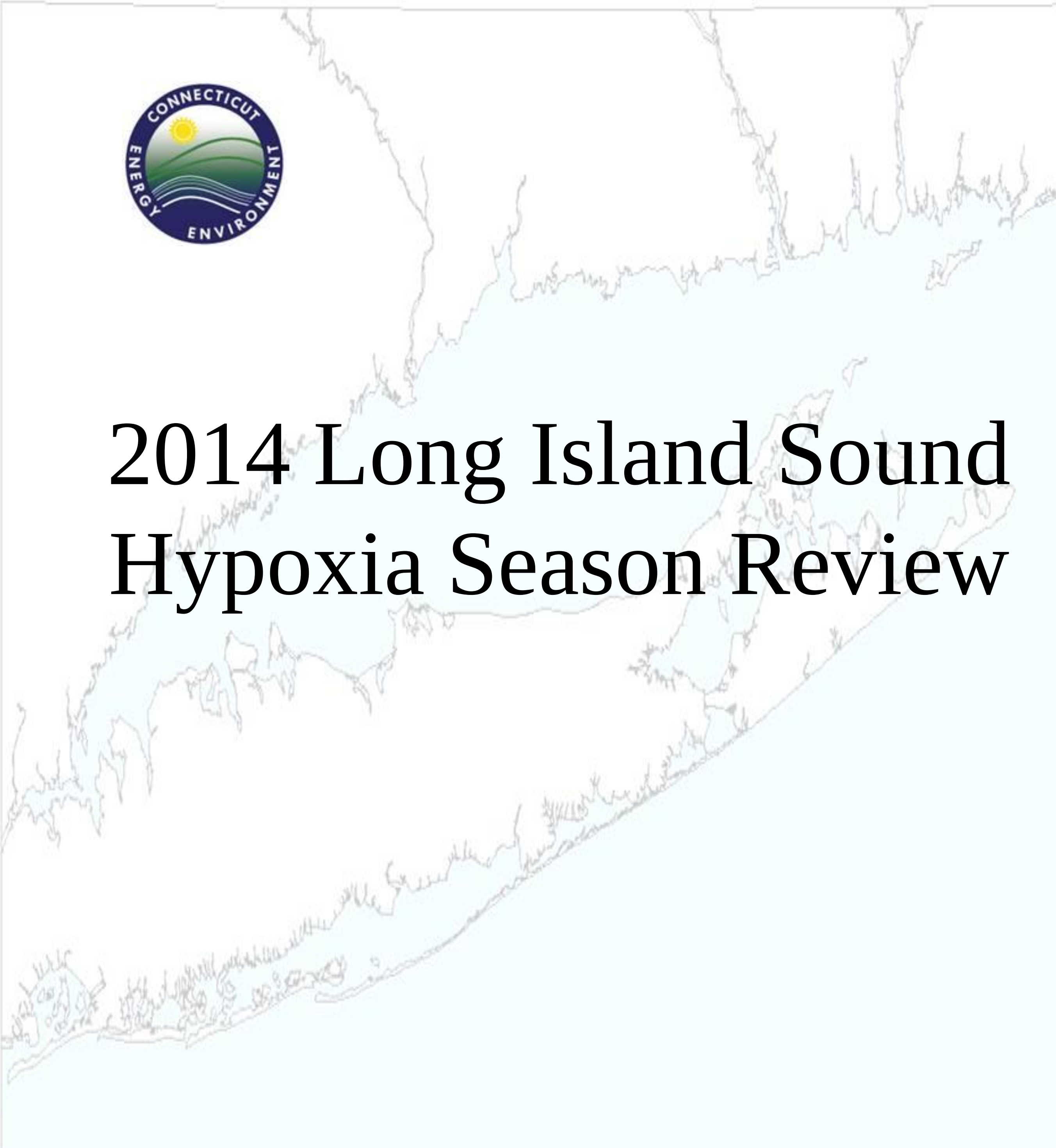


2014 Long Island Sound Hypoxia Season Review

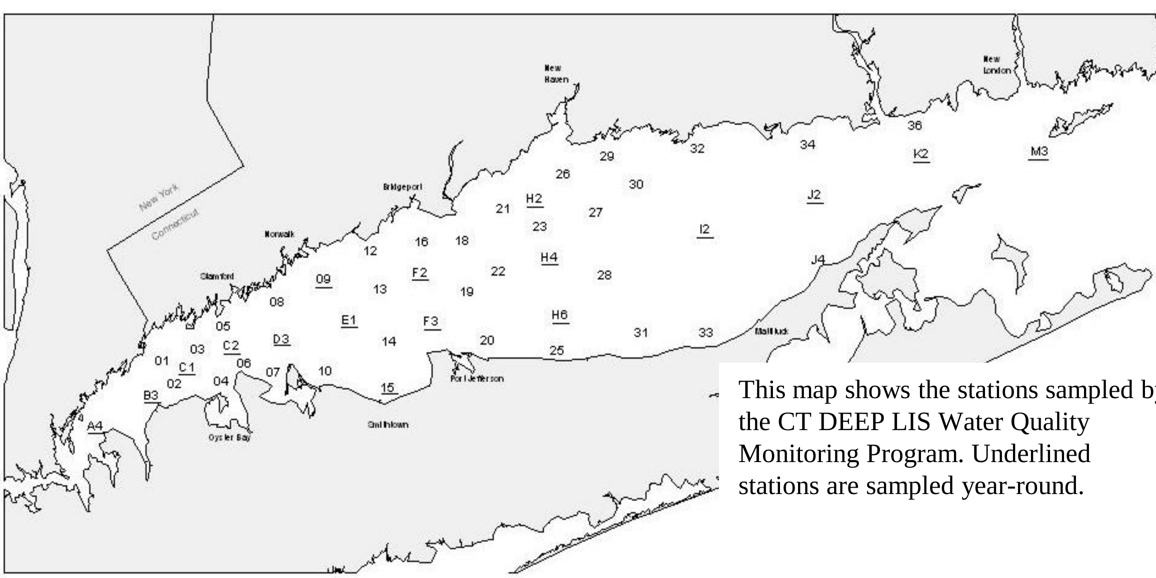
CONNECTICUT DEPARTMENT OF ENERGY & ENVIRONMENTAL PROTECTION
79 ELM STREET, HARTFORD, CT 06106
ROBERT J. KLEE, COMMISSIONER

MONITORING LONG ISLAND SOUND 2014

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.

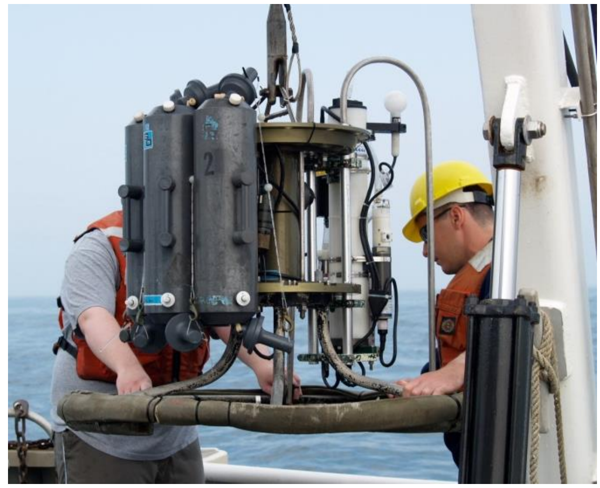
R/V John Dempsey



This map shows the stations sampled by the CT DEEP LIS Water Quality Monitoring Program. Underlined stations are sampled year-round.

Methods

Dissolved oxygen, temperature, pH, and salinity data are collected *in situ* using an electronic instrument called a 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.



Water samples are collected using Niskin water sampling bottles that are attached to the Rosette Sampler. The Rosette is lowered off the stern of the *Dempsey* and the bottles are triggered remotely to take a water sample at any depth. Parameters for which surface and bottom waters are tested include dissolved silica, particulate silica, particulate carbon, dissolved organic carbon, dissolved nitrogen, particulate nitrogen, ammonia, nitrate + nitrite, particulate phosphorus, total dissolved phosphorus, orthophosphate, chlorophyll *a*, and total suspended solids.

Samples are filtered aboard the mini laboratory and preserved for later analyses at the Center for Environmental Science and Engineering at the University of Connecticut. From October to May, *in situ* and nutrient samples are collected once a month from 17 sites. Bi-weekly hypoxia surveys start in mid-June and end in September with up to 48 stations being sampled during each survey for *in situ* parameters.

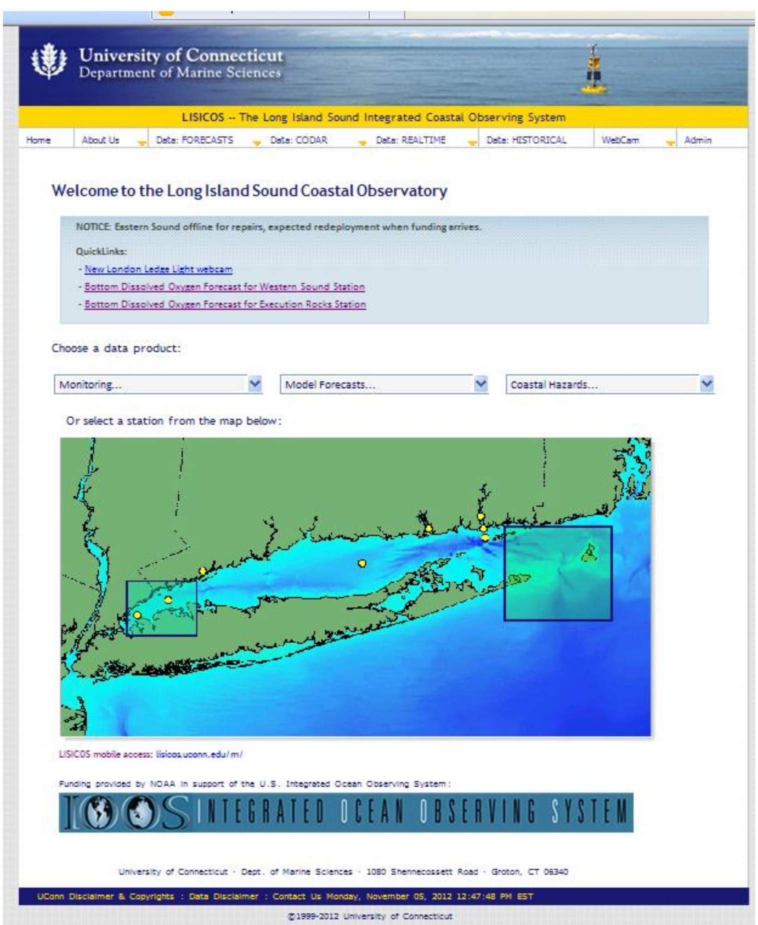
Since 2002, CT DEEP has collected zooplankton samples from six stations and phytoplankton from ten stations across Long Island Sound. The samples are sent to researchers at the University of Connecticut who identify species composition, abundance, community structure, and spatial and temporal distribution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

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 EMPACT grant program and is now provided 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”.

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 (telemetered) where they are stored in a database and uploaded to the internet. The system is maintained by the University of Connecticut.

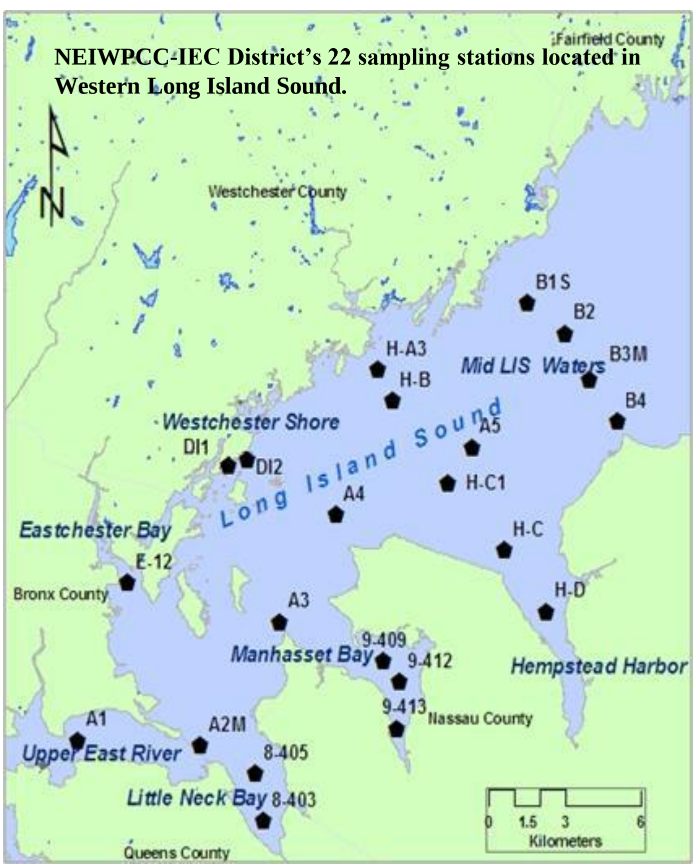


IEC District

The Interstate Environmental Commission District (IEC) is a tri-state water and air pollution control agency. Established in 1936 the IEC serves the States of New York, New Jersey, and Connecticut (www.iec-nynjct.org). The IEC's area of jurisdiction runs west from New Haven, CT and Port Jefferson, NY on Long Island Sound.

IEC has conducted monitoring in far western LIS and the Upper East River since 1991. IEC collects *in situ* data from 22 stations between June and September. *In situ* parameters include pH, temperature, salinity, water clarity (Secchi disk depth) and dissolved oxygen. More information about the program can be found on the IEC website under the Publications menu http://www.iec-nynjct.org/publications.htm.

Provisional IEC dissolved oxygen data collected during 2014 have been used to create hypoxia map interpolations in the far western Sound and appear on pages 12-17 adjacent to CTDEEP hypoxia maps. These maps are for illustrative purposes only.



NEIWPCC-IEC District's 22 sampling stations located in Western Long Island Sound.

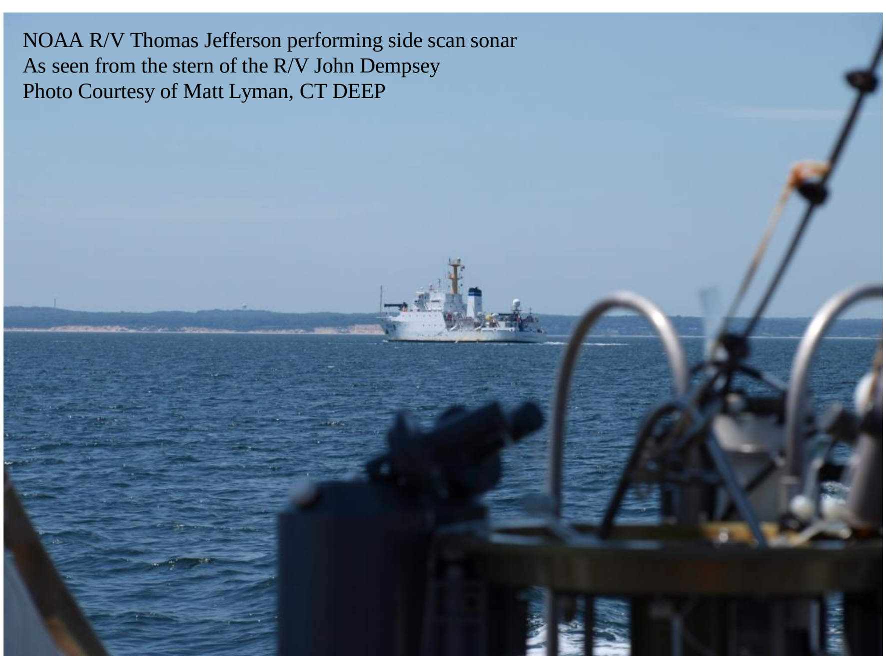
NEIWPCC-IEC District Analyst utilizes a multi-parameter meter at station A2M during a summer monitoring survey

This report presents a summary of the 2014 *in situ* data collected by CT DEEP. Data from LISICOS and IEC are presented with permission for informational purposes.

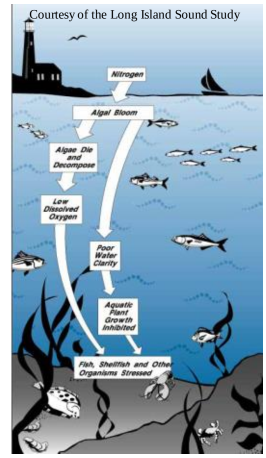
The CT DEEP LIS Water Quality Monitoring Program is synoptic in nature and is intended to characterize water quality conditions at one moment in time over a broad area (the entire Sound). Water column profile data provided by the program are useful for future determinations of volume of hypoxic waters. CT DEEP's program supports a long term monitoring database designed to detect changes in hypoxia due to changing conditions (i.e. management actions, climate change, productivity). The program also provides nutrient and biological data not available from fixed station buoy applications.

The LISICOS water quality sensors are attached to fixed locations and provide a holistic view of the conditions over a long span of time (i.e., continuous data from one station). The LISICOS continuously recording buoys have shown instances where vertical mixing within the water column raises the DO concentrations above the hypoxic thresholds for extended periods of time (e.g., days). These episodic conditions are not captured by CT DEEP surveys which occur bi-monthly during the hypoxic season.

As such CT DEEP's data provides a snapshot of hypoxic conditions at one time 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.


