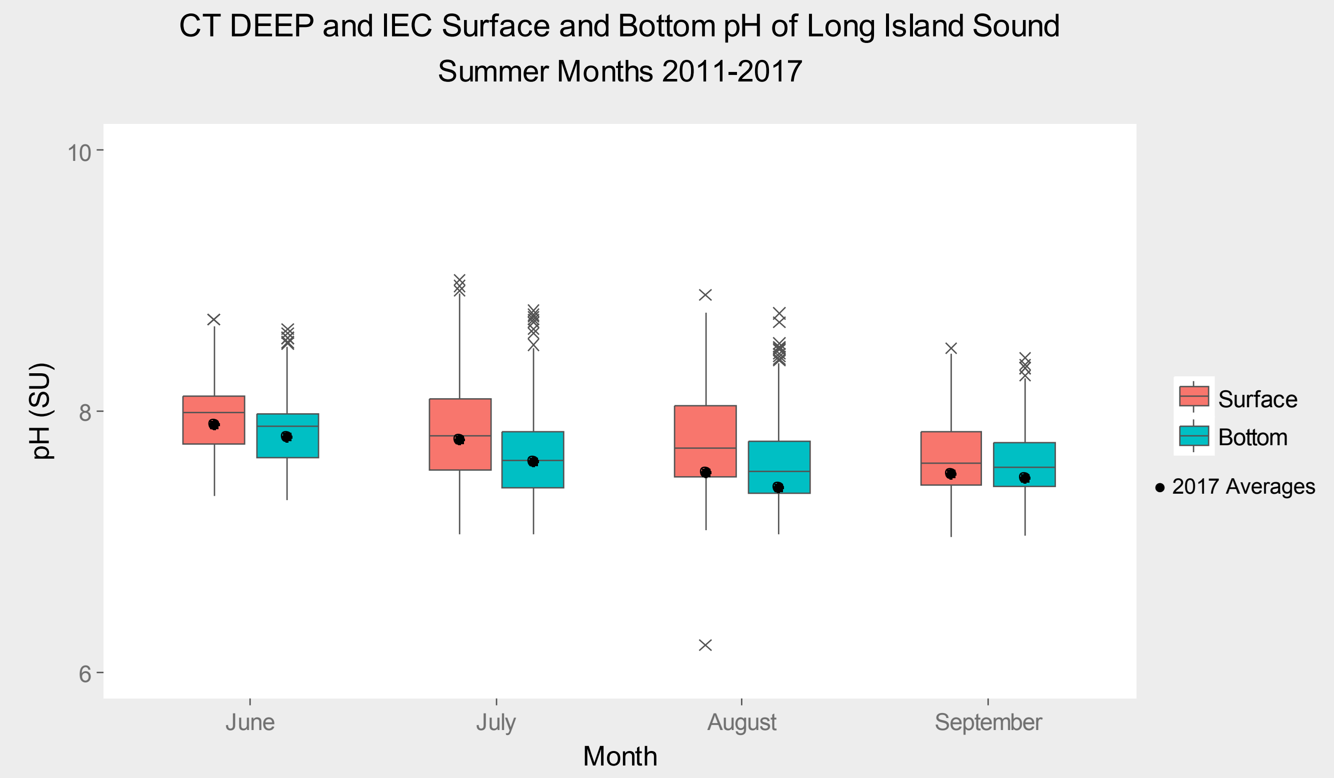


Figure 66: Source http://www.pmel.noaa.gov/co2/story/Ocean+Acidification

Ocean acidification is further complicated by excessive nutrient loading (eutrophication) and wastewater outputs. While eutrophication of coastal zones has contributed to the spatial increase of hypoxic zones, it has also driven the increase of microbial degradation of organic matter and the consequent production of CO2.

In Long Island Sound eutrophication can lead to coastal acidification (Wallace et. al., 2014). Excess nutrients fuel algae and phytoplankton growth. As the phytoplankton die and decay, carbon dioxide is released. This release has the same effect on pH as carbon dioxide from atmospheric deposition (NECAN undated). The Northeast Coastal Acidification Network website (NECAN undated) is a great resource for information and research on Coastal Acidification. EPA is still developing guidelines for measuring changes in pH and carbonate chemistry in eastern coastal waters. Two of four major directly measurable parameters are needed to describe the seawater carbonate system- pCO_2, DIC, alkalinity, and pH, along with temperature and salinity measurements. As of 2017, CT DEEP and IEC only collect one of the four needed parameters - pH.

