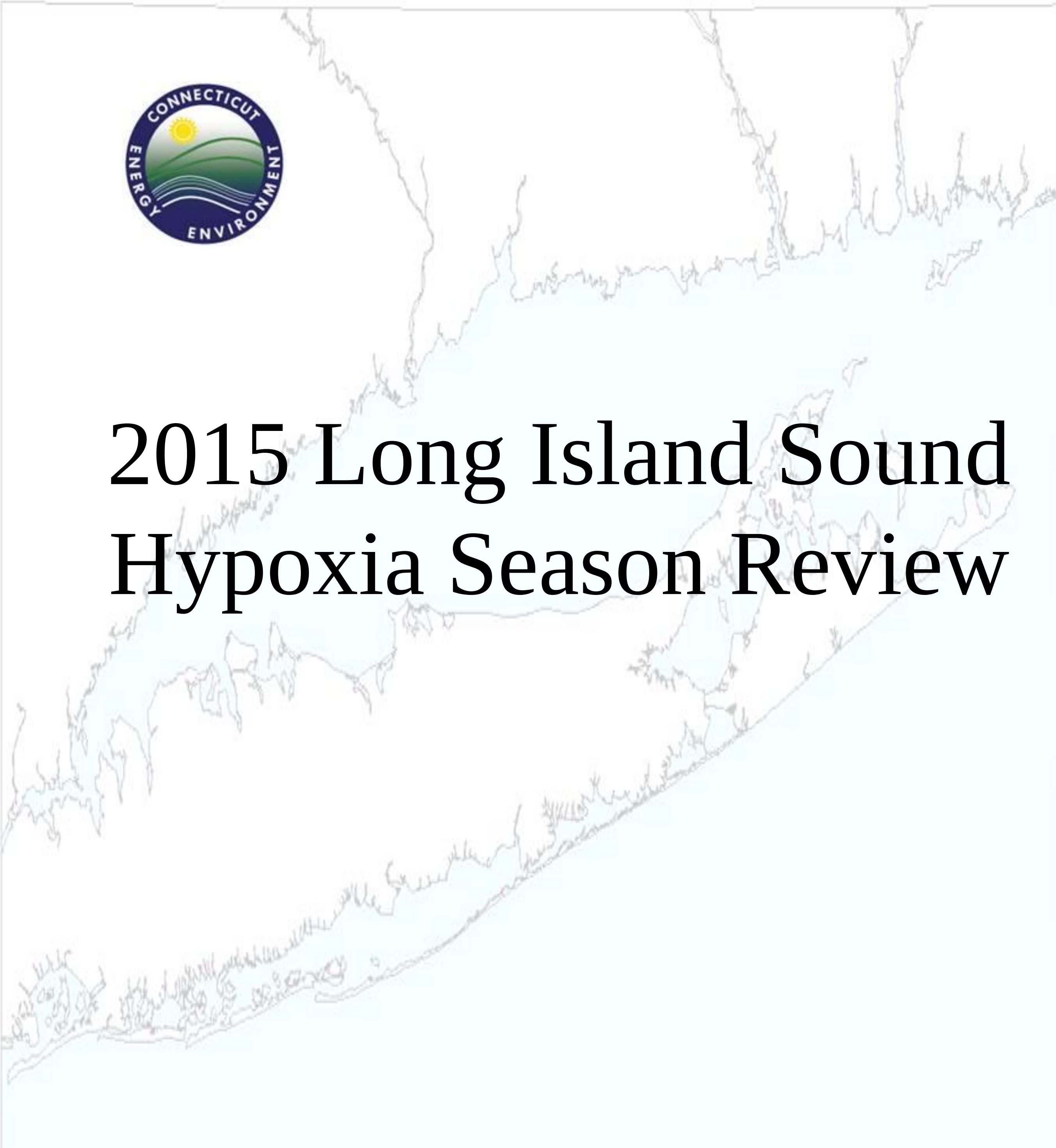


2015 Long Island Sound Hypoxia Season Review

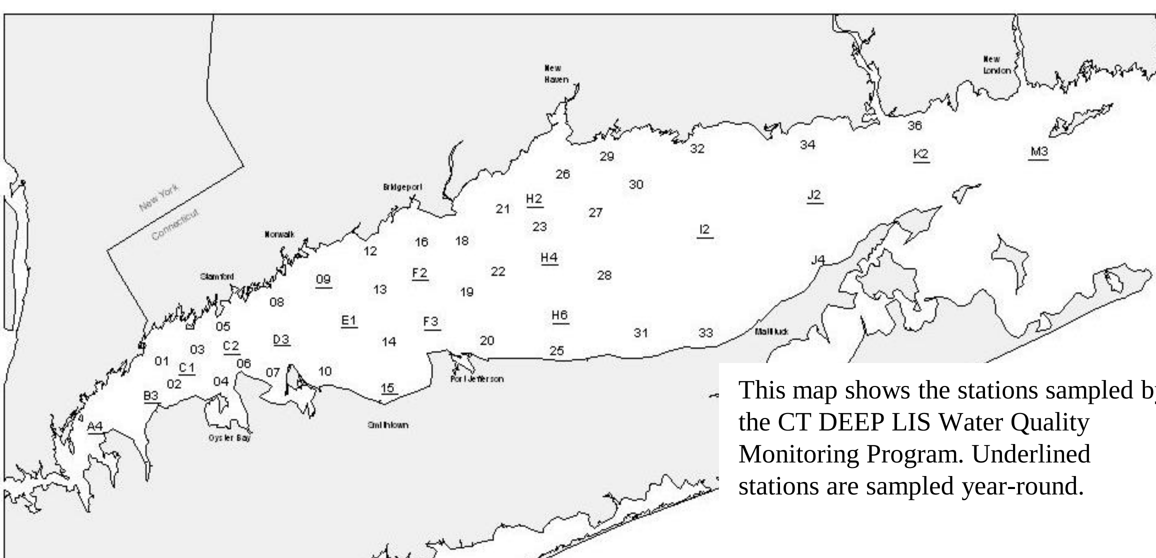
CONNECTICUT DEPARTMENT OF ENERGY & ENVIRONMENTAL PROTECTION
79 ELM STREET, HARTFORD, CT 06106
ROBERT J. KLEE, COMMISSIONER

MONITORING LONG ISLAND SOUND 2015

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.

CT DEEP Methods

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) 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* data 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.

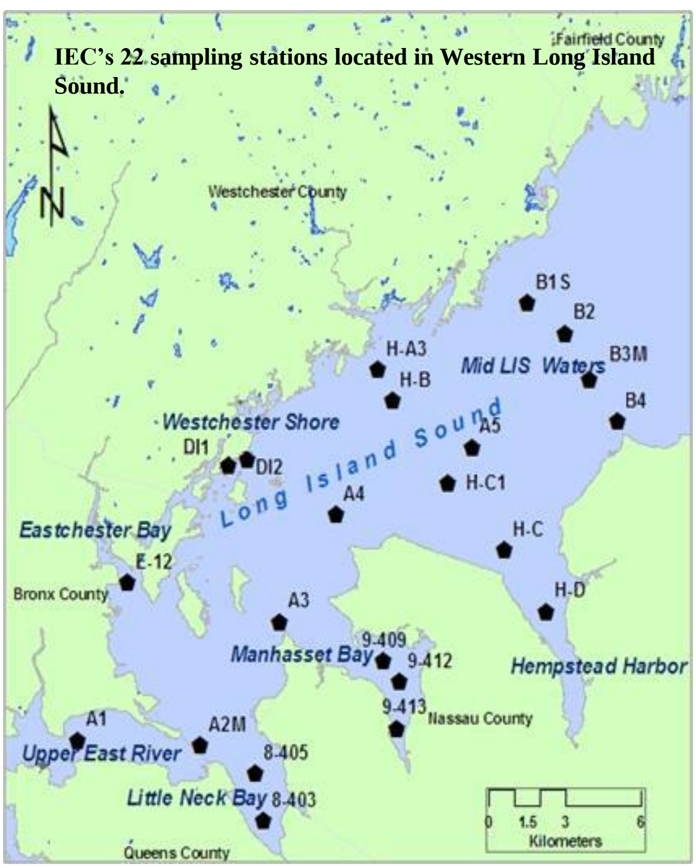
Since 2002, CT DEEP has collected zooplankton samples from six stations and phytoplankton from ten stations across Long Island Sound. The samples are sent to researchers at the University of Connecticut who identify species composition, abundance, community structure, and spatial and temporal distribution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

IEC

The Interstate Environmental Commission (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 the 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 2015 have been used to create hypoxia map interpolations in the far western Sound and appear on pages 13-22 adjacent to CTDEEP hypoxia maps. These maps are for illustrative purposes only.