NOAA R/V Thomas Jefferson performing side scan sonar
As seen from the stern of the R/V John Dempsey
Photo Courtesy of Matt Lyman, CT DEEP

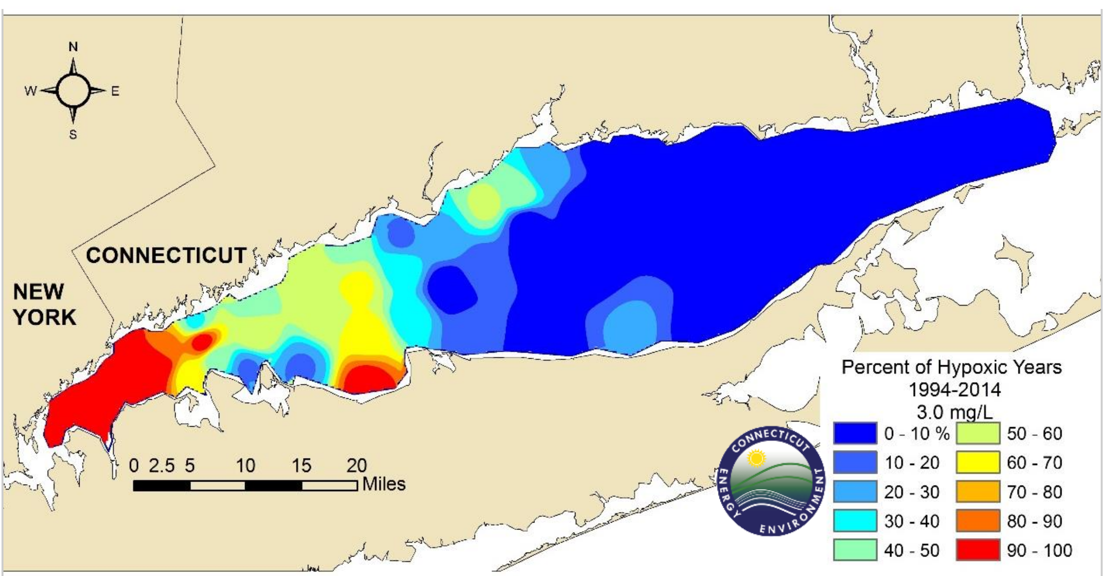
What is Hypoxia?



Courtesy of the Long Island Sound Study

The term "hypoxia" means low dissolved oxygen ("DO") concentrations in the water. Marine organisms need oxygen to live, and low concentrations, depending on the duration and the size of the area affected, can have serious consequences for a marine ecosystem. As defined by the Long Island Sound Study, hypoxia exists when DO drops below a concentration of 3 milligrams per liter (mg/L), although ongoing national research suggests that there may be adverse affects to organisms even above this level, depending upon the length of exposure. In 2011, Connecticut adopted revised water quality criteria for dissolved oxygen. These criteria, designed to protect the state's 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, studies of the limited historical data base for the Sound suggest that summer oxygen depletion in Western Long Island Sound has grown worse since the 1950s.

THE FREQUENCY OF HYPOXIA IN LONG ISLAND SOUND BOTTOM WATERS



How Does Low Oxygen Impact the Sound?

Each summer low oxygen levels render hundreds of square miles of bottom water unhealthy for aquatic life. DO 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. 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.

2014 Important Facts

CT DEEP conducted eight cruises during the summer of 2014 between 2 June and 16 September. Over the course of the season, seven (7) different stations were documented as hypoxic and of the 263 site visits completed in 2014, hypoxic conditions were found twice. Compared to the 23-year averages, 2014 was below average in area and duration. In fact, 2014 had the fourth smallest area behind 1997, 1992, and 2013 (see page 9) and the 35 day duration joined 1995 and 2000 in a three-way-tie for the second shortest duration on record (see page 9).

Cruise	Start Date	End Date	Number of stations sampled	Number of hypoxic stations
WQJUN14	6/2/2014	6/4/2014	17	0
HYJUN14	6/19/2014	6/19/2014	21	0
WQJUL14	6/30/2014	7/2/2014	38	0
HYJUL14	7/14/2014	7/15/2014	30	0
WQAUG14	8/4/2014	8/6/2014	43	7
HYAUG14	8/18/2014	8/20/2014	41	0
WQSEP14	9/2/2014	9/4/2014	44	1
HYSEP14	9/15/2014	9/16/2014	29	0

The peak event occurred during the WQAUG14 cruise between 4 and 6 August. The lowest dissolved oxygen concentration (1.67 mg/L) was also documented during the WQAUG14 cruise at Station B3. The hypoxia area maps for 2014 appear on pages 12-17.

Based on CT DEEP and NEIWPCC-IEC data

	Event #1	Event #2	Total
Estimated Start Date	7/24/2014	8/27/2014	
Estimated End Date	8/13/2014	9/9/2014	
Duration (days)	21	14	**35**
Maximum Area (mi^2)			**87.1**

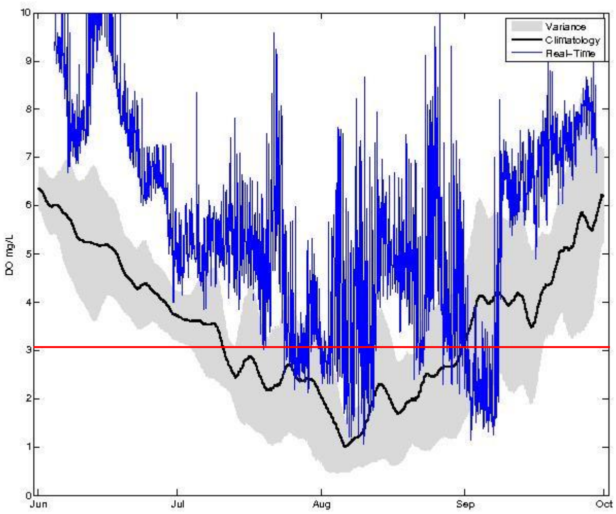
Start date and end date are estimated by plotting CT DEEP and NEIWPCC-IEC data from stations A4 and B3 in Excel using a line with markers chart and then interpolating when the DO concentration drops below/rises above 3.0 mg/L. In 2014, IEC often sampled the same weeks as CT DEEP. Therefore, LISICOS data were also included. There was a clear period when concentrations rose above 3 mg/L and remained there for 14 days in the middle of August before again dropping below the Hypoxia threshold. Concentrations remained above 3.0 mg/L threshold during the HYSEP14 cruise.

Duration Based on Buoy Data Obtained From the LISICOS Network on 29 September 2014

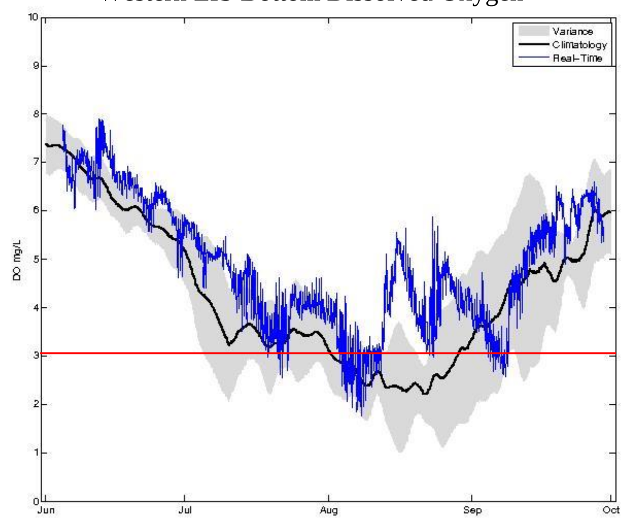
The figures below are from the LISICOS website and depict the 2014 real-time bottom dissolved oxygen data (blue line); the average of the 9 or 12 year dataset, depending on the station (black line); and the variability observed over the historical station record (gray shading).

There were three periods of decreased oxygen in the bottom waters that were captured by the LISICOS buoys.

Execution Rocks Bottom Dissolved Oxygen



Western LIS Bottom Dissolved Oxygen



Based on LISICOS Buoy Data Collected Between 1 June to 29 September

	Execution Rocks	Western LIS
Estimated Dates Event #1	7/24/14-8/13/14	7/21/14-7/23/14
Estimated Dates Event #2	8/21/14-8/23/14	8/3/14-8/12/14
Estimated Dates Event #3	8/27/14-9/8/14	9/5/14-9/8/14
Duration below 3.0 mg/L (cumulative days)	15.43	7.65
Duration below 2.0 mg/L (cumulative days)	4.02	0.28
Duration below 1.0 mg/L (cumulative days)	0.00	0.00
Minimum DO value (mg/L)	1.07 (10 August)	1.76 (8 August)
Days with no data		5.06

Data obtained from the LISICOS Execution Rocks and Western Sound Buoy Bottom Dissolved Oxygen Prediction Tool webpages (http://lisicos.uconn.edu/do_fcst.php?site=exrx and http://lisicos.uconn.edu/do_fcst.php?site=wlis). 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.***

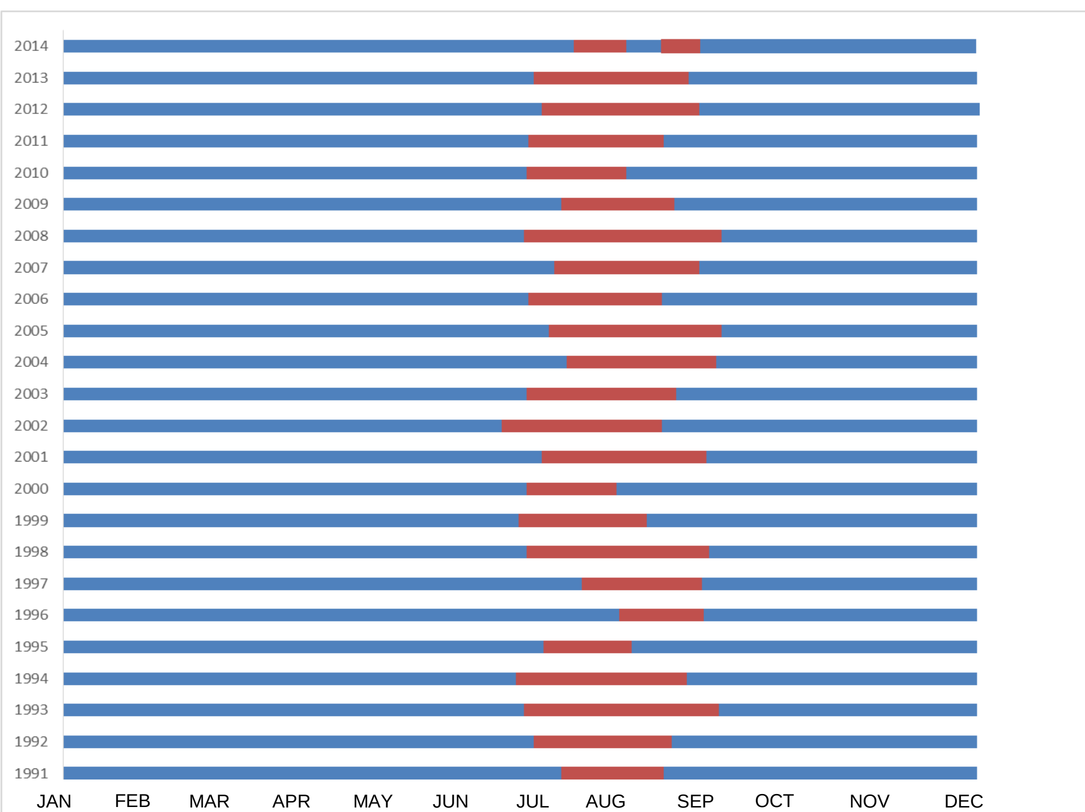
Timing and Duration of Hypoxia, 1991 - 2014

Year	Estimated Start Date	Estimated End Date	Maximum Area (mi²)	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 15	305	35
1996	Aug 10	Sept 12	220	34
1997	July 27	Sept 12	30	48
1998	July 5	Sept 15	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
Average	July 12	Sept 3	175	55
Deviation	±10 days	±12 days	± 87 mi²	± 13 days

The figure and table below display the onset, duration, and end of the hypoxia events from 1991 through 2014 based on the 3.0 mg/L standard.

Based on the LISS standard of 3.0 mg/L, the average date of onset was July 11 (± 10 days), the average end date was September 3 (± 12 days), and the average duration was 55 days (± 13 days). The earliest onset of hypoxia (red text) occurred on 25 June 2002 and the latest end date (green text) occurred on 20 September 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.

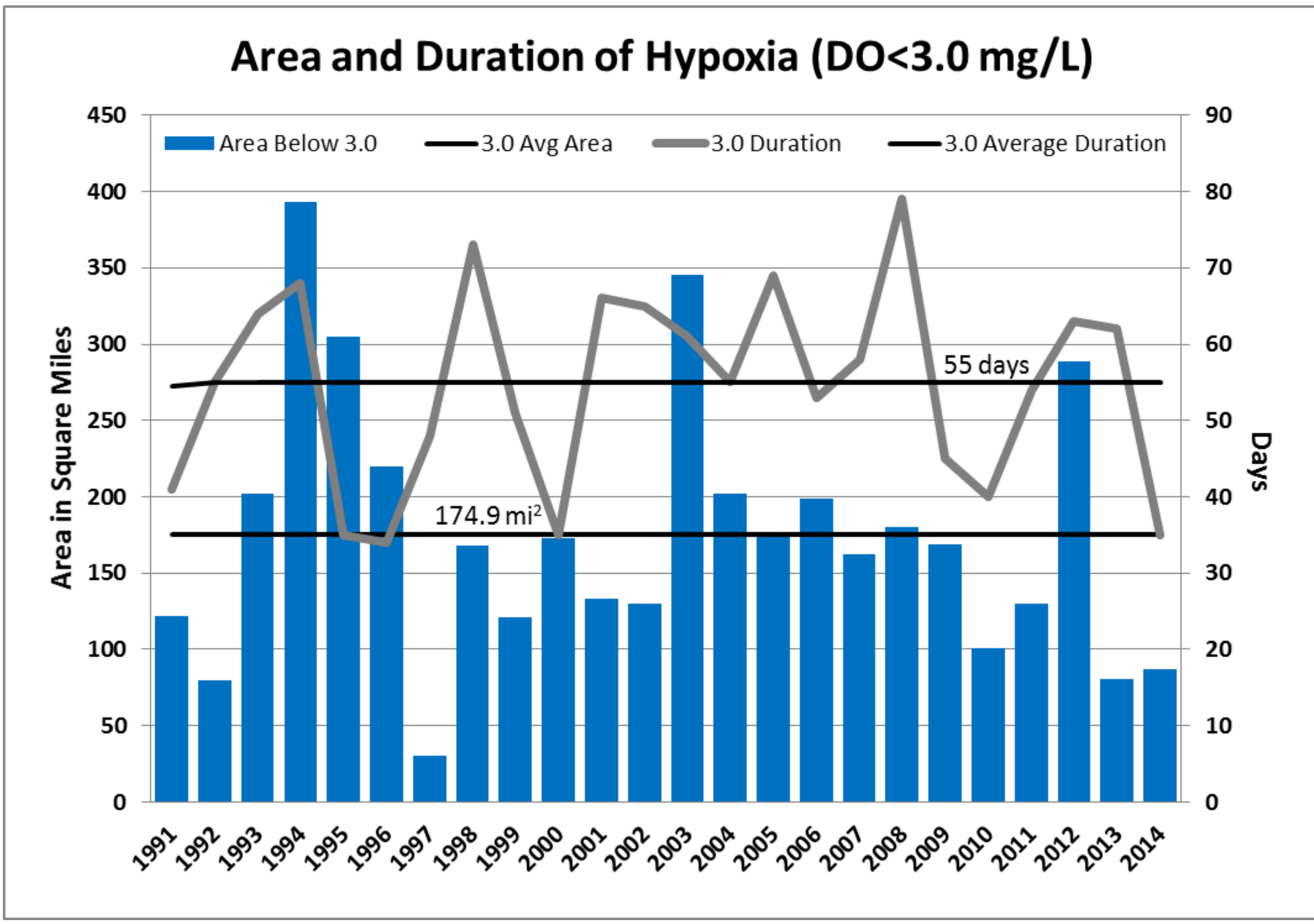
* In 2014 there was a clear period of 14 days where the DO concentration rose above the 3.0 mg/L threshold in the middle of August before dipping again during late August and early September.



Timing and Duration of Hypoxia based on 3.0 mg/L

Yearly Comparison of Maximum Areal Extent and Duration of Hypoxia

This graph utilizes the data presented on the previous page to illustrate the year-to-year differences in the maximum areal extent of hypoxic conditions. Based on the 3.0 mg/L DO standard the average areal extent was 174.9 mi^2 and the average duration was 55 days.