Data from the 2011-2017 monitoring seasons, depicted in Figure 67, 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 67

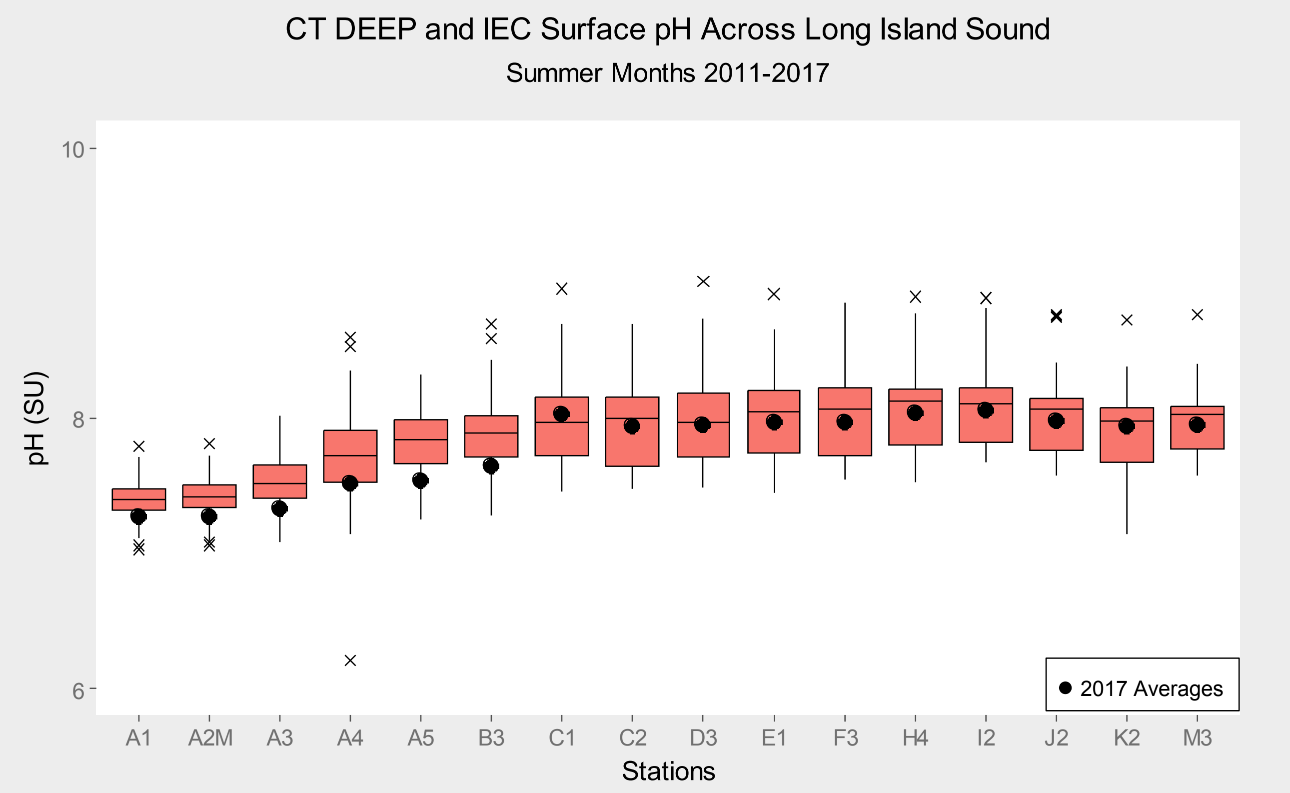


Figure 68

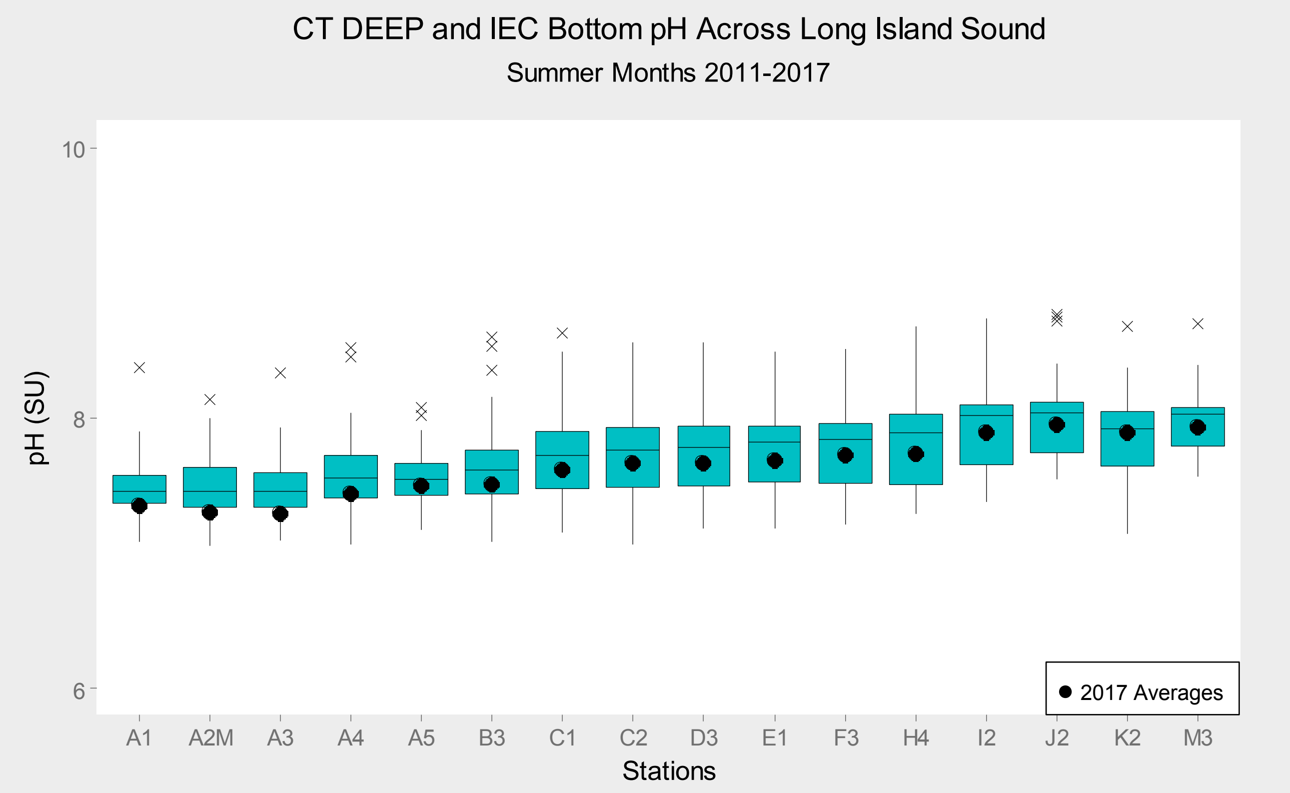


Figure 69

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.

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.

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.

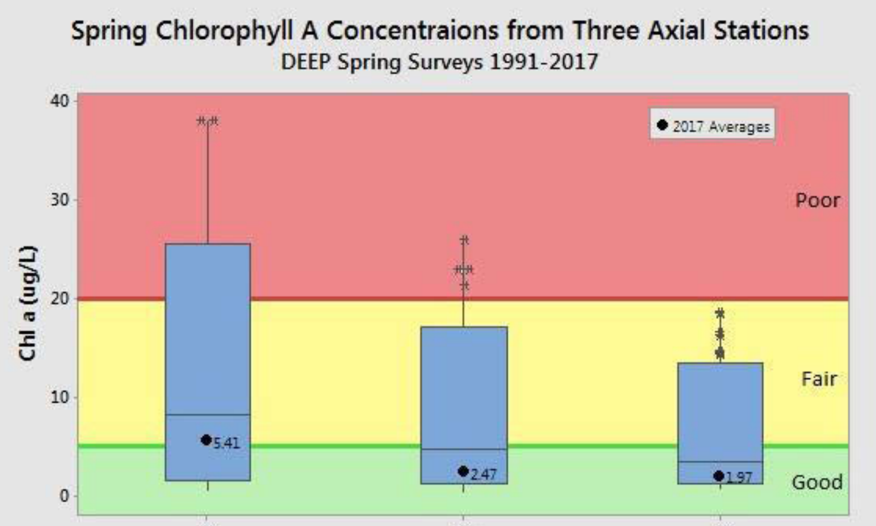


Figure 70
No Feb-Mar 2012 or 2013 Data Due to a Calibration Error

Figure 70 examines spring (February-April) surface chlorophyll-a data from three stations (B3, D3, and F3) in the Western/central portion of LIS from 1991 to 2017. Data from February, March, and April 2012 and 2013 are not included due to a lab calibration error.

At stations D3 and F3, 90% of the individual data are less than 20 ug/L and 75% of the data at B3 are less than 20 ug/L. This would place these stations in the fair category. The average concentration at each station is less than 20 ug/L but about or above 5 ug/L.

	n	Min	th 10 %	th 25 %	Median	th 75 %	th 90	Maximum	Mean	St Dev
B	8	0.33	1.52	3.43	8.100	15.75	25.45	38.00	10.61	8.91
D	8	0.26	1.18	2.37	4.60	17.04	9.60	26.00	6.76	6.21
F	7	0.50	1.10	1.50	3.40	6.00	13.44	18.60	4.85	4.51

Figure 71 examines recent DEEP spring chl a data by survey.