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

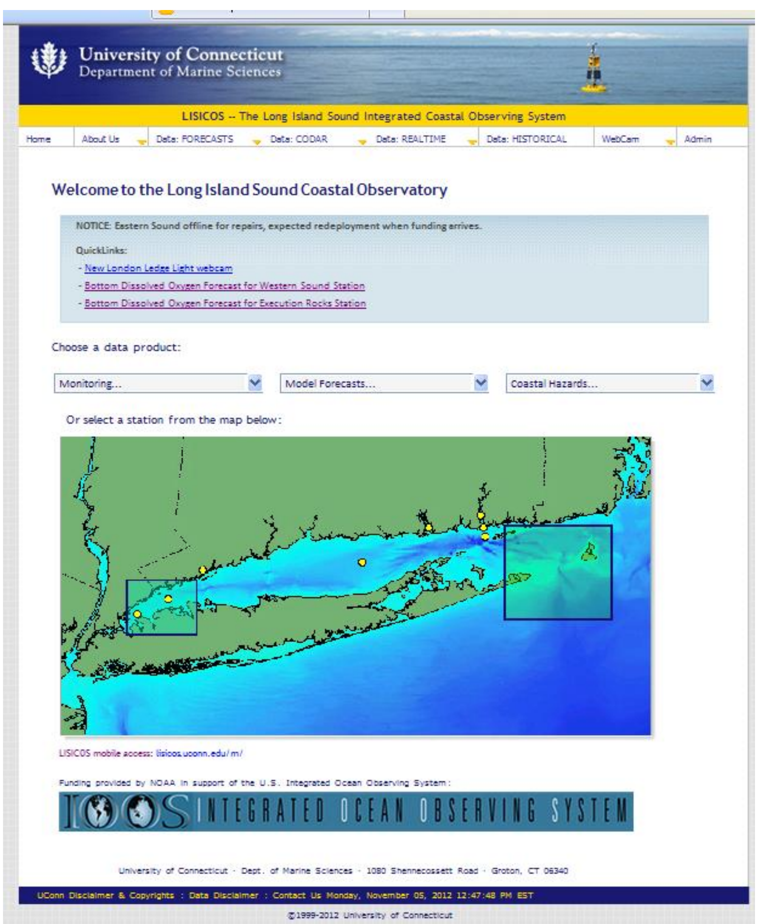
IEC Analyst utilizes a multi-parameter meter at station A2M during a summer monitoring survey

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.