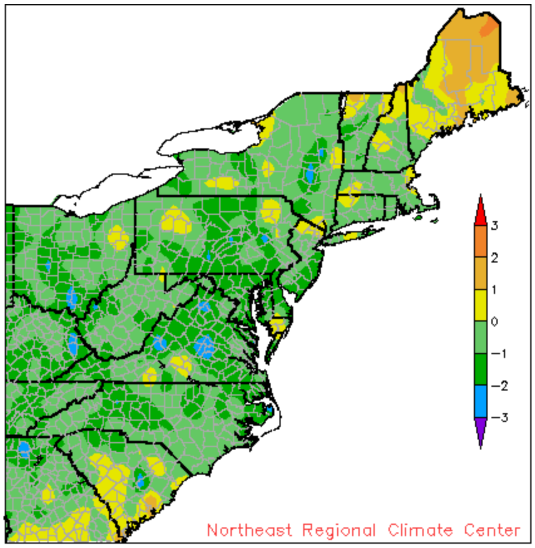
2014 Summer Weather Conditions

The Northeast Regional Climate Center at Cornell is tasked with disseminating climate data and information for 12 states. The NRRC included the following graphics in their Eastern Region Quarterly Climate Impacts and Outlook Summary (September 2014). http://www.nrcc.cornell.edu/newsletter/2014-09.pdf

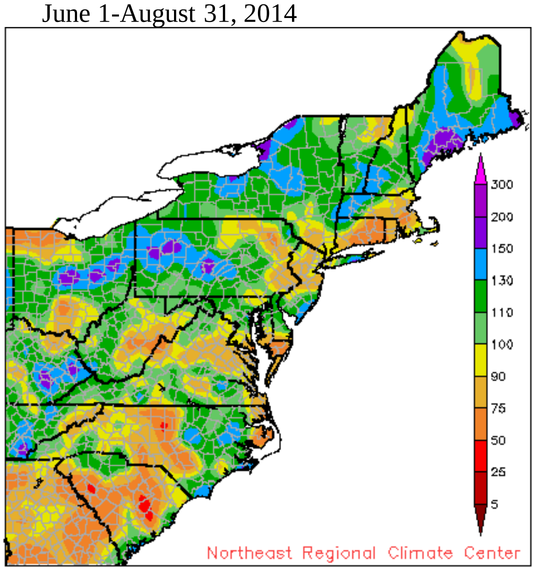
Average spring air temperatures were below normal for the area through March but warmer to above normal in May. June-August average temperatures across the Northeast were cooler than normal. September temperatures, however, were above normal (1.7ºF in CT).

Spring precipitation was about normal for CT and Long Island, while snowfall during March was below normal. Precipitation over the summer was above normal for some Northeast states and below normal for others. Hurricane Arthur provided some wet weather for 4th of July celebrations. In Connecticut, August rainfall was 80% of normal. Long Island was abnormally dry, until 12-13 August. September and October have been dry with the region classified as being abnormally dry or in a moderate drought by the US Drought Monitor http://www.nrcc.cornell.edu/page_drought.html.

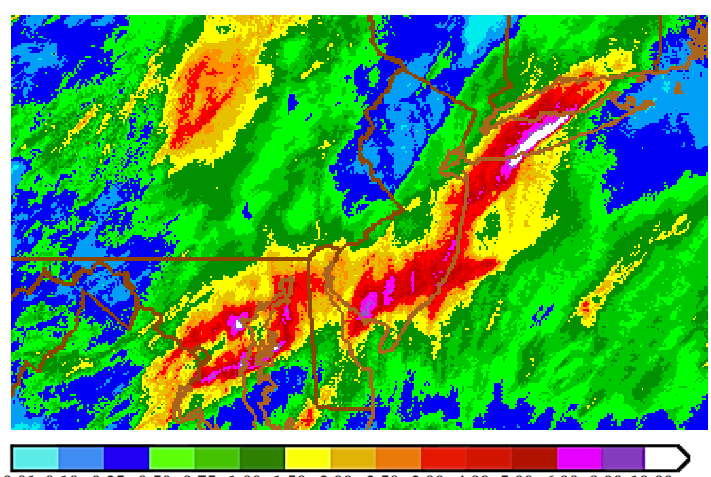
This information is useful as physical processes influence the timing and duration of hypoxia.



Departure from Normal Temperature (ºF)
June 1-August 31, 2014



Percent of Normal Precipitation (%)
June 1- Aug 31, 2014



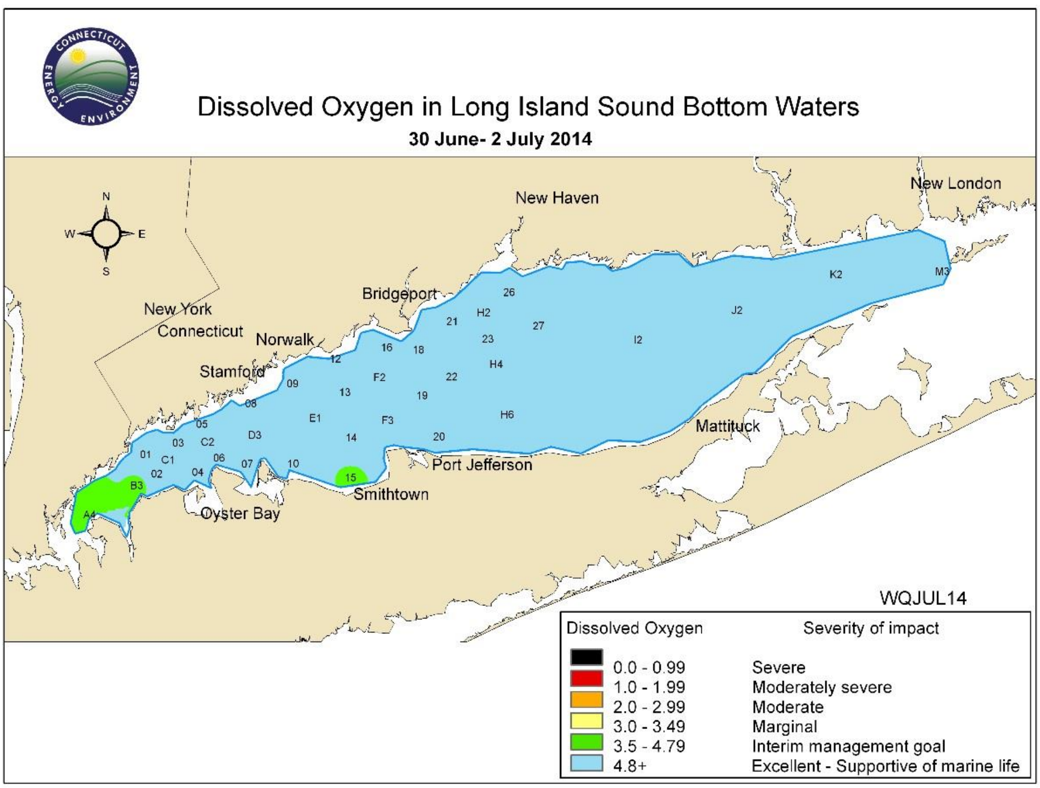
24 Hour Precipitation August 12-13, 2014

Islip, NY, saw 13.57 inches of rain on August 12-13. The site set a New York State 24-hour precipitation record, had its wettest August on record, and tied its all-time wettest month on record. This was a 200-year storm event, meaning rainfall of that magnitude is only expected to occur once in a 200-year period. The preliminary NOAA Atlas-14 amounts were extremely close to the Northeast Regional Climate Center Extreme Precipitation Analysis for the 10–100 year event for durations of 6 and 24 hours. Baltimore, MD, and Portland, ME, which both saw over 6 inches of rain on the 12th or 13th, had their highest amount of precipitation for any calendar day that was non-tropical based. In addition, Portland set hourly and consecutive two-hour rainfall records

Hypoxia Maps

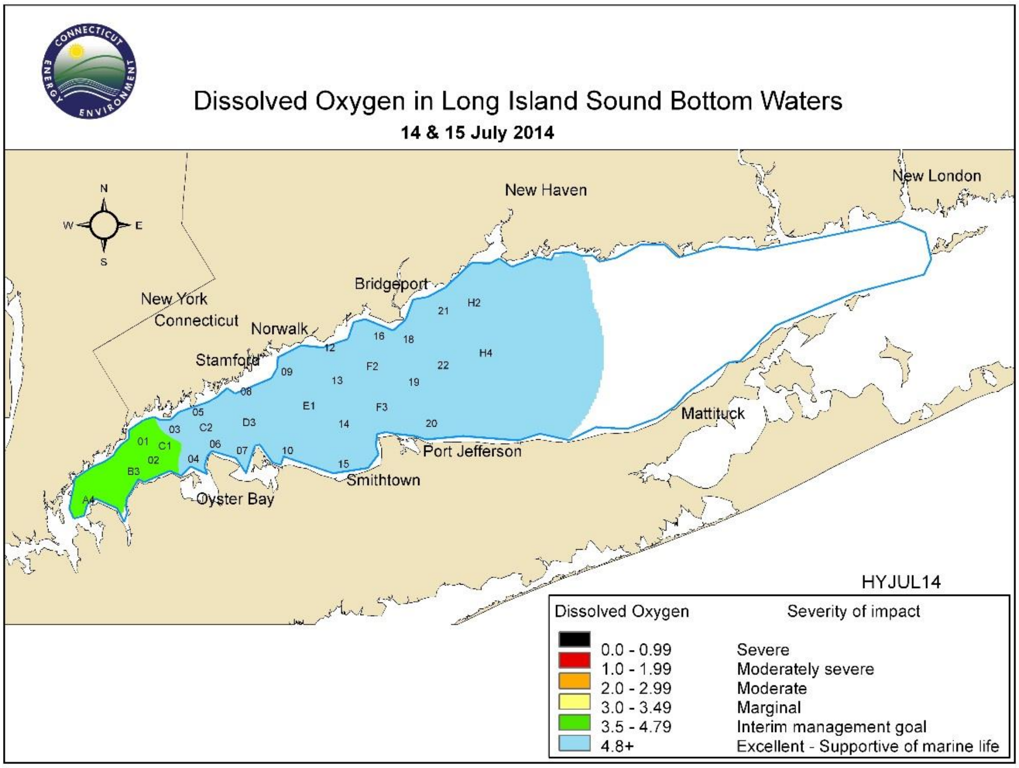
The following maps depict the development of hypoxia based on CT DEEP cruise data through the 2014 season. Data for all surveys are available upon request. NEIWPCC-IEC data were also mapped to provide additional details on hypoxic conditions in the far western Sound.

During the HYJUN14 survey all stations (CT DEEP and IEC) had DO concentrations above 4.8 mg/L.

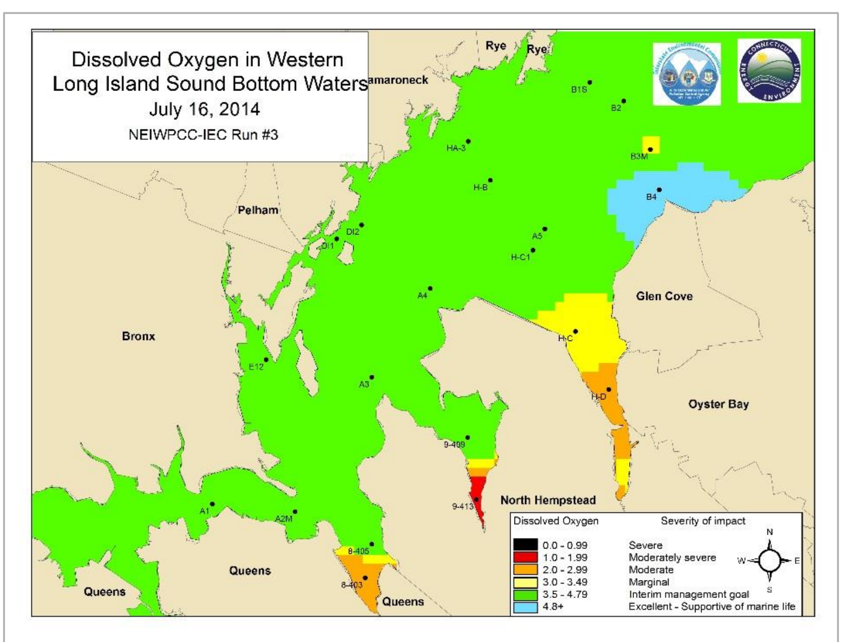


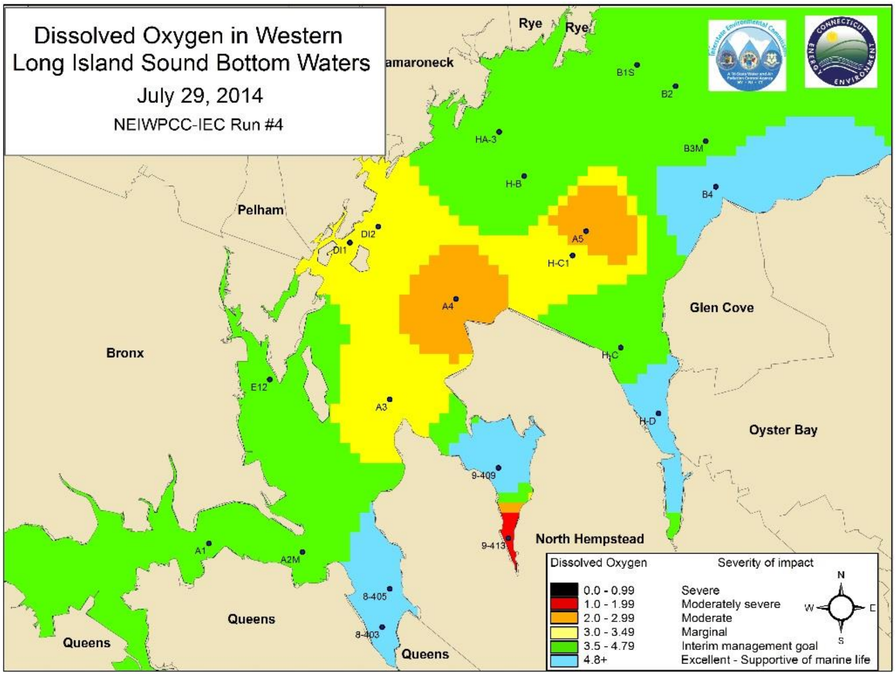
During the WQJUL14 survey DO concentrations were less than 4.8 mg/L at three CT DEEP stations. IEC data during this week are not available.

During the HYJUL14 survey, DO concentrations dropped below 4.8 mg/L at 5 stations with no stations below 3.5 mg/L.



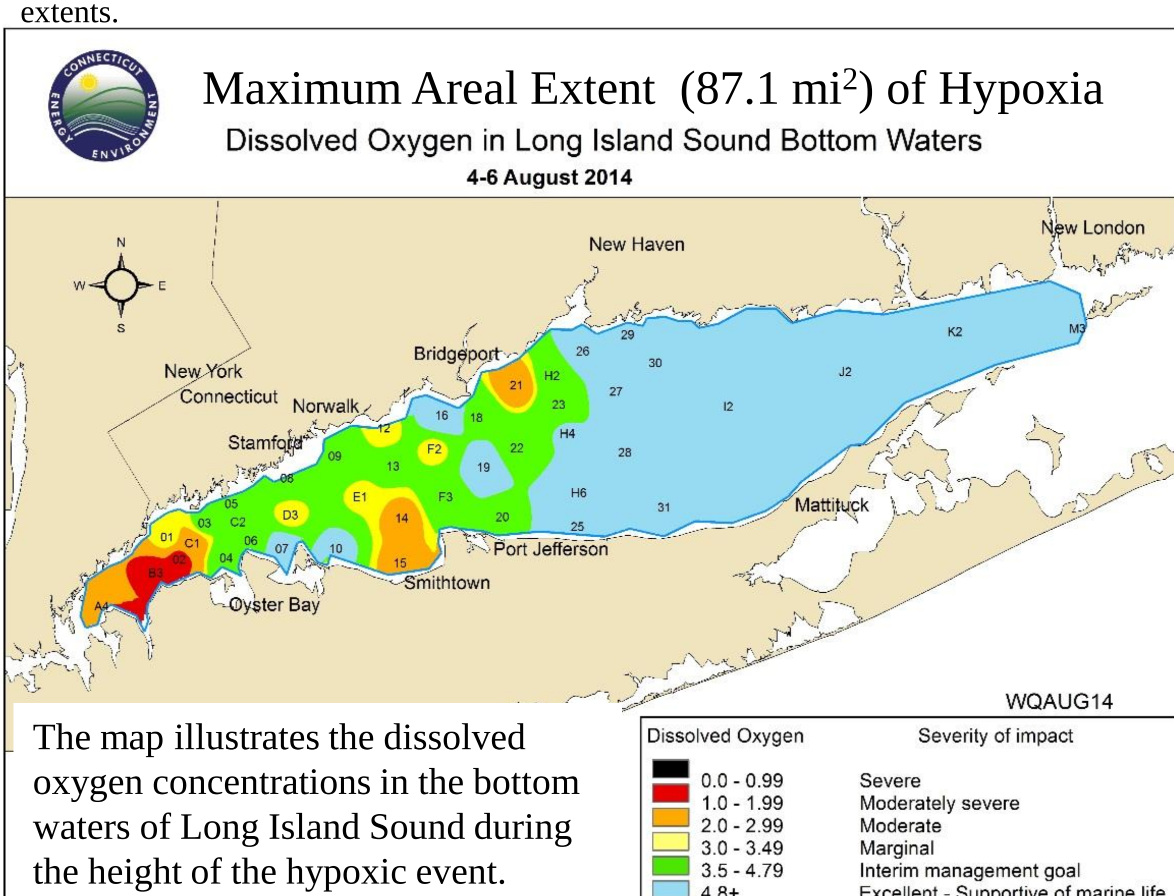
During IEC Run #3, 21 out of 22 stations revealed DO concentrations below 4.8 mg/L. Of those, two stations were below 3.5 mg/L, 2 stations were below 3 mg/L and one station was below 2 mg/L.