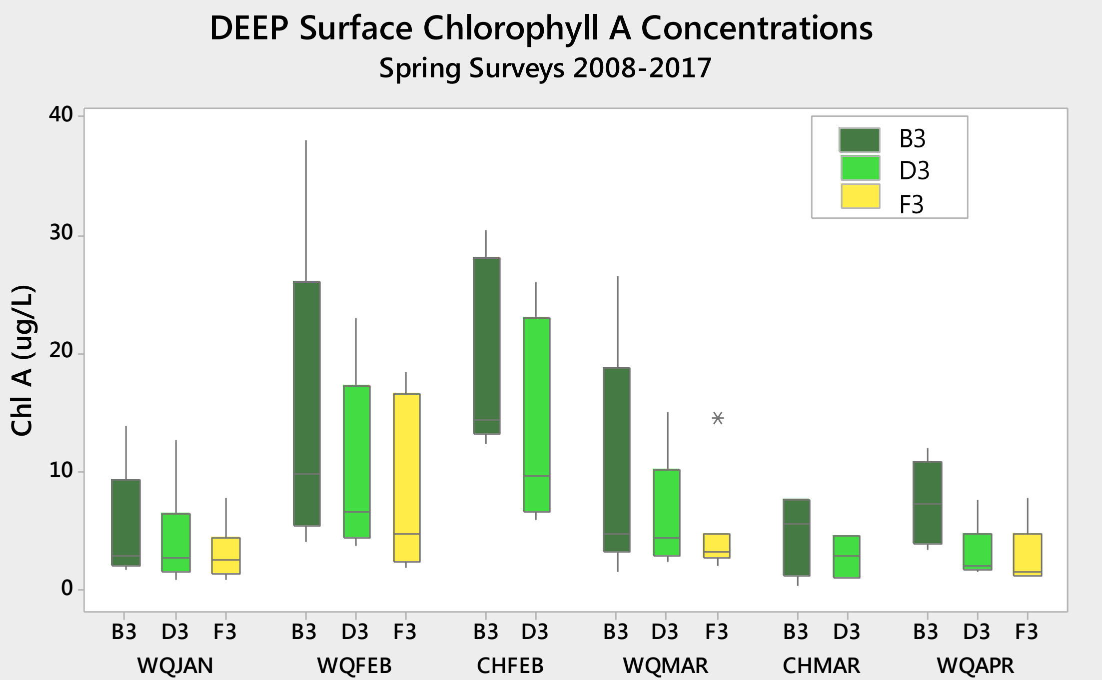


Figure 71
No Feb-Mar 2012 or 2013 Data Due to a Calibration Error

Figures 72 and 73 depict the temporal and spatial distribution of CT DEEP chlorophyll-a values from 2008-2017 in Long Island sound.

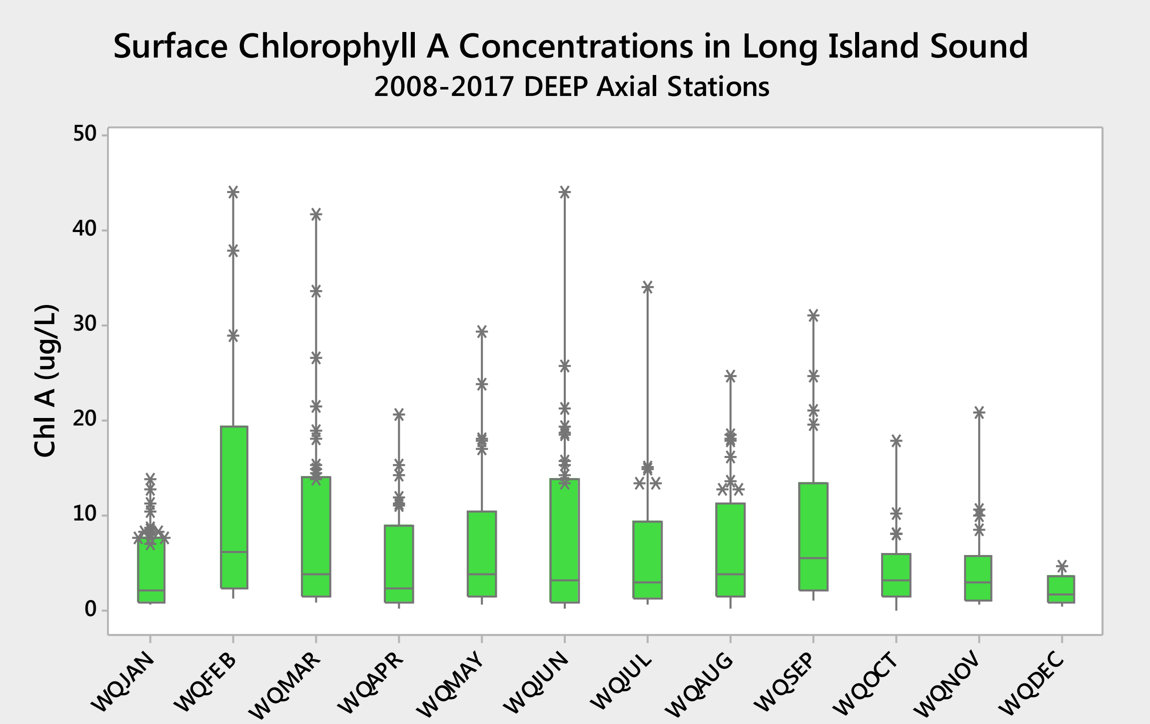

Surface Chlorophyll A Concentrations in Long Island Sound
2008-2017 DEEP Axial Stations