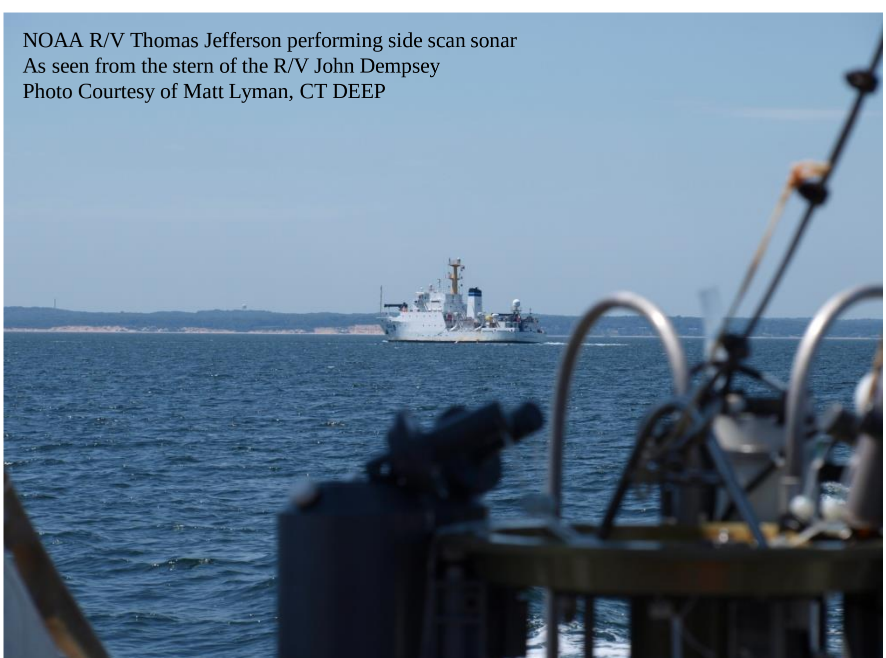


This report presents a summary of the 2015 *in situ* data collected by CT DEEP. Data from LISICOS and IEC are presented with permission for informational purposes.

The CT DEEP and IEC LIS Water Quality Monitoring Programs are synoptic in nature and are 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 programs are useful for future determinations of volume of hypoxic waters. Both programs support long term monitoring databases designed to detect changes in hypoxia due to changing conditions (i.e. management actions, climate change, productivity). The CT DEEP program also provides nutrient and biological data not available from fixed station buoy applications.

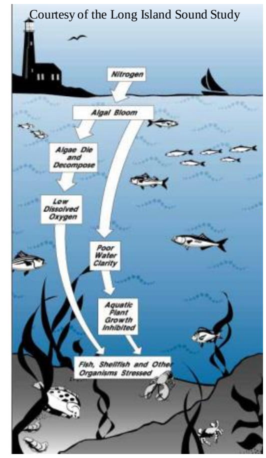
The LISICOS water quality sensors are attached to fixed locations and provide a holistic view of the conditions over a more detailed span of time (i.e., data measured every 15 minutes from one station as opposed to every two weeks). The LISICOS continuously recording buoys have shown instances where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

As such CT DEEP and IEC data provide 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.

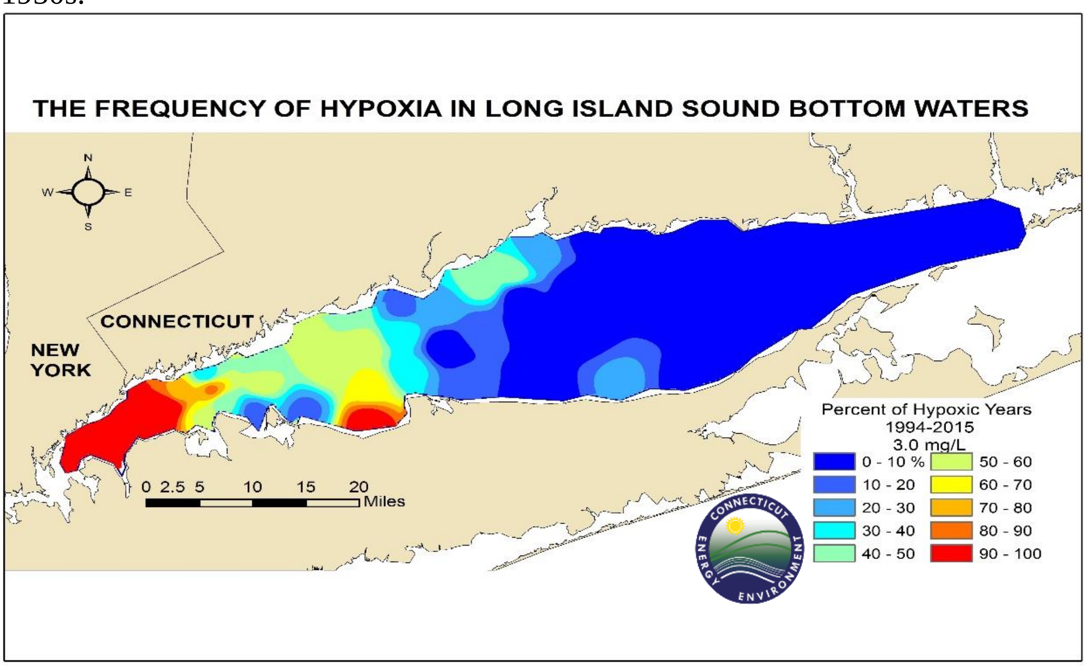


NOAA R/V Thomas Jefferson performing side scan sonar
As seen from the stern of the R/V John Dempsey
Photo Courtesy of Matt Lyman, CT DEEP

What is Hypoxia?