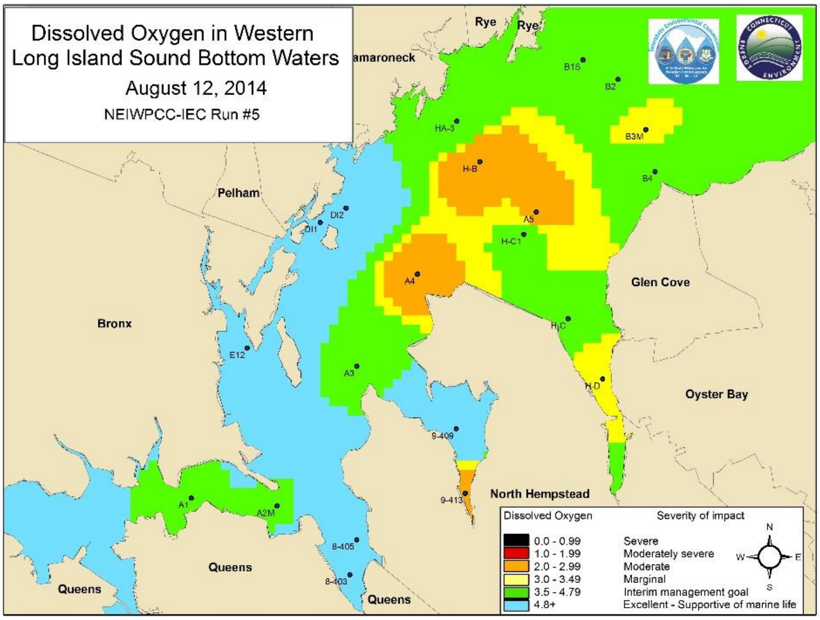


IEC Run #4 occurred a week prior to the CTDEEP WQAUG14 survey. Conditions continued to deteriorate. At Station A4 the DO had dropped to 2.68 mg/L. Station B3 was at 4.29 mg/L.

During the WQAUG14 survey, DO concentrations plummeted. Five stations had DO concentrations below 3 mg/L including A4 and C1. At Station B3 concentrations dropped below 2.0 mg/L. An additional 5 stations exhibited DO concentrations below 3.5 mg/L. This would be the height of the hypoxic event. 2014 had the fourth lowest areal extent over the course of the 23-year sampling program, with only 1991, 1997, and 2013 having lower areal extents.



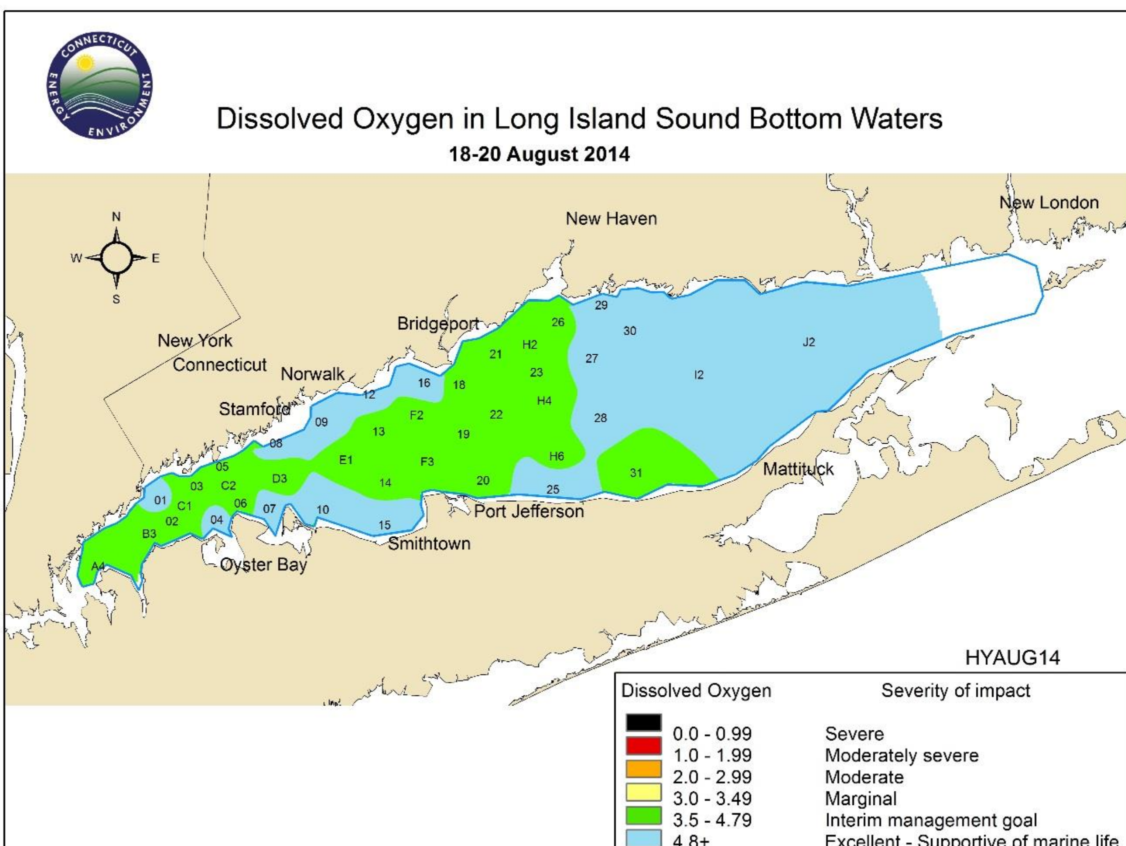
The map illustrates the dissolved oxygen concentrations in the bottom waters of Long Island Sound during the height of the hypoxic event.



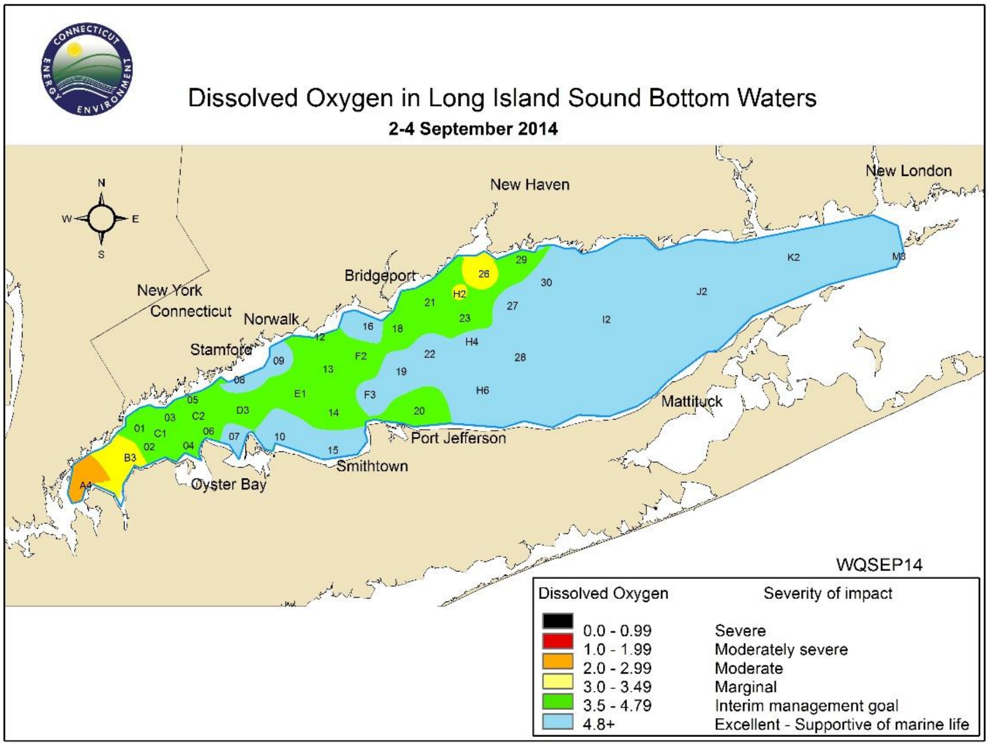
Concentrations improved for IEC Run #5 with DO at A4 measuring 2.74 mg/L and B3 measuring 3.38 mg/L.

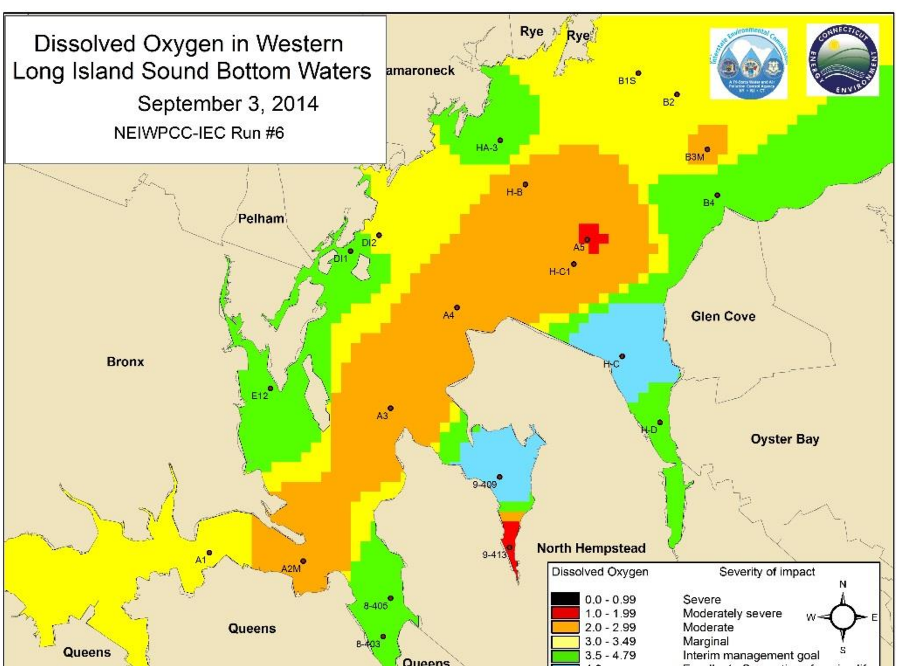
A climatic event brought heavy rain and wind to the area on 13 August. A record 13.51 inches of rain fell on Long Island with 2-5 inches falling across Connecticut. Winds gusted to 38 mph at Bridgeport.

During the HYAUG14 survey DO concentrations across the Sound were greater than 3.0 mg/L. 25 stations had concentrations between 3.5 and 4.8 mg/L. LISICOS data show that A4 remained above the 3.0 mg/L mark for about 7 days following the storm, before dipping back to 2.4 mg/L on 21 August.

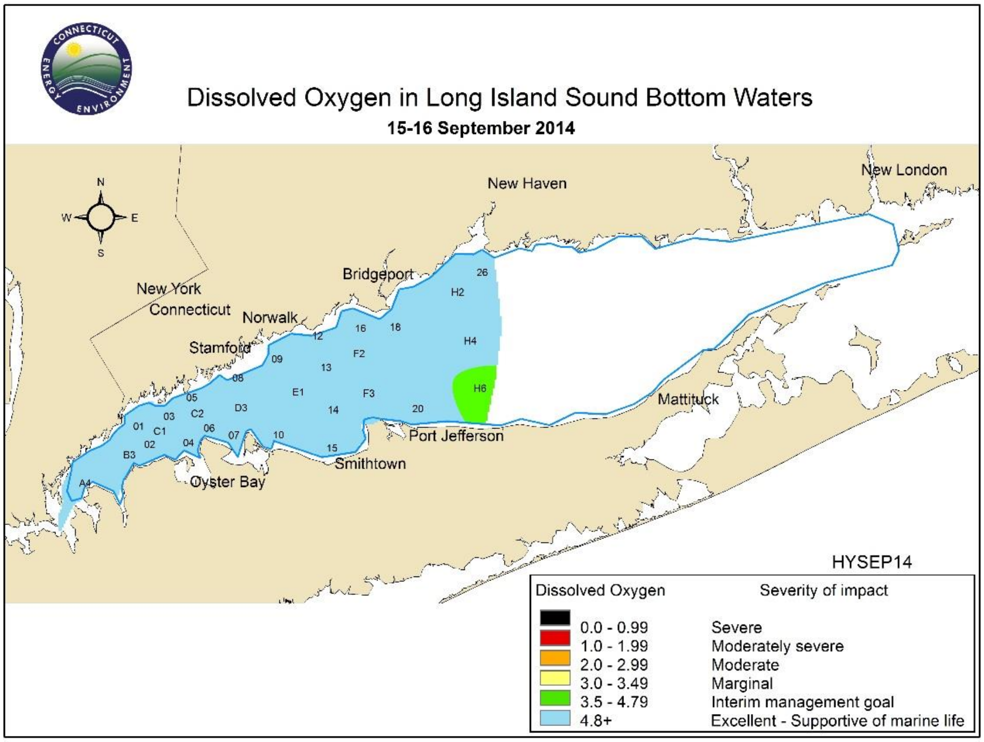


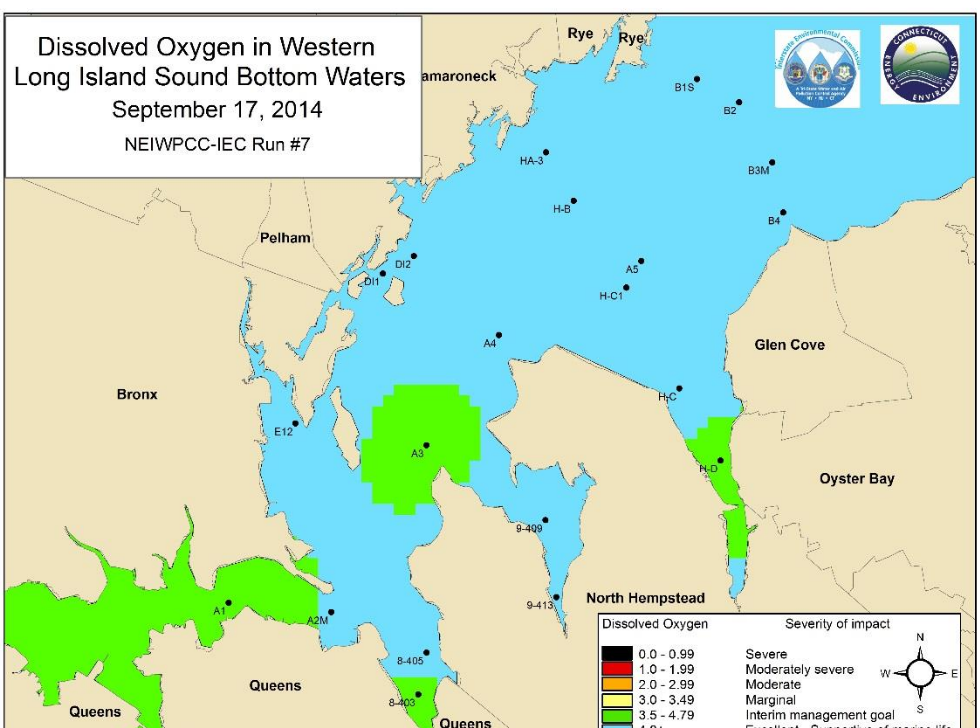
The WQSEP13 survey and IEC Run #6 found conditions had worsened slightly. A brief period of heat and humidity atypical for September helped concentrations at A4 and B3 to fall back to 2.74 and 3.3 mg/L, respectively. Two stations off New Haven Harbor were below 3.5 mg/L and an additional 19 stations were below 4.8 mg/L. IEC found concentrations at an additional six stations in WLIS to be below 3 mg/L with Station A5 measuring 1.97 mg/L.





Conditions rebounded for the HYSEP13 survey with only one CT DEEP station exhibiting DO concentrations below 4.8 mg/L (H6). IEC found four stations with DO less than 4.8 mg/L. The LISICOS buoy data showed concentrations climbing above 3.0 mg/L and staying above 3 beginning on or about 8 September.

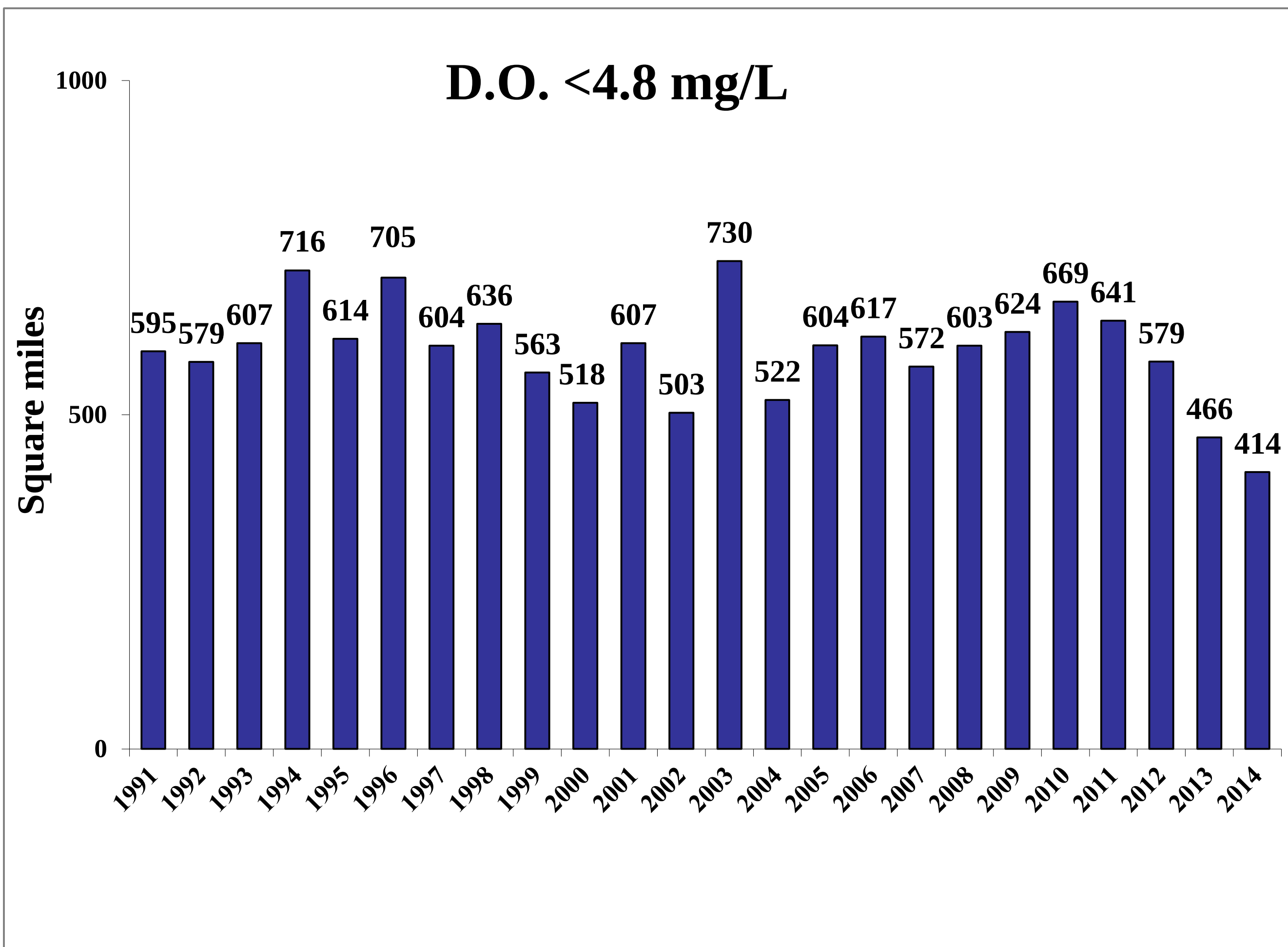




Area of Dissolved Oxygen Below the Chronic Criterion for Growth and Protection of Aquatic Life for LIS

Aquatic organisms are harmed based on a combination of minimum oxygen concentration and duration of the low DO excursion. A DO concentration of 4.8 mg/L meets the chronic criterion for growth and protection of aquatic life regardless of the duration.