Figure 72

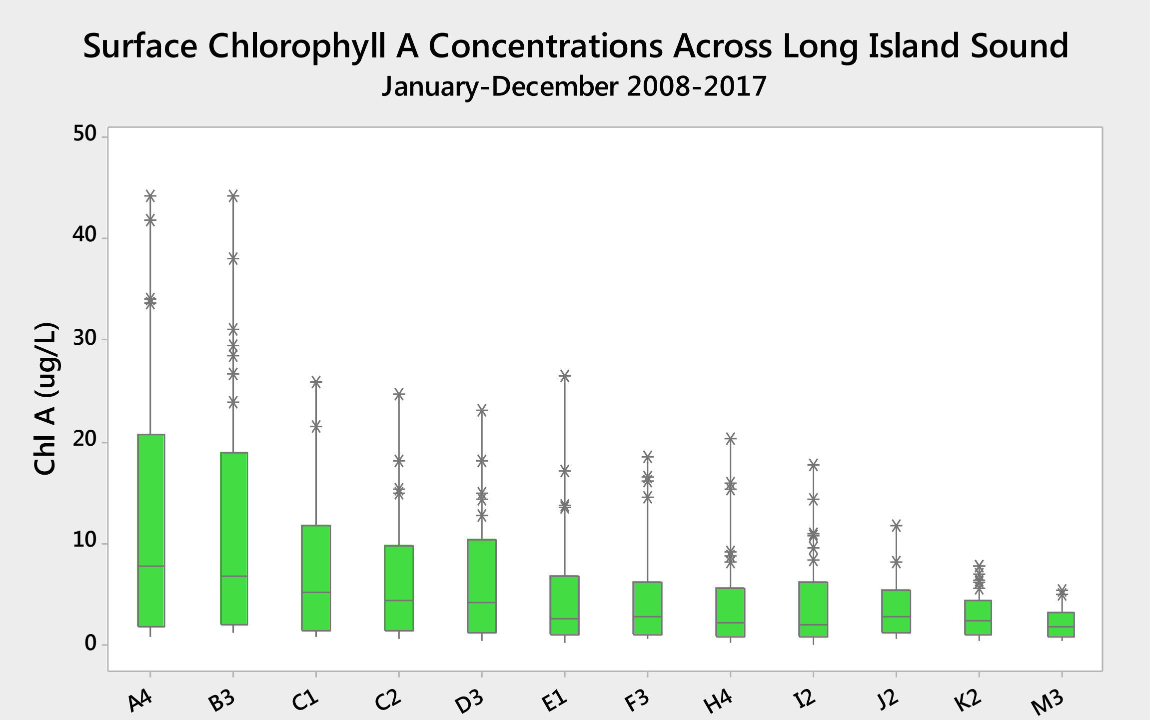

Surface Chlorophyll A Concentrations Across Long Island Sound
January-December 2008-2017

Figure 73

Figures 74 and 75 depict combined CT DEEP and IEC 2017 surface summertime chlorophyll a data.