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.



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.

2015 Important Facts

CT DEEP conducted eight cruises during the summer of 2015 between 28 May and 16 September. Over the course of the season, five (5) different stations were documented as hypoxic and of the 252 site visits completed in 2015, hypoxic conditions were found four surveys. Compared to the previous 24-year average, 2015 was below average in area and near average in duration. In fact, 2015 had the second smallest area behind 1997 (see page 9).

Cruise	Start Date	End Date	Number of stations sampled	Number of hypoxic stations	Hypoxic Area (mi^2)
WQJUN15	5/28/15	6/5/15	17	0	0
HYJUN15	6/17/15	6/19/15	28	0	0
WQJUL15	7/6/15	7/8/15	40	0	0
HYJUL15	7/20/15	7/23/15	39	3	29.4
WQAUG15	8/3/15	8/6/15	39	3	34.8
HYAUG15	8/17/15	8/19/15	36	3	38.3
WQSEP15	8/31/15	9/2/15	31	2	21.7
HYSEP15	9/16/15	9/16/15	22	0	0

The peak event occurred during the HYAUG15 cruise between 17 and 19 August. The lowest dissolved oxygen concentration (2.12 mg/L) was documented during the HYJUL15 and HYAUG15 cruises at Station A4. The hypoxia area maps for 2015 appear on pages 12-21.