This chart illustrates the maximum area of bottom waters within Long Island Sound with DO concentrations less than 4.8 mg/L. In 2014, the maximum area occurred during the HYAUG14 survey and was estimated at 414 square miles and was the lowest over the 23-year sampling program. From 1991-2014, the area affected by concentrations less than 4.8 mg/L averages 595.3 square miles and varies slightly from 414 to 730 square miles.

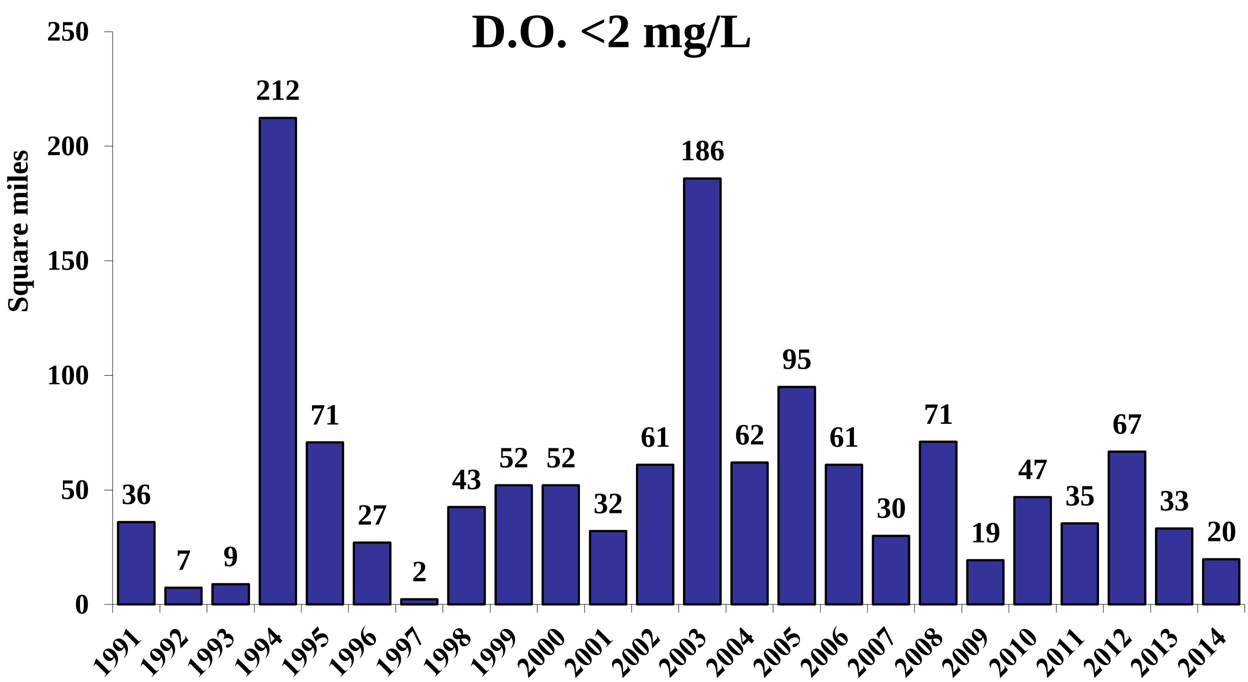


Severe Hypoxia

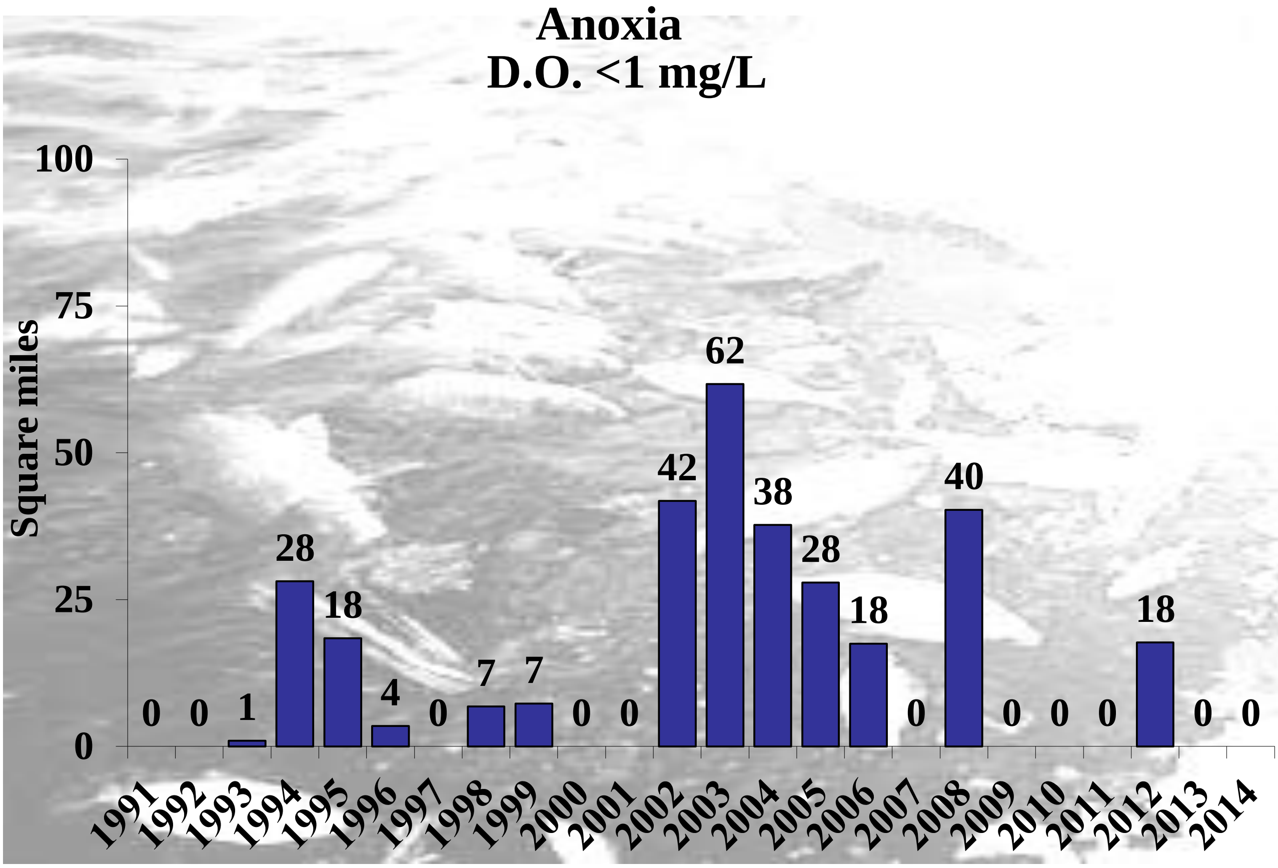
The Long Island Sound Study provides information on LIS Hypoxia for inclusion in EPA's *Report on the Environment* (http://www.epa.gov/ncea/roe/) which reports on "the best available indicators of information on national conditions and trends in air, water, land, human health, and ecological systems…". The ROE Report 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.

This chart illustrates the maximum area of bottom waters of Long Island Sound with concentrations less than 2 mg/L. In 2014, the maximum area of LIS affected by severe hypoxia was 19.8 mi^2, a decrease from 2013. The average area, calculated from 1991-2014, is 55.4 mi^2. Based on CT DEEP data there were 2 days when DO was less than 2.0 mg/L. Based on the LISICOS Execution Rocks data there were 4.02 days below 2.0 mg/L.

For comparisons, the average size of the hypoxic zone in the northern Gulf of Mexico from 1985-2010 is roughly 5330 mi^2 (larger than the State of CT). The maximum area of the Gulf of Mexico hypoxic zone occurred in 2002 and was estimated at 8,841 mi^2 (22,898 km^2). The 2014 hypoxic zone covered 5052 mi^2 (13080 km^2) and was smaller than 2013 (http://www.gulfhypoxia.net/Research/Shelfwide%20Cruises/2014/PressRelease2014.pdf).



In LIS, 1994 and 2003 appear to be especially bad years for concentrations less than 2 mg/L. 1994 had cold winter bottom water temperatures and an unusually warm June which led to the establishment of strong stratification. The highest average Delta T in July 1994 was 8.54 ºC. 2003 was the second hottest summer since 1895 and the 28th wettest which also led to the Sound being very strongly stratified. Strong stratification (Delta T greater than 4) lasted for four months in 1994 (May-August) and only one month (July) in 2003.

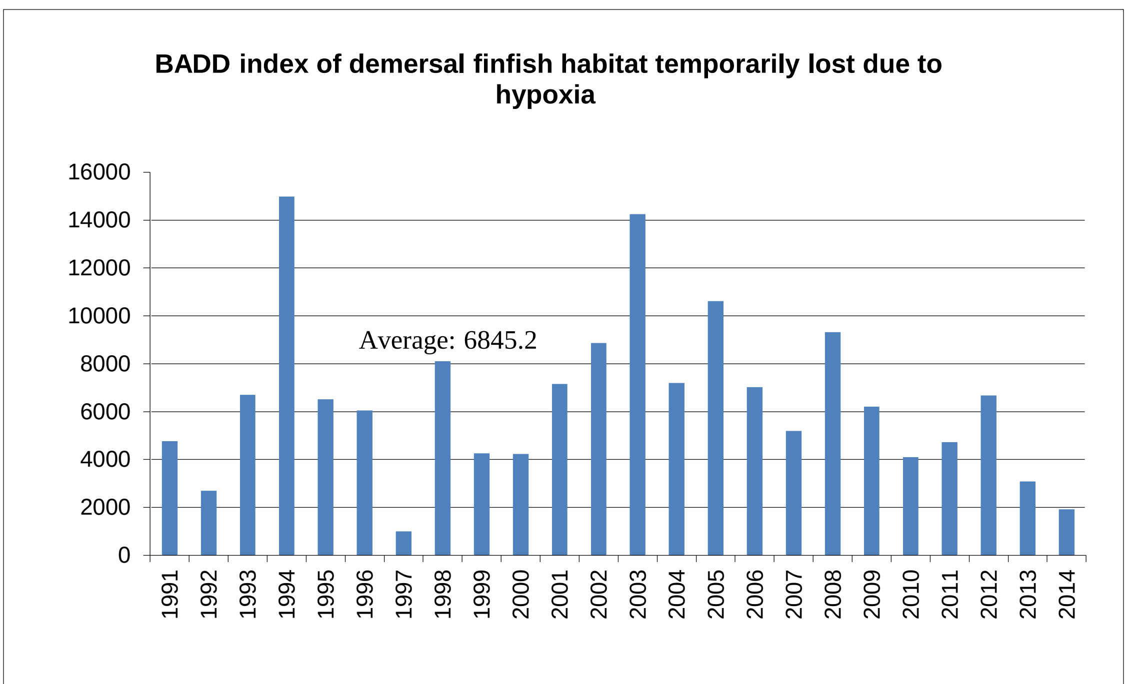


For management purposes the Long Island Sound Study defines anoxia as DO concentrations less than 1 mg/L. In ten of the twenty-two years there was no anoxia reported by CT DEEP. The greatest area with D.O. below 1 mg/L observed in LIS, based on ~biweekly sampling by CT DEEP, was during the summer of 2003. Prior to 2002, the average area of bottom waters affected by anoxia was 5.92 mi^2. From 2002-2012 the average area affected was 22.24 mi^2. The overall average area affected from 1991-2013 is 13.5 mi^2. A consistent decline was observed from 2003-2007. During the summer of 2008 three stations (A4, B3, and 02) were observed to have gone anoxic. In 2009, 2010, and 2011 CT DEEP did not document any stations with DO < 1 mg/L. However, in 2009 and 2010 the Interstate Environmental Commission documented two stations that were anoxic. In 2011, no stations were documented to have gone anoxic by either the IEC or CT DEEP. However, the lowest concentration reported at the LISICOS Execution Rocks buoy (Station A4) for 2011 was 0.61 mg/L. In 2012, CT DEEP documented two stations that were anoxic (A4 and B3). IEC documented two anoxic stations (A3 (further west than A4, Hewlett Point and H-C in Hempstead Harbor). LISICOS also documented anoxic conditions (4.04 days and minimum DO of 0.52 mg/L). In 2013 and 2014, anoxic conditions were not documented by CT DEEP, IEC or LISICOS.

HABITAT IMPAIRMENT ASSOCIATED WITH HYPOXIA

Simpson *et al*, (1995) identified low oxygen tolerance thresholds for 16 individual species of finfish and lobster, and six aggregate species indices. For the most sensitive species (scup, striped sea robin) dissolved oxygen becomes limiting at less than 4.0 mg/L, whereas more highly tolerant species (Atlantic herring and butterfish) did not decline in abundance until oxygen levels were below 2.0 mg/L. Both demersal species biomass and demersal species richness begin to decline when dissolved oxygen levels fall below about 3.5 mg/L. No finfish or macroinvertebrates were observed when dissolved oxygen fell below 1.0 mg/L.

An index of habitat impairment (Biomass Area-Day Depletion, BADD) was developed based on the percent reduction in demersal finfish biomass associated with each 1 mg/L interval below 3.0 mg/L. Based on Simpson *et al* (1996), demersal finfish biomass is reduced 100% (total avoidance) in waters with DO<1.0 mg/L. From 1.0-1.9 mg/L biomass is reduced 82%, while a 41% reduction occurs at 2.0-2.9 mg/L, and a 4% reduction occurs at 3.0-3.9 mg/L dissolved oxygen. These rates are applied to the area-days within each DO interval calculated during each survey and summed over the hypoxia season defined here as 24 July – 9 September (35 days *see page 7 for details). The index is then expressed as a percentage of the available area-days (sample area 2,723 km^2 x 35 d, or 95,305 area-days).

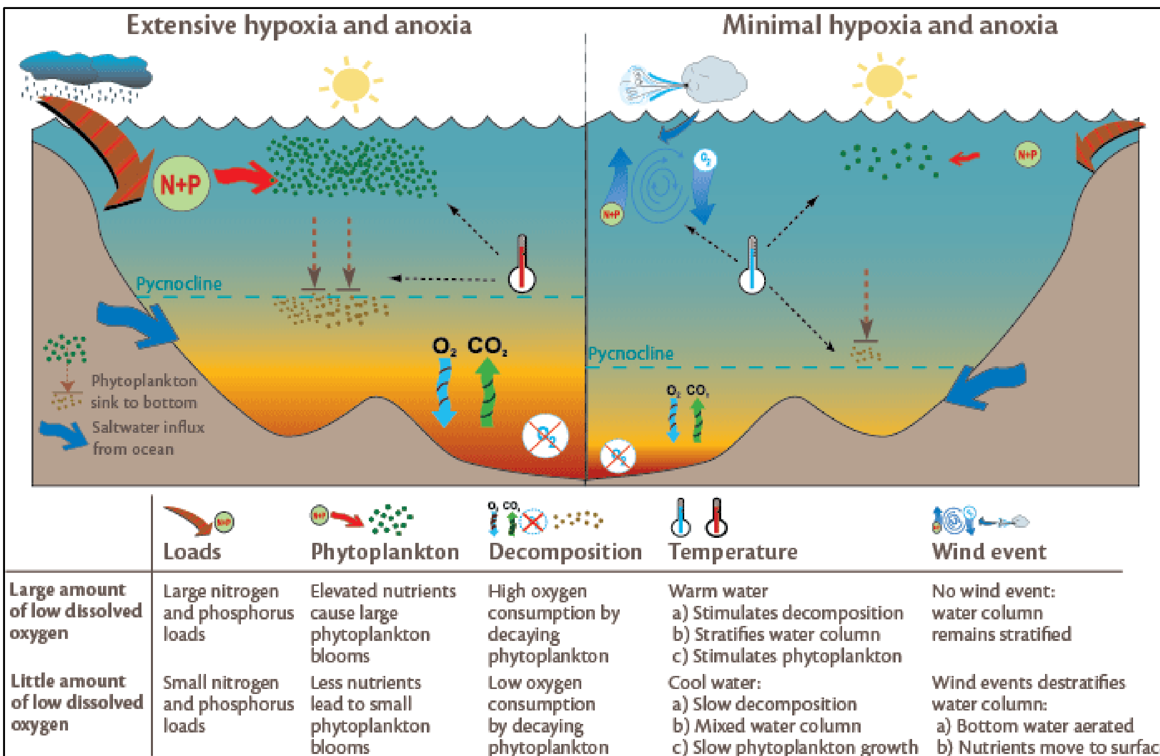


Simpson, David G., Kurt Gottschall, and Mark Johnson. 1995. Cooperative interagency resource assessment (Job 5). In : A study of marine recreational fisheries in Connecticut, CT DEP Marine Fisheries Office, PO Box 719, Old Lyme, CT 06371, p 87-135.