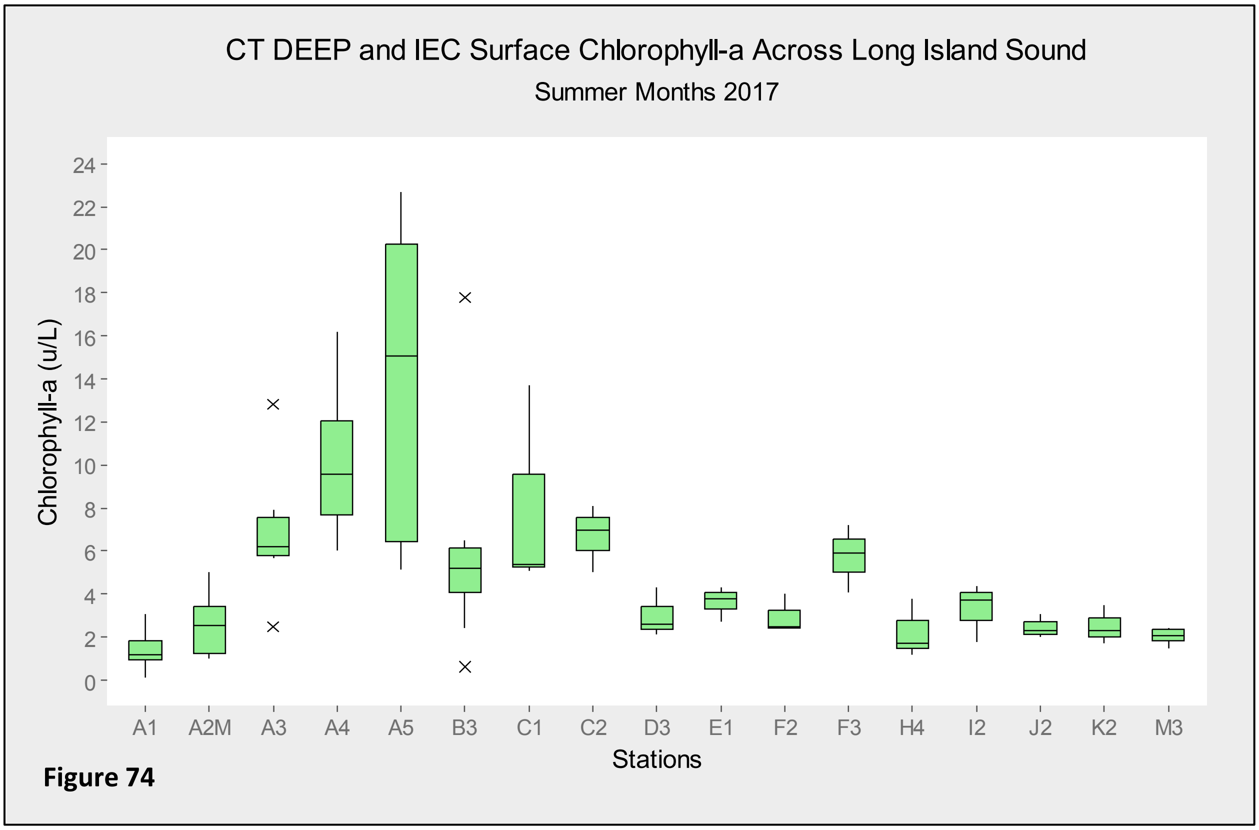


Figure 74

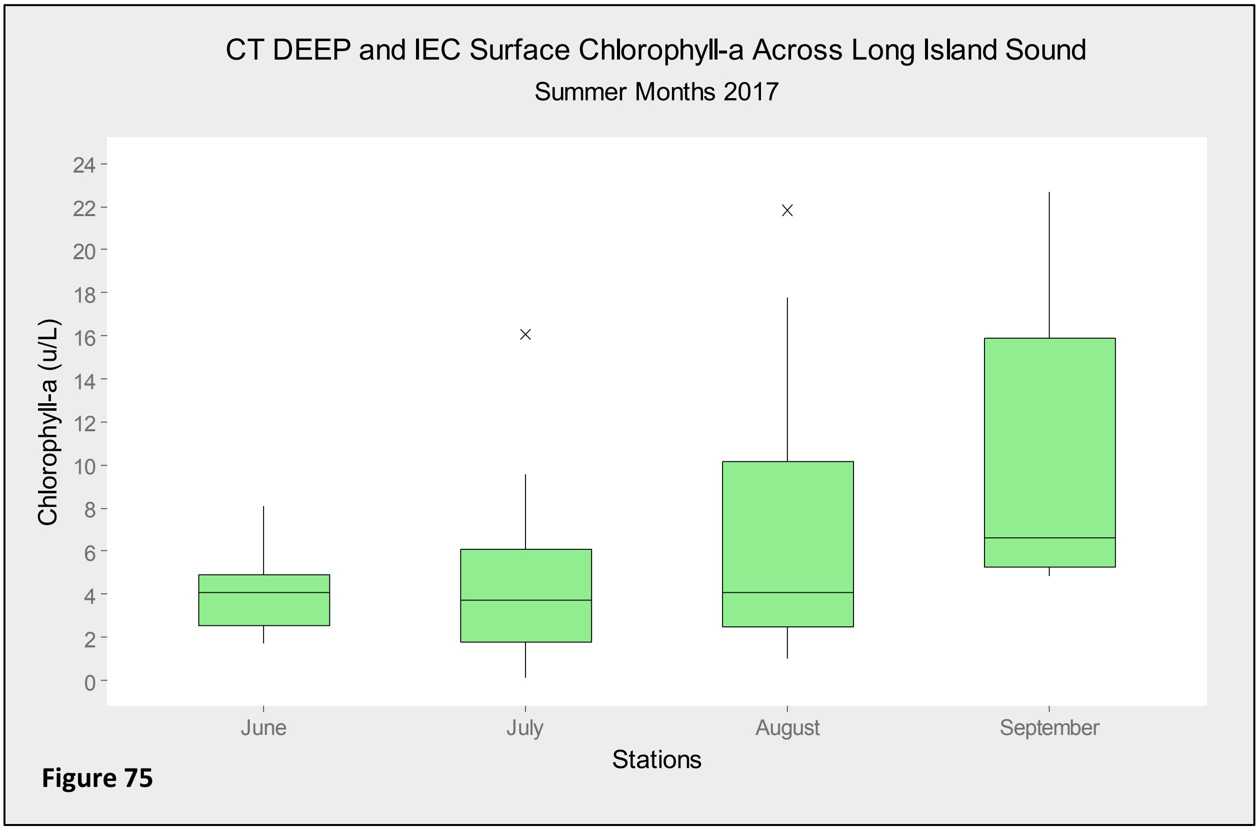


Figure 75

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Appendix A- IEC Embayment Monitoring

As a part of its ambient water quality monitoring program IEC has been monitoring three seven stations located in embayments located in the far western long Island sound. These stations are located in Little Neck Bay, Manhasset Bay, and Hempstead Harbor. Monitoring water quality in these embayments is important given the frequency and severity of hypoxia these locations exhibit. Figure # shows embayment locations and sampling stations.