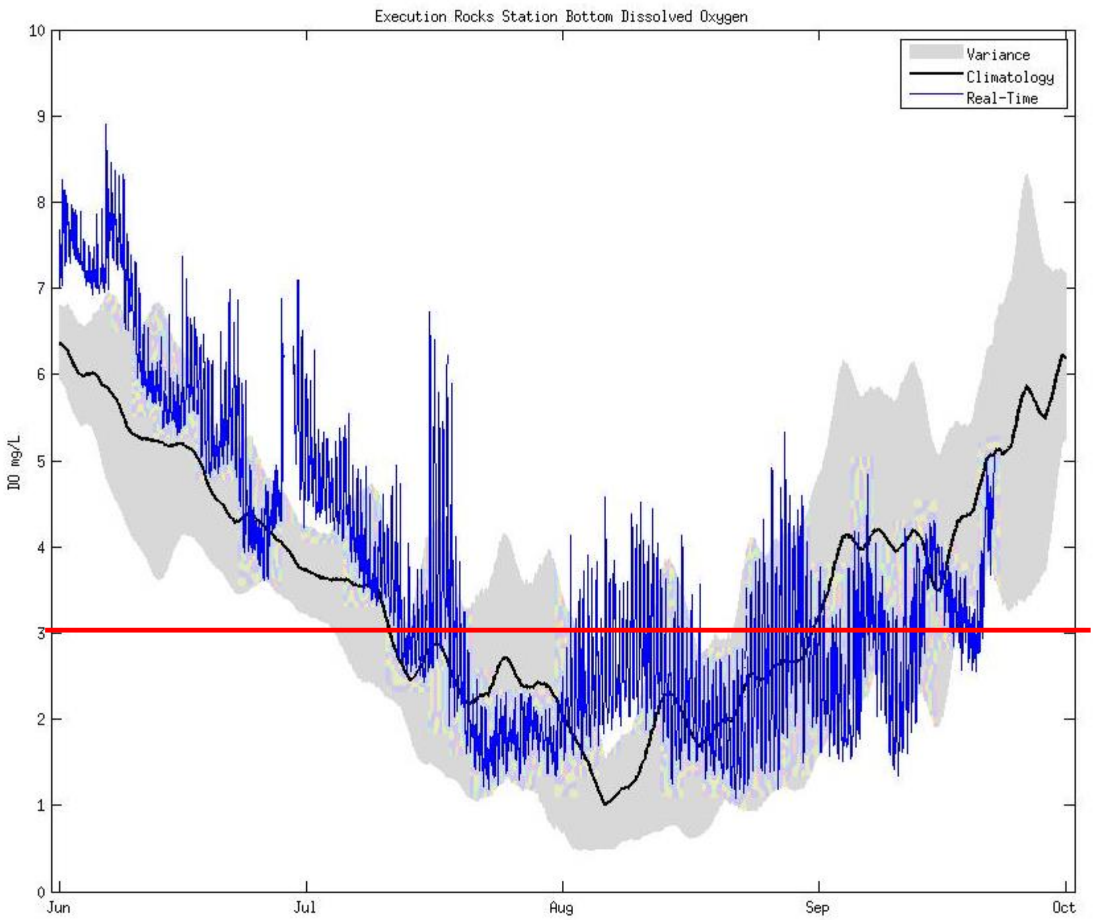
Based on CT DEEP and NEIWPCC-IEC data

Estimated Start Date	7/16/2015
Estimated End Date	9/10/2015
Duration (days)	57
Maximum Area (mi^2)	**38.3**

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.

Duration Based on Buoy Data Obtained From the LISICOS Network on 28 September 2015

The figure below is from the LISICOS website and depicts the 2015 real-time bottom dissolved oxygen data (blue line); the average of the 10 year dataset (black line); and the variability observed over the historical station record (gray shading) from the Execution Rocks Buoy. The Western Sound Buoy was offline the entire summer after sustaining damage over the winter of 2014-2015.



Based on LISICOS Buoy Data Collected Between 1 June to 28 September

	<u>Execution Rocks</u>
Estimated Start Date	7/12/15
Estimated End Date	9/21/15
Duration below 3.0 mg/L (cumulative days)	50.07
Duration below 2.0 mg/L (cumulative days)	22.25
Duration below 1.0 mg/L (cumulative days)	0.00
Minimum DO value (mg/L)	1.09 (21 August)

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

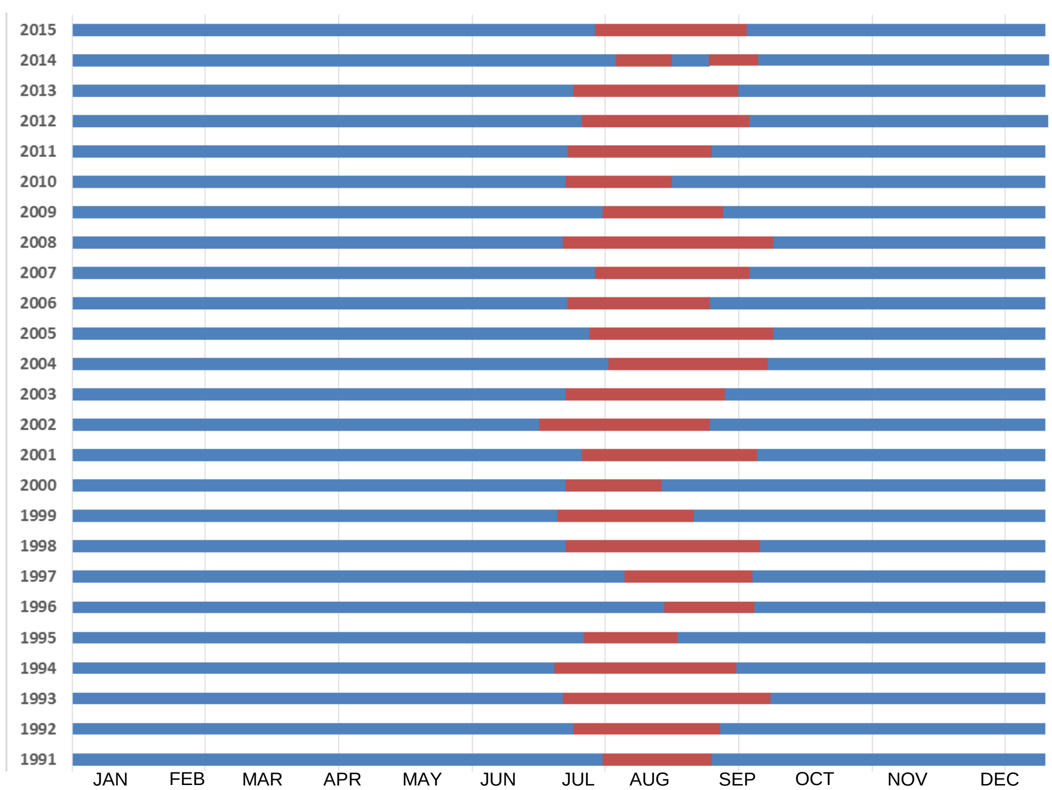
Timing and Duration of Hypoxia, 1991 - 2015