Simpson, David G., Kurt Gottschall, and Mark Johnson. 1996. Cooperative interagency resource assessment (Job 5). In : A study of marine recreational fisheries in Connecticut, CT DEP Marine Fisheries Office, PO Box 719, Old Lyme, CT 06371, p 99-122.

WATER TEMPERATURE AND HYPOXIA

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. CT DEEP's monitoring program records water temperatures and salinity year round, but data collected during the 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 stratification. (Stratification is discussed more on page 24.) 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.

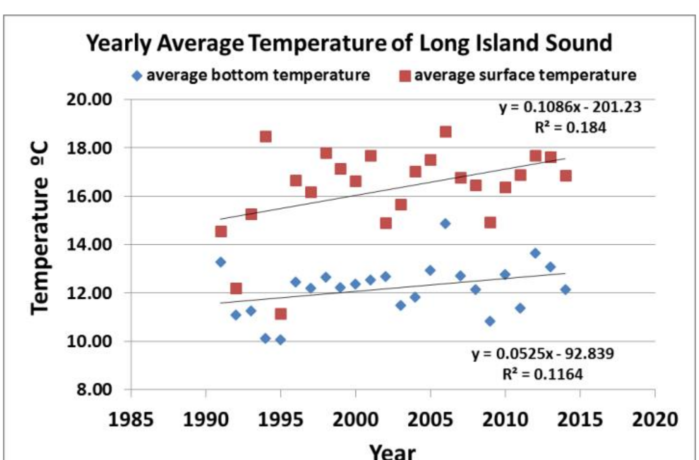


Conceptual diagram detailing the factors that determine the dissolved oxygen content of the tidal waters of Chesapeake Bay
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Ecocheck

2014 Water Temperature Data

2014 maximum, minimum, and average water temperature (ºC) data are summarized below. Data are integrated across Long Island Sound (i.e., all stations and all depths) and are displayed by cruise. Data were obtained using the CT DEEP Sea Bird Sea Cat Conductivity, Temperature, Depth (CTD) profiler.

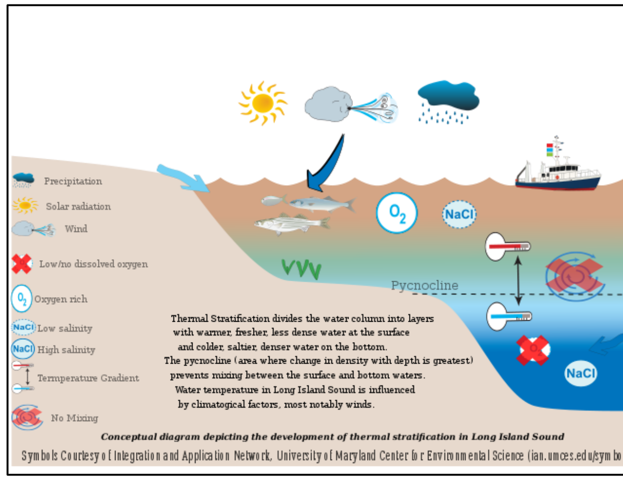
Cruise	2014 Max	1991-2014 Max	2014 Min	1991-2014 Min	2014 Average	1991-2014 Average
WQJAN	4.538	9.311	0.621	0.500	2.819	4.477
WQFEB	3.231	6.748	-0.158	-1.325	1.128	2.113
CHFEB	0.458	4.464	**-0.288**	**-0.288**	-0.058	2.219
WQMAR	2.255	6.611	-0.499	-0.783	0.562	2.319
CHMAR	No Survey	6.575	No Survey	0.113	No Survey	3.519
WQAPR	4.479	10.072	1.757	1.309	2.764	4.768
WQMAY	11.647	14.145	6.806	5.054	8.078	8.597
WQJUN	17.343	21.436	9.748	8.239	12.657	12.764
HYJUN	20.023	22.458	12.421	11.116	16.265	15.858
WQJUL	22.687	25.336	14.146	11.639	16.907	17.375
HYJUL	23.163	27.493	16.505	15.038	18.663	19.301
WQAUG	25.749	27.067	18.832	14.018	21.013	20.514
HYAUG	23.349	25.517	20.897	18.678	21.732	21.659
WQSEP	**25.857**	**25.857**	19.328	16.390	22.351	21.721
HYSEP	22.242	23.484	20.847	19.533	21.707	21.673
WQOCT	20.869	21.571	19.477	14.161	20.283	19.211
WQNOV		16.601		10.467		13.893
WQDEC		12.712		0.000		9.188



The Sound is coldest during February and March and warmest during August and September. The yearly average surface and bottom temperature of the Sound show slight increases over the period 1991-2014.

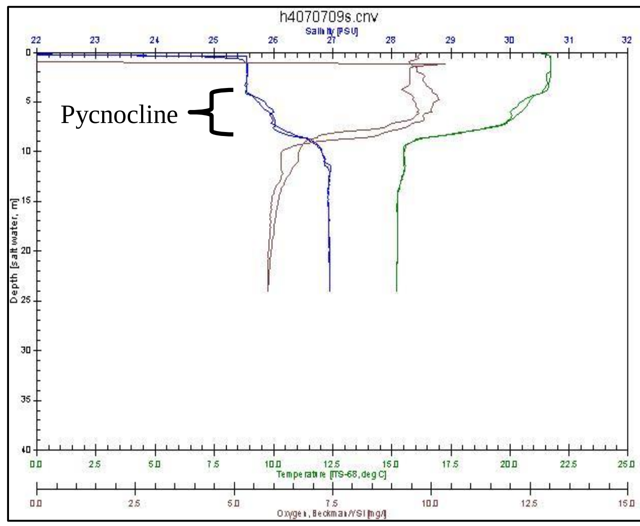
Delta T and Stratification

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 that 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 deplete bottom waters exacerbating the 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 and 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/eliminated. The smallest Delta Ts 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

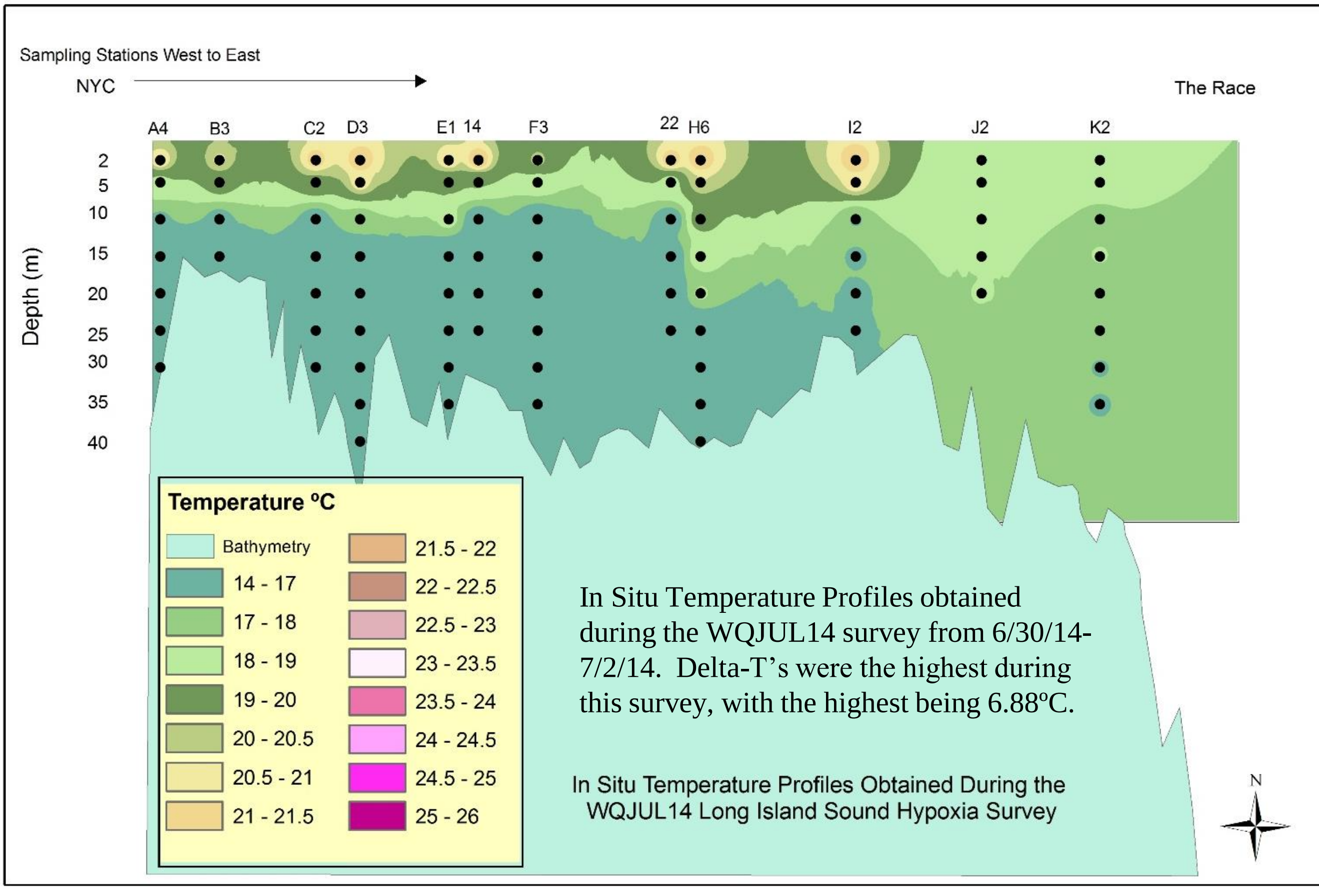


Conceptual diagram depicting the development of thermal stratification in Long Island Sound

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

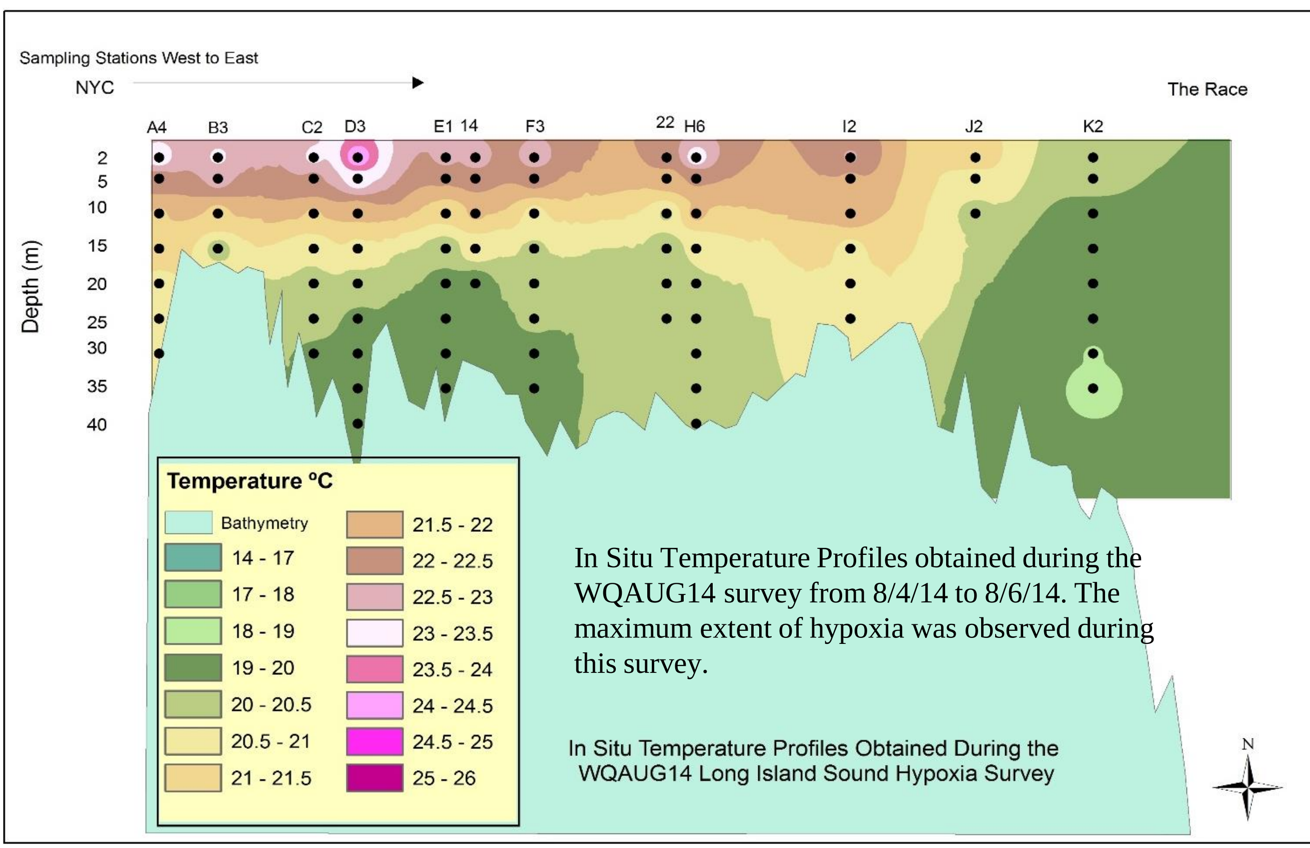


The temperature graphs on page 25 show computer interpolations along the west-east axis of LIS generated from profile data collected during two CT DEEP surveys. During the WQJUL14 survey, surface water temperatures had warmed to an average of 20.67 ºC while the bottom water remained cooler around an average of 15.45ºC. This set up the largest differences in temperatures between the surface and bottom waters. The second graph shows how the water column was thermally stratified during theWQAUG14 survey when hypoxic conditions were at their worst. The graphs on page 26 show how the Delta T's varied over the course of the summer sampling season. Delta T's increased from the WQAPR14 survey through the WQJUL14 survey, setting up the stratification and leading to the maximum extent of hypoxia in early August. By the September survey Delta T's decreased to around 1.5ºC over much of the Sound. Delta T's continued to decrease during the HYSEP14 survey to around 0.03ºC, allowing the oxygenated surface waters to mix through to the bottom, leading to the end of the hypoxic event. The graphs also show how the Delta T varies spatially. The western Sound has higher Delta T's due to the limited flushing capacity, topology, 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.



In Situ Temperature Profiles obtained during the WQJUL14 survey from 6/30/14-7/2/14. Delta-T's were the highest during this survey, with the highest being 6.88ºC.

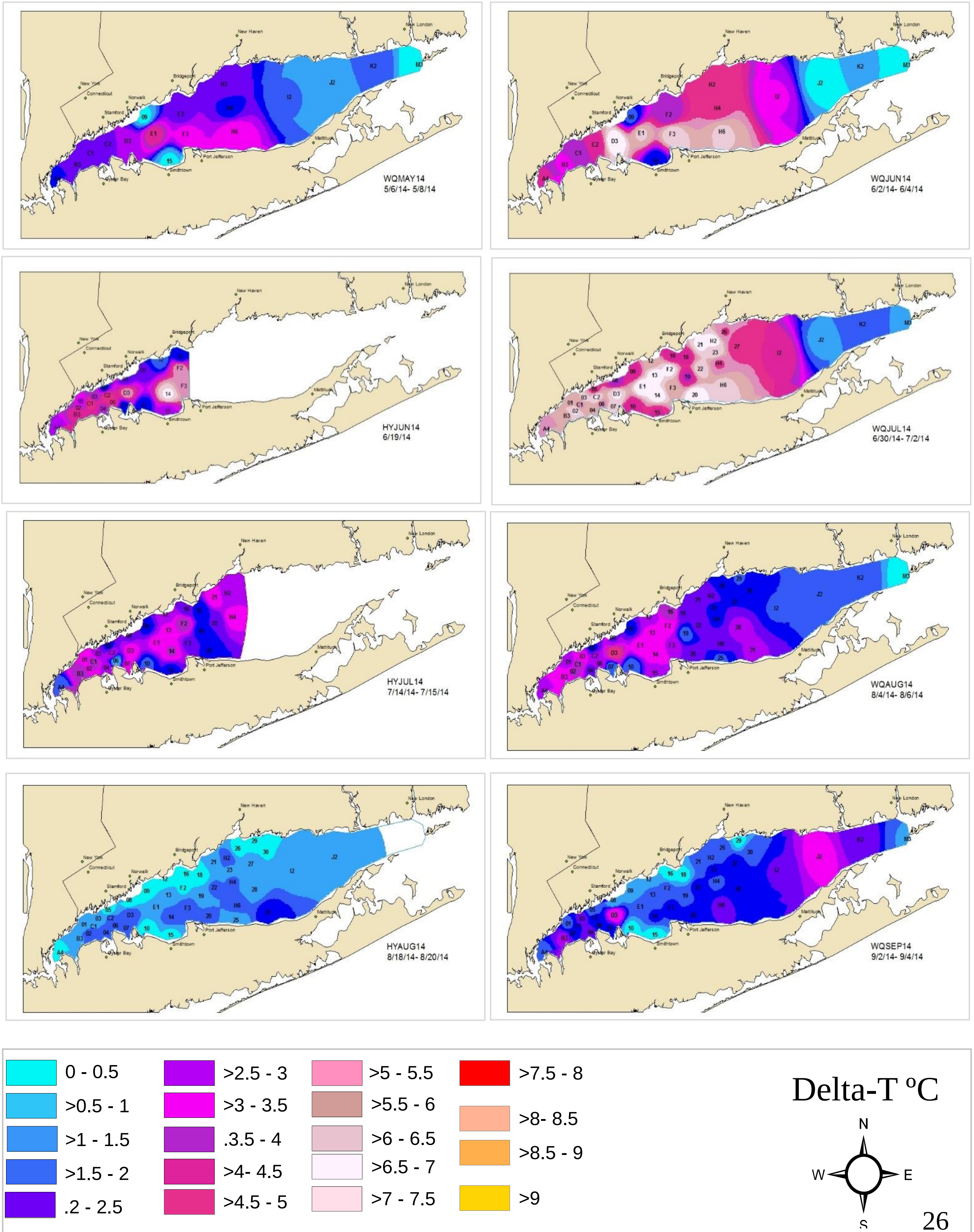
In Situ Temperature Profiles Obtained During the WQJUL14 Long Island Sound Hypoxia Survey



In Situ Temperature Profiles obtained during the WQAUG14 survey from 8/4/14 to 8/6/14. The maximum extent of hypoxia was observed during this survey.