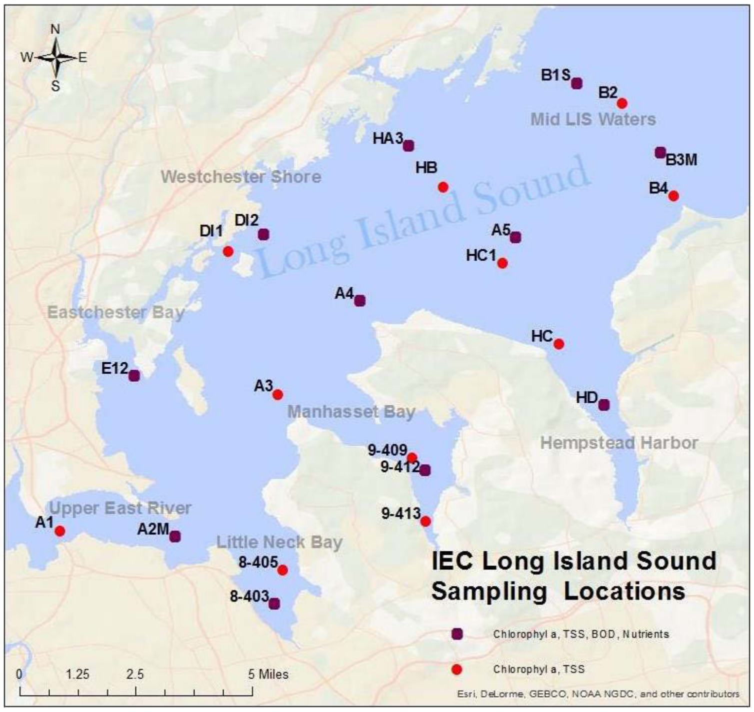

Figure 76 is based on data collected during IEC surveys from June – September between 1997 and 2017 and show the median surface and bottom DO, range, interquartile range, and outliers by station. Surface in this case refers to data collected 0.5 meters below the air/water interface. Bottom in this case refers to data collected 0.5-1 meters above the sediment/water interface.

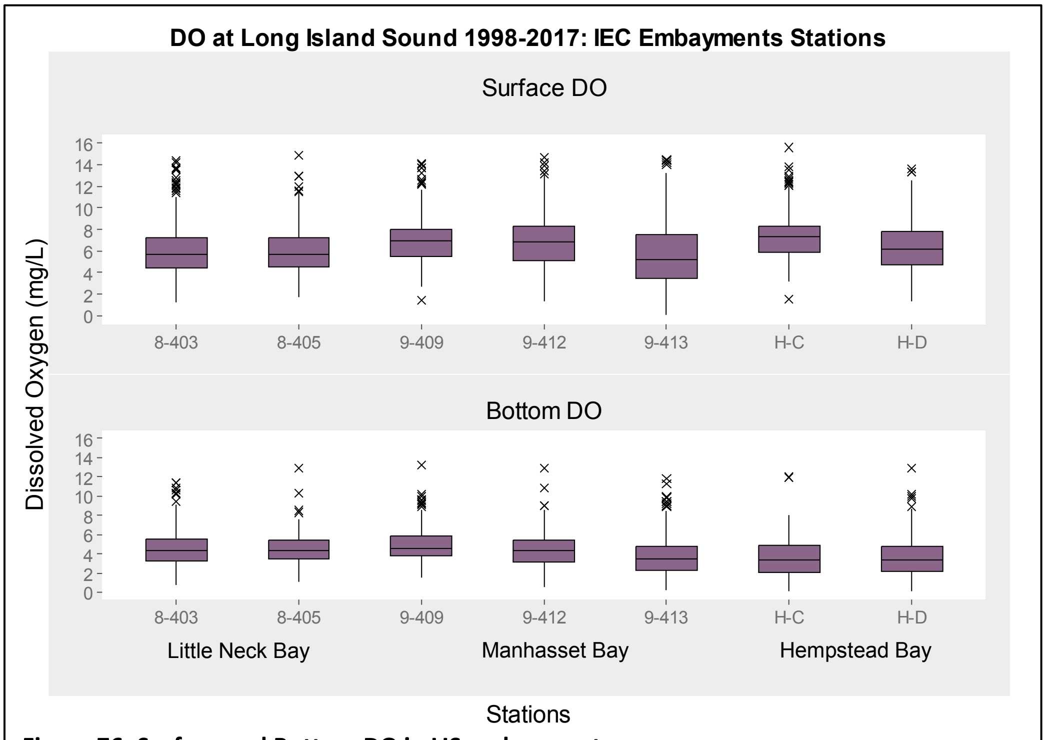

Figure 76: Surface and Bottom DO in LIS embayments

Figure 77 is based on data collected during IEC surveys from June – September between 1997 and 2017 and shows the median surface and bottom water temperature, range, interquartile range, and outliers by month. The range depicted in figure 48 is noticeably different indicating that embayment water temperatures differ from axial water temperatures.