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 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
2015	July 16	Sept 10	38.3	57
Average	July 12	Sept 4	169	55
Deviation	±10 days	±12 days	± 87 mi^2	± 13 days

The figure and table below display the onset, duration, and end of the hypoxia events from 1991 through 2015 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 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 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.

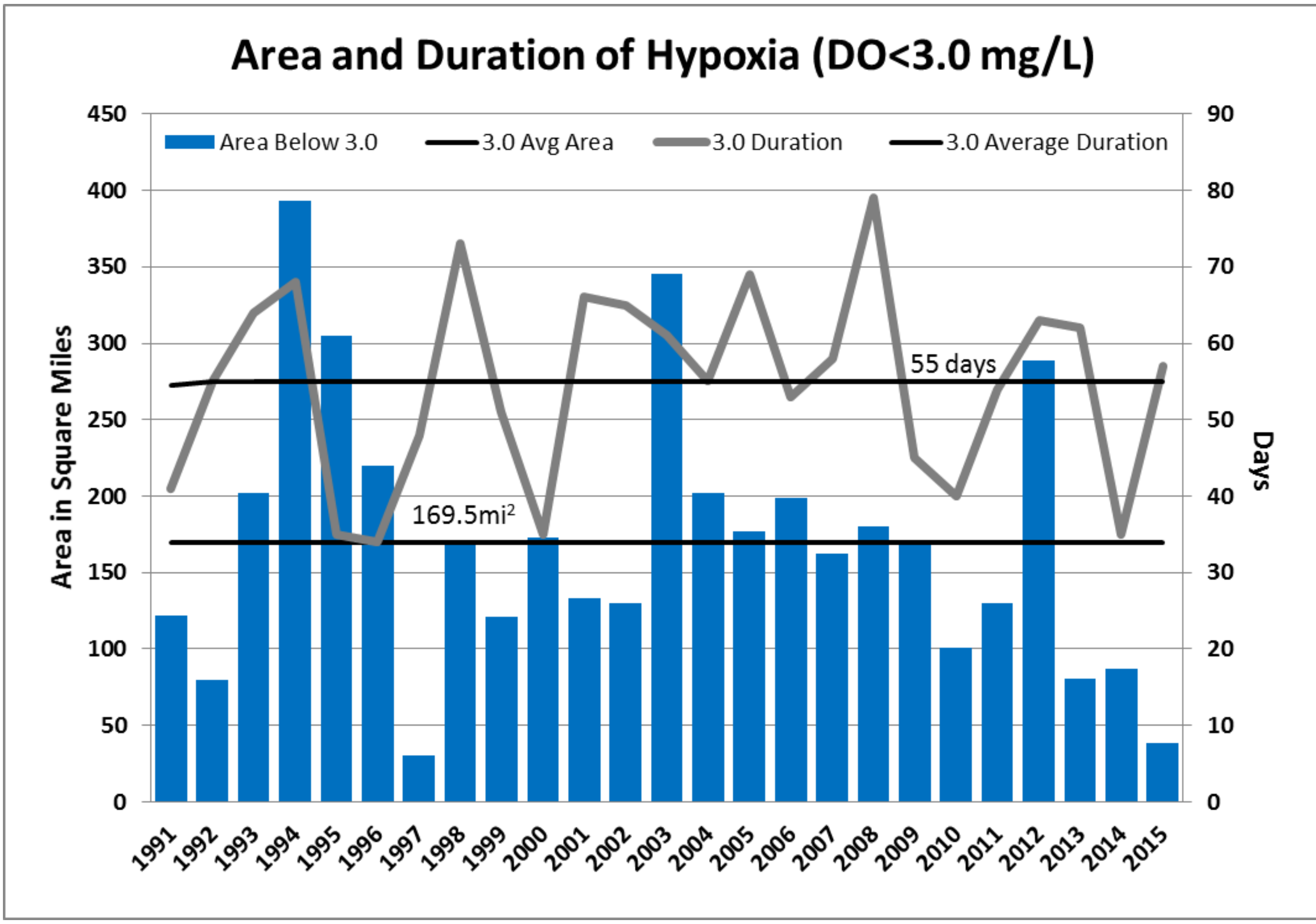
* In 2014 there was a clear period of 14 days where the DO concentration rose above the 3.0 mg/L threshold in the middle of August before dipping again during late August and early September.