In Situ Temperature Profiles Obtained During the WQAUG14 Long Island Sound Hypoxia Survey

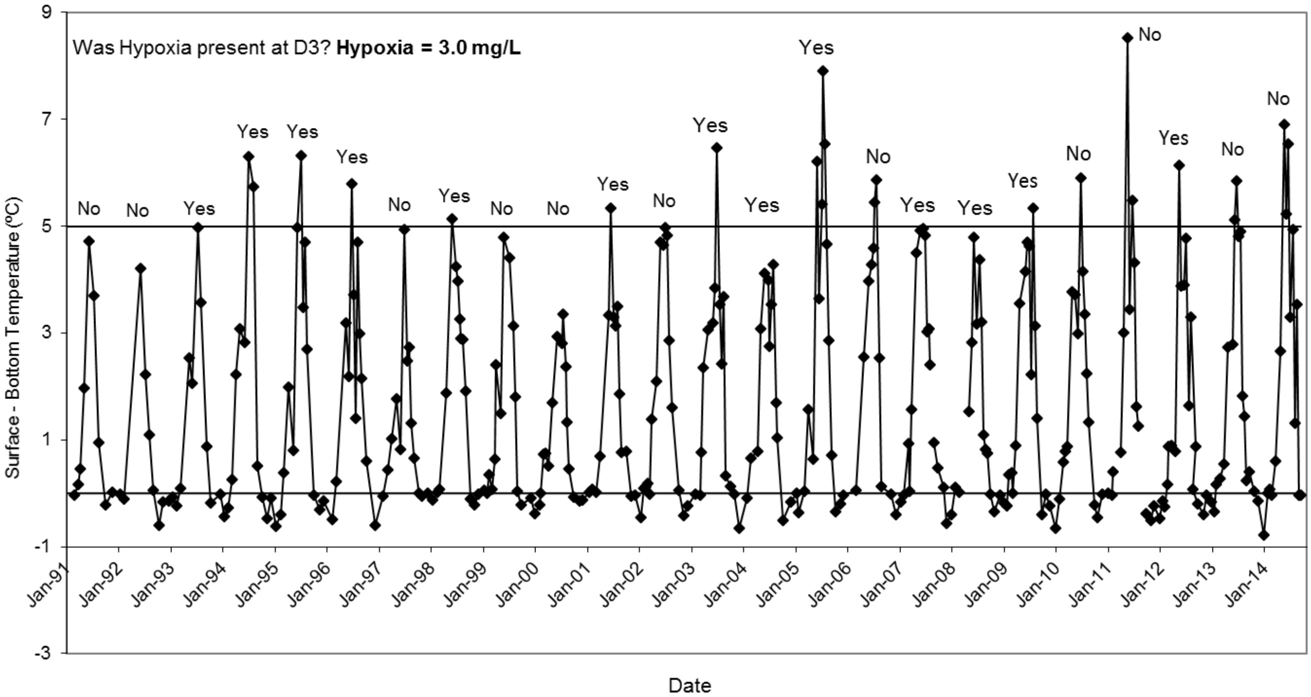
2014 Delta-T Maps



This table summarizes the minimum winter temperatures (January, February, and March), the maximum summer temperatures (June, July, August, and September), the maximum Delta T, and maximum hypoxic area at **Station D3**. Station D3 is located in the eastern-most and deepest portion of the Narrows (see map on page 1). The CT DEP 1991-1998 Data Review report (Kaputa and Olsen, 2000) found a positive correlation between the maximum Delta T observed at D3 and the maximum area of hypoxia in the same year. Delta T was not correlated to the duration of hypoxia. 2012 had the warmest minimum winter temperature, 2004 had the lowest water temperature recorded, 2006 had the highest, 2011 had the highest ΔTmax, and 1994 had the largest area of hypoxia.

Year	Minimum Winter Temp (ºC)	Maximum Summer Temp (ºC)	Maximum ΔT (ºC)	Maximum Area of Hypoxia (mi^2) DO<3.0 mg/L
1991	2.69	22.23	4.75	122
1992	1.86	20.89	4.83	80
1993	1.06	22.68	5.33	202
1994	-0.68	24.08	6.33	**393**
1995	0.95	23.78	6.33	305
1996	-0.19	23.78	5.91	220
1997	1.87	21.81	4.96	30
1998	3.40	23.20	5.22	168
1999	2.67	23.41	5.51	121
2000	0.57	21.99	6.02	173
2001	1.67	23.20	5.38	133
2002	4.03	23.47	5.52	130
2003	-0.52	22.88	6.74	345
2004	**-0.93**	23.09	4.33	202
2005	0.53	25.10	8.19	177
2006	2.17	**25.11**	6.72	199
2007	0.83	23.03	5.12	162
2008	2.45	22.47	4.91	180.1
2009	0.72	24.31	5.90	169.1
2010	1.35	24.91	6.36	101.1
2011	0.66	22.32	**8.34**	130.3
2012	**4.09**	24.85	6.13	288.5
2013	2.00	24.23	5.85	80.7
2014	0.07	25.86	6.90	87.1

Kaputa, Nicholas P., and Christine B. Olsen. 2000. Long Island Sound summer hypoxia monitoring survey 1991-1998 data review. CTDEP Bureau of Water Management, Planning and Standards Division, 79 Elm Street, Hartford, CT 06106-5127, 45 p.



Time series of ΔT (surface water temperature - bottom water temperature) at station D3, 1991 through 2014.

Prior to 2004, when Station D3 became hypoxic the observed maximum delta-T was greater than 5ºC. Since 2004, this trend/pattern does not seem to hold. Over the period of record, 2011 had the highest observed Delta T at Station D3 (>8ºC) but the lowest dissolved oxygen concentration recorded in 2011 at D3 was 3.22 mg/L. In 2012, the Delta T was again over 5ºC and D3 was in fact hypoxic (lowest dissolved oxygen was 2.84 mg/L). In 2013, D3 was not hypoxic despite the Delta T again being over 5ºC (lowest concentration was 3.13 mg/L). In 2014, the maximum Delta T at D3 was 6.90ºC but D3 was not hypoxic (lowest DO 3.33 mg/L).

Salinity

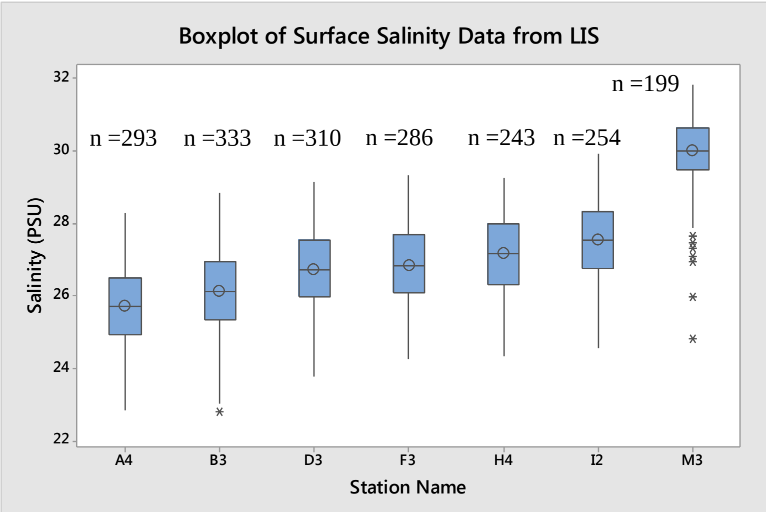
Salinity is a measure of the dissolved salts content of seawater. It is usually expressed in practical salinity units (PSU). Salinity levels across Long Island Sound vary from 23 PSU in the Western Sound at Station A4 to 33 PSU in the eastern Sound at Station M3. The Thames, Connecticut, and Housatonic rivers are the major sources of freshwater entering the Sound. Summary statistics for salinity data collected from seven stations across the Sound from 1991-2014 are presented in the tables below. Data collected this year are also presented separately.

		1991-2014 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	303	23.823	28.727	26.37	26.361	0.0529	0.921	0.849
B3	351	24.259	28.926	26.641	26.633	0.0491	0.92	0.847
D3	328	24.912	29.215	27.27	27.39	0.0483	0.876	0.767
F3	307	25.153	29.432	27.627	27.681	0.0483	0.846	0.716
H4	263	25.508	29.7	27.777	27.822	0.0512	0.83	0.688
I2	285	25.762	29.985	28.086	28.165	0.0494	0.833	0.694
M3	239	28.608	32.622	30.606	30.587	0.0467	0.722	0.522

		2014 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	15	25.462	27.810	26.647	26.727	0.170	0.658	0.433
B3	15	25.645	28.073	26.869	27.014	0.175	0.679	0.461
D3	15	26.345	28.299	27.411	27.628	0.148	0.574	0.330
F3	14	26.765	28.480	27.808	28.017	0.143	0.537	0.288
H4	13	26.843	28.578	28.002	28.199	0.150	0.541	0.293
I2	11	26.880	29.035	28.224	28.446	0.214	0.710	0.504
M3	10	29.051	31.173	30.511	30.838	0.218	0.689	0.474

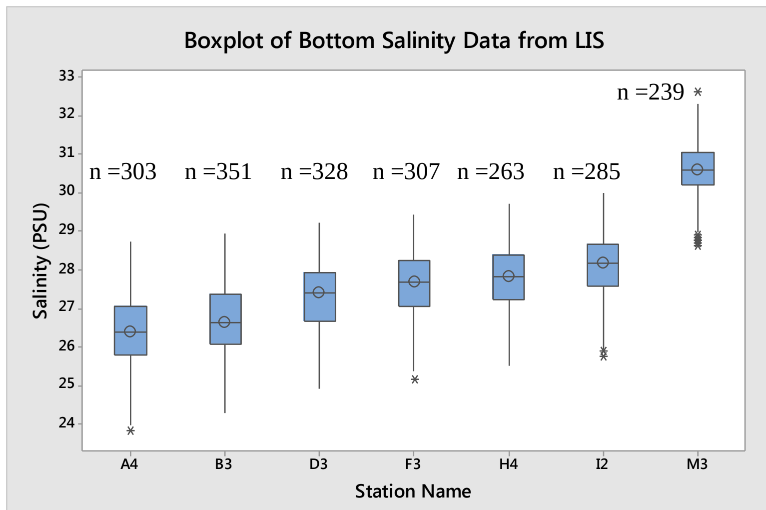
		1991-2014 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	293	22.833	28.278	25.681	25.694	0.0609	1.043	1.088
B3	333	22.8	28.84	26.074	26.126	0.0586	1.07	1.145
D3	310	23.772	29.146	26.701	26.692	0.06	1.056	1.115
F3	286	24.246	29.307	26.843	26.835	0.0636	1.075	1.155
H4	243	24.315	29.262	27.103	27.17	0.0685	1.067	1.139
I2	254	24.56	29.909	27.513	27.545	0.0645	1.028	1.056
M3	199	24.789	31.837	29.937	29.993	0.0745	1.051	1.105

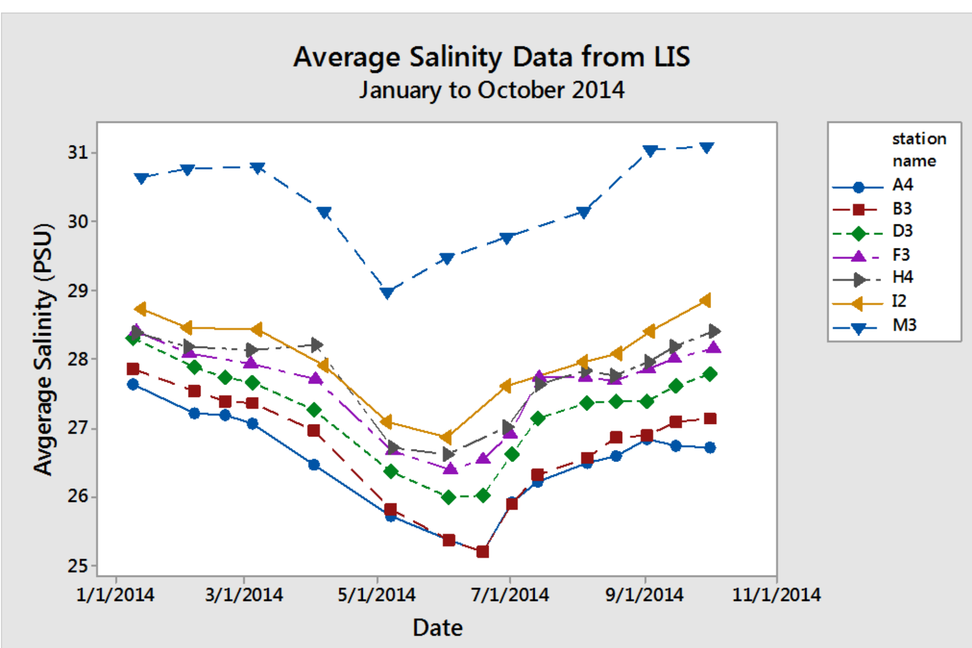
		2014 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	15	24.218	26.890	25.904	26.123	0.245	0.951	0.904
B3	14	24.637	27.505	26.255	26.429	0.271	1.014	1.029
D3	15	25.174	28.283	26.835	27.084	0.267	1.033	1.068
F3	13	25.576	28.230	26.939	27.179	0.267	0.964	0.928
H4	12	25.860	28.169	27.276	27.495	0.263	0.912	0.831
I2	11	26.553	28.772	27.632	27.557	0.239	0.794	0.631
M3	10	26.950	30.926	29.326	30.097	0.483	1.529	2.337



This box plot, based upon data collected during CT DEEP surveys from January 1991 – October 2014, shows the median surface salinity, range, interquartile range, and outliers by station. Surface in this case refers to data collected two (2) meters below the air/water interface. Salinity increases from west to east across the Sound.

This box plot, based upon data collected during CT DEEP surveys from January 1991- October 2014 shows the median bottom salinity, range, interquartile range, and outliers by station. Bottom in this case refers to data collected five (5) meters above the sediment/water interface. The bottom waters are generally saltier than the surface waters.

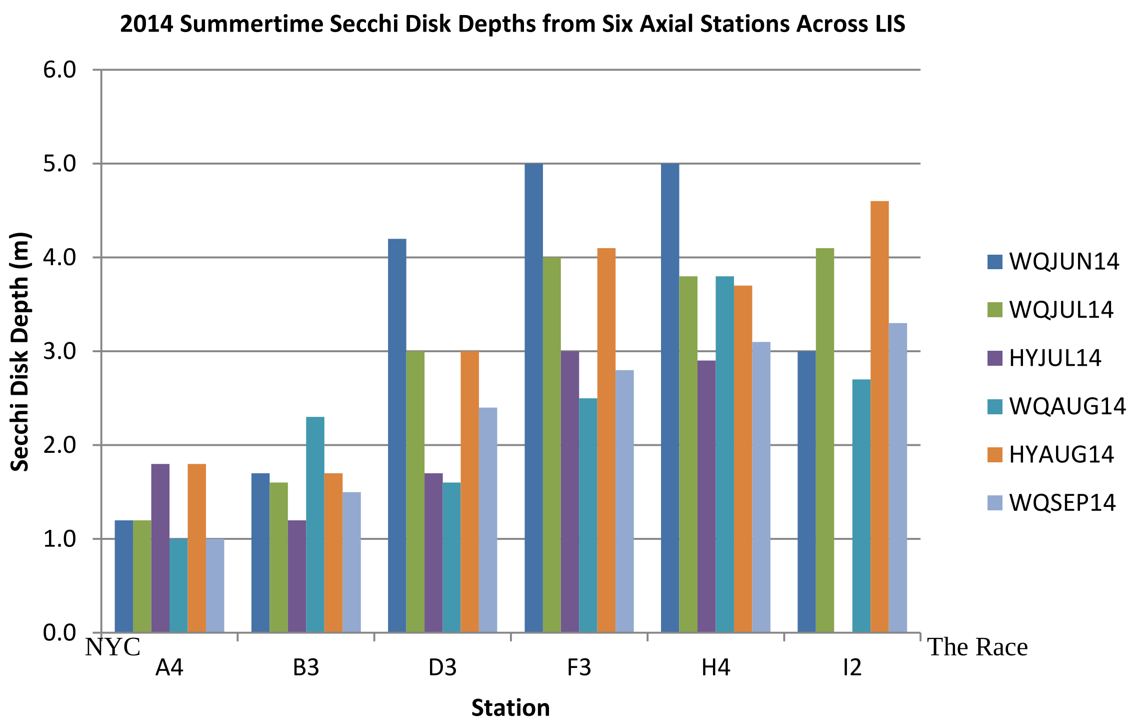




This plot illustrates the temporal variability of the mean salinity values by station from January- October 2014.