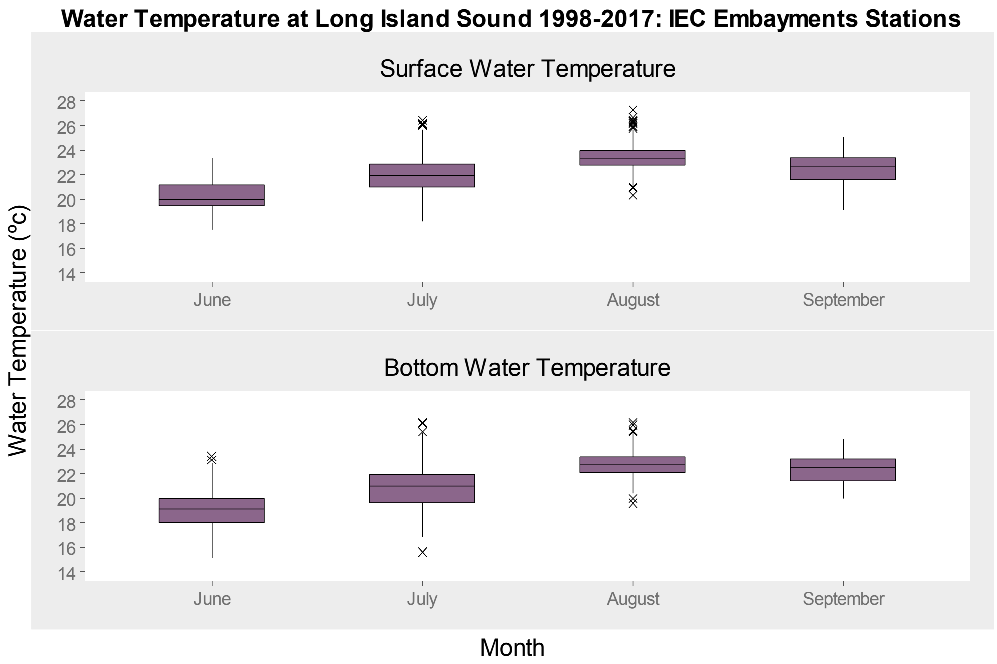

Figure 77: Surface and Bottom WT in LIS embayments

Figure 78 depicts the median surface and bottom salinity, range, interquartile range, and outliers by month.

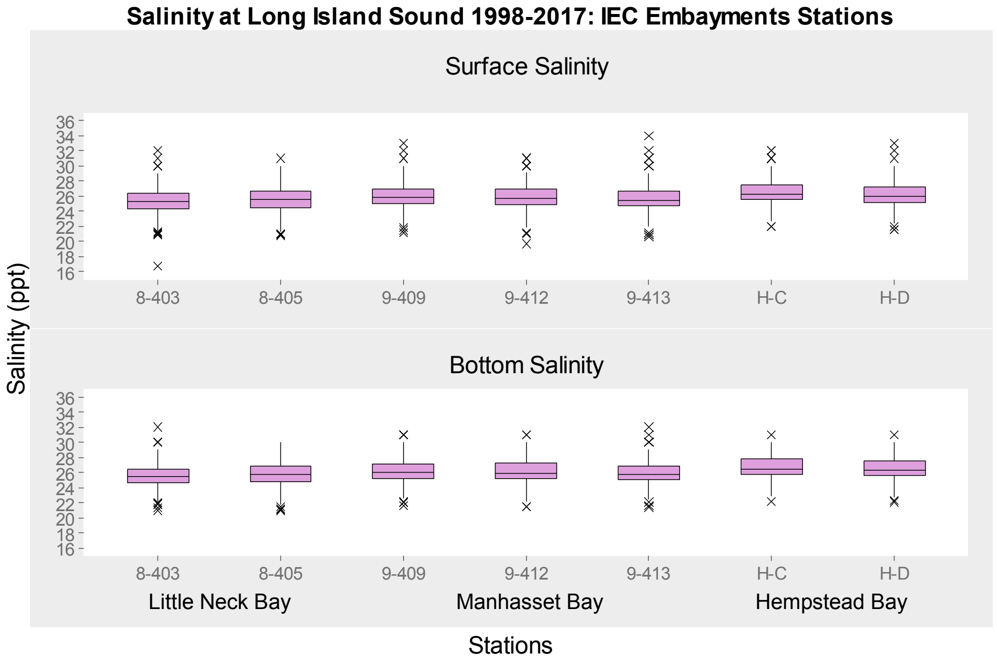

Figure 78: Surface and Bottom Salinity in LIS embayments

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

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