Water Clarity

Water clarity is measured by lowering a Secchi disk into LIS by a measured line 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. Transparency may be reduced by both absorption and scattering of light. Water absorbs light, but absorption is greatly increased by the presence of organic acids that stain the water a brown "tea" color and by particles. Scattering is largely due to turbidity, which can be attributable to both inorganic silt or clay particles, or due to organic particles such as detritus or planktonic algae suspended in the water. CT DEEP began taking Secchi Disk measurements in June 2000. Since then, 3037 measurements have been entered into our database; of those 1,847 are from the 17 stations sampled annually. The 2000-2014 average Secchi depth is 2.3 m with a minimum depth of 0.4 m (WQSEP05, station A4) and a maximum depth of 6.2 m (WQNOV00 Station K2). Below is a graph depicting Secchi disk depths from six of the axial stations sampled by CT DEEP LISS Water Quality Monitoring Program between May and September 2014.



2014 data

- **Average Secchi Disk Depth: 2.83 m (n=294)**
- **Minimum Secchi Disk Depth: 1.0 m on multiple dates/stations**
- **Maximum Secchi Disk Depth: 5.1 m at Station 09 during the WQAPR14 cruise**

2013 data

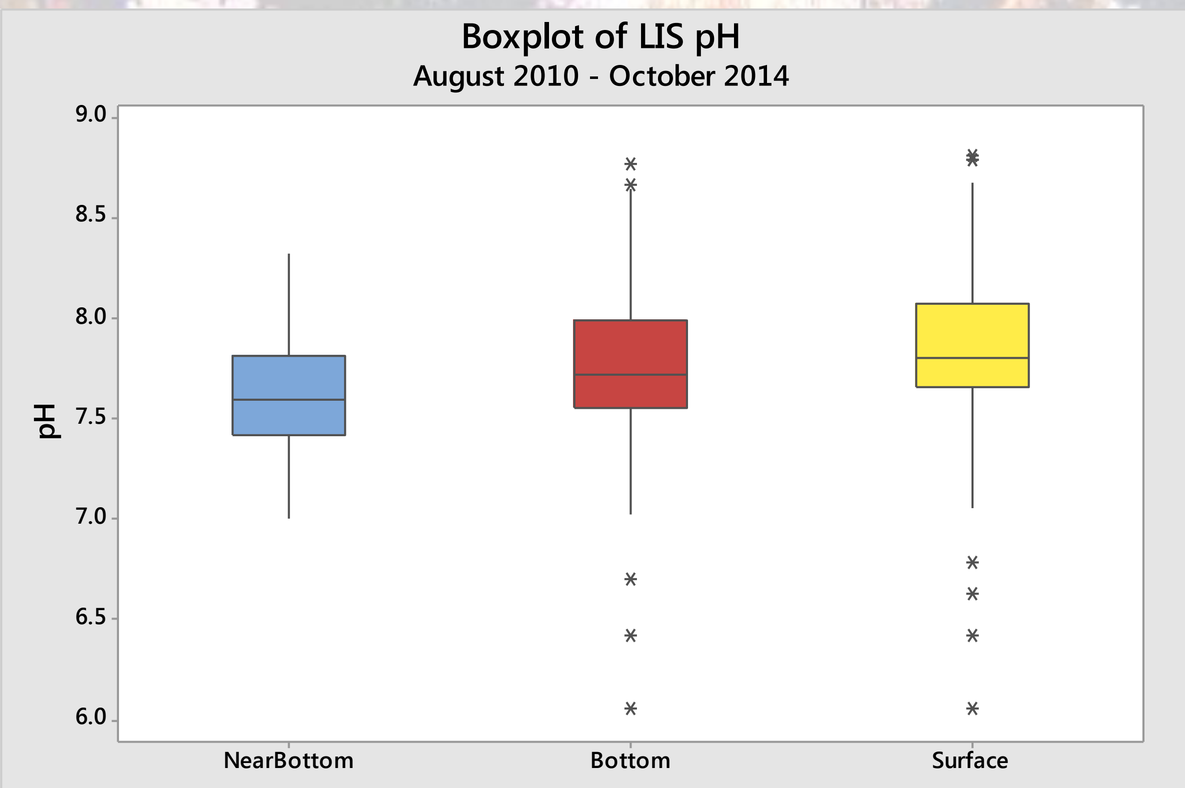
- **Average Secchi Disk Depth: 2.33 m (n=260)**
- **Minimum Secchi Disk Depth: 0.9 m at Station A4 during the WQAUG13 cruise**
- **Maximum Secchi Disk Depth: 4.2 m at Stations J2 during the WQAPR13 cruise**

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. Carbonate ions are utilized by marine organisms in shell and skeletal formation. According to the NOAA Pacific Marine Environmental Laboratory Ocean Acidification Home Page, the pH of the ocean surface waters has already decreased from an average of 8.21 SU to 8.10 SU since the beginning of the industrial revolution and the Intergovernmental Panel on Climate Change predicts a decrease of an additional 0.3 SU by 2100. (See http://www.pmel.noaa.gov/co2/OA/background.html.)

With this issue in mind, CT DEEP upgraded its SeaCat Profilers and began collecting and reporting pH data in August 2010. Data collected through the WQOCT14 survey are summarized below.

	n	Maximum	Minimum	Mean	Median	SE Mean	StDev	Variance	Q1	Q3
Near Btm	993	8.3150	7.0030	7.6165	7.5940	0.00791	0.2491	0.0621	7.4420	7.8160
Bottom	1019	8.762	6.061	7.7604	7.7210	0.00949	0.3028	0.0917	7.5490	7.9910
Surface	1558	8.8060	6.0660	7.8445	7.7970	0.00700	0.2763	0.0763	7.6520	8.0700



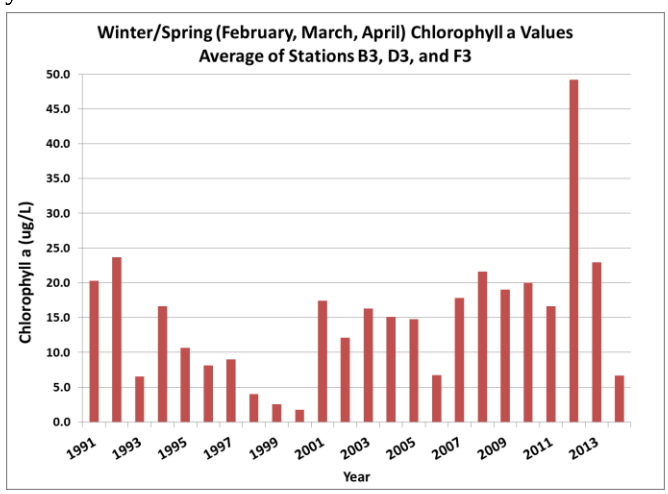
Chlorophyll a

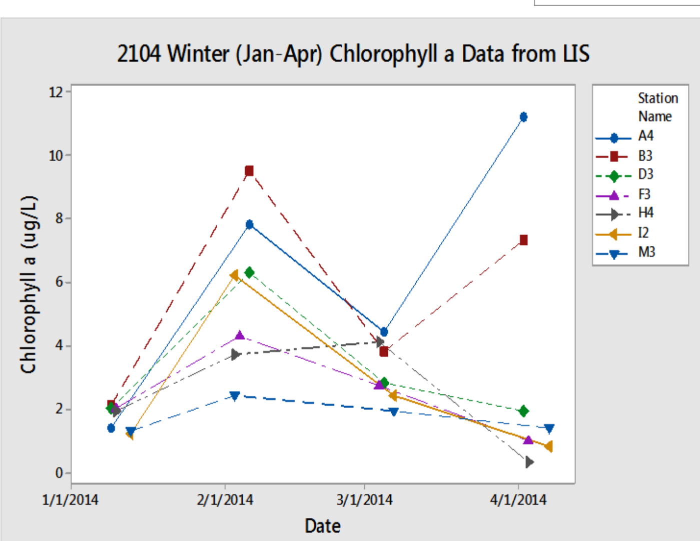
Chlorophyll is a pigment found in plants that gives them their green color. It allows plants to absorb light from the sun and convert it to chemical energy during photosynthesis. In photosynthesis carbon dioxide and water are combined to produce sugar giving off oxygen as a byproduct. Microscopic plants, called phytoplankton, form the basis of the food web in Long Island Sound. However, as in most cases in nature, too much phytoplankton may not be a good thing. 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.

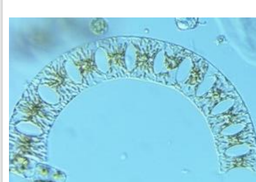
Chlorophyll a concentrations are measured *in situ* using the CTD fluorometer as well as through the collection of grab samples using Niskin bottles. The grab samples are brought back into the onboard lab, filtered, and then sent to UConn for analysis.

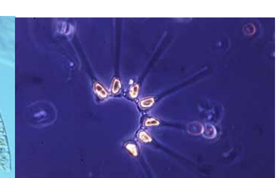
The spring phytoplankton bloom occurs in Long Island Sound between February and April. Historically high levels of chlorophyll a in the western Sound during this time have been linked to summertime hypoxia conditions.



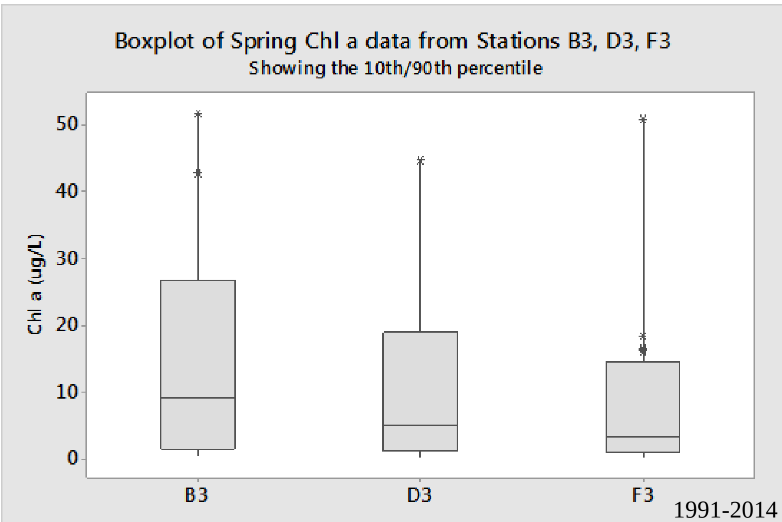


This plot illustrates the temporal variability of the surface chlorophyll a values (grab samples) by station from January-April 2014. The spring bloom was captured during the WQFEB14 (2/3-6/14) survey.





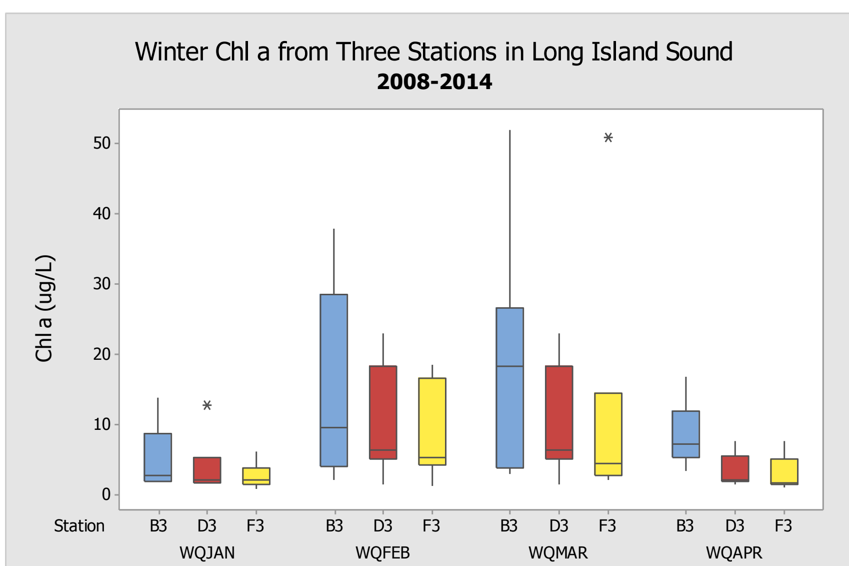
The Integration and Application Network at the University of Maryland Center for Environmental Science is preparing a report card for Long Island Sound to be released to the public in 2015. Chlorophyll a is a potential indicator with proposed thresholds at 5 ug/L and 20 ug/L. The National Coastal Condition 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.

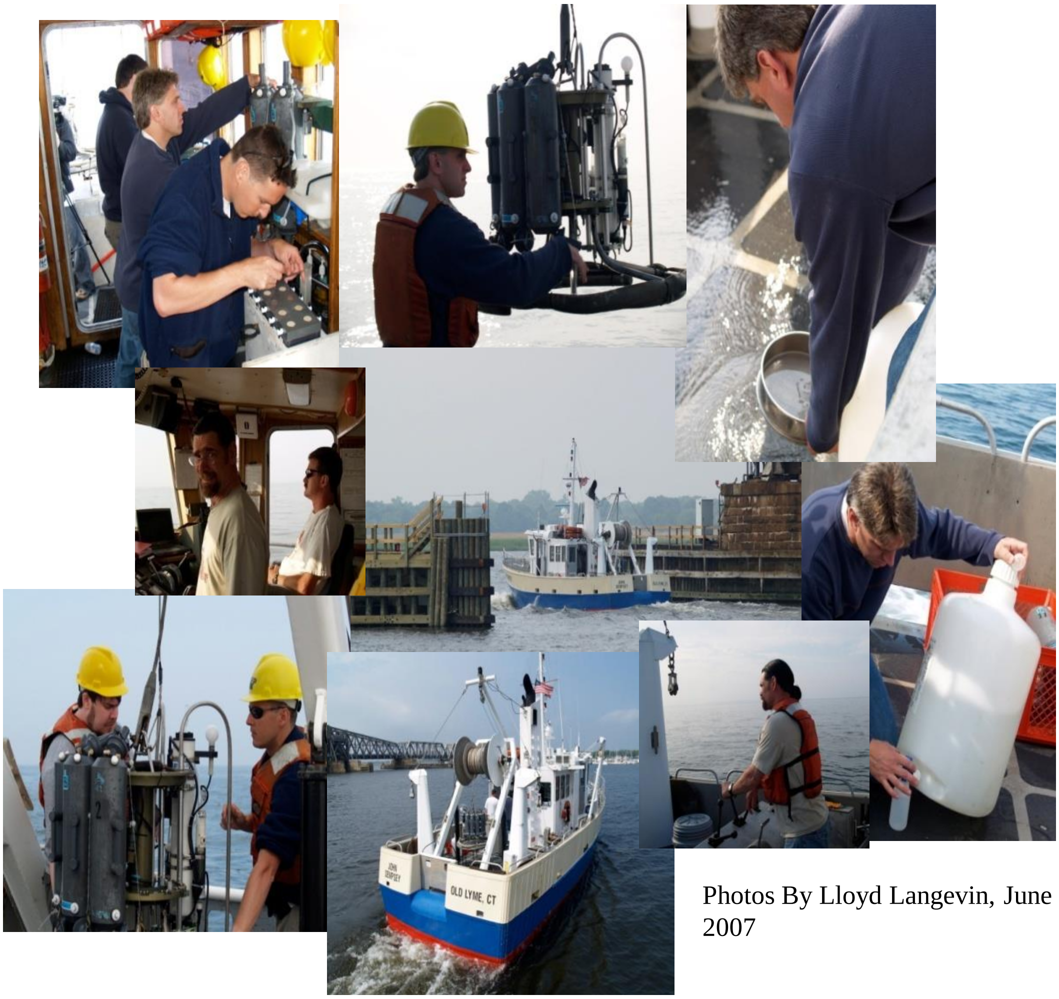


This boxplot examines spring (January- April) surface chlorophyll a data from three stations- B3, D3, and F3, in the western/central portion of LIS from 1991 to October 2014. At stations D3 and F3, 90% of the individual data are less than 20 ug/L and 75% of the data at B3 are less than 20 ug/L. This would place these stations in the fair category. The average concentration at each station is less than 20 ug/L but above 5 ug/L.

	n	Min	10th %	25th %	Median	75th %	90th %	Maximum	Mean	St Dev
B3	86	0.40	1.653	3.50	9.33	17.69	26.91	51.90	12.16	1.16
D3	85	0.50	1.26	2.488	5.10	12.15	19.1	44.80	8.00	7.902
F3	68	0.50	1.1	1.50	3.450	7.075	14.52	51.00	5.693	0.873

This boxplot examines recent data by survey. CHFEB and CHMAR surveys were not included because they did not occur in all years.





Photos By Lloyd Langevin, June 2007

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