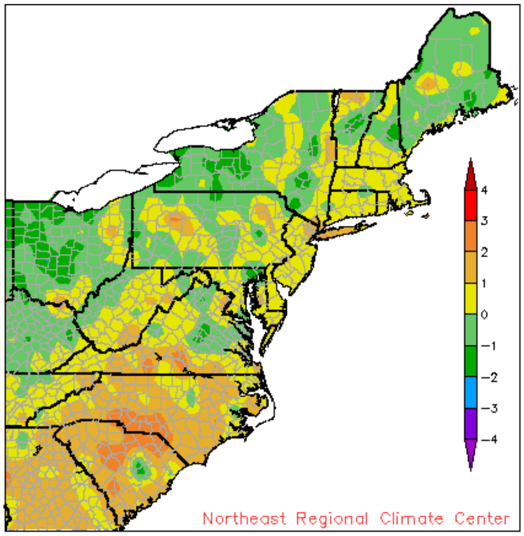


Timing and Duration of Hypoxia based on 3.0 mg/L

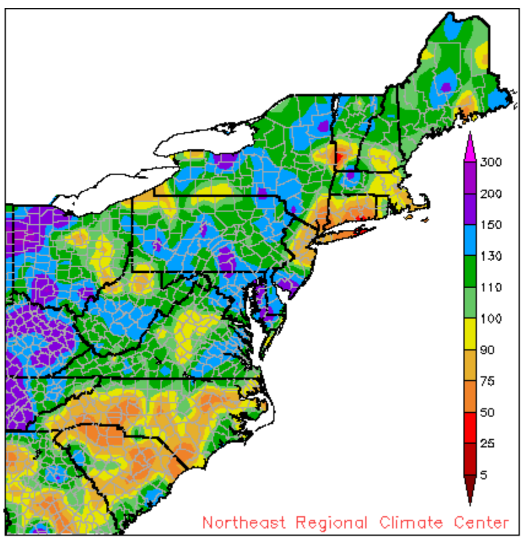
Yearly Comparison of Maximum Areal Extent and Duration of Hypoxia

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 169.5 mi^2 and the average duration was 55 days.

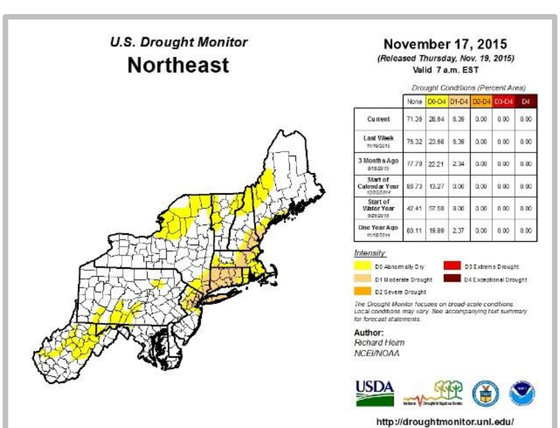




Departure from Normal Temperature (ºF)
June 1-August 31, 2015



Percent of Normal Precipitation (%)
June 1- Aug 31, 2015



2015 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 2015.
http://www.nrcc.cornell.edu/services/reports/reports/2015-09.pdf

Average spring air temperatures were below normal for the area through March but warmer to above normal in May. June saw average temperatures across the region. July and August average temperatures across the region were above normal by 2-3 degrees. Record warmth was seen at Kennedy Airport during August. September temperatures continued above normal with Islip, NY marking the first part of the month as its warmest on record, 5 degrees above normal. Bridgeport, CT reported its second warmest September on record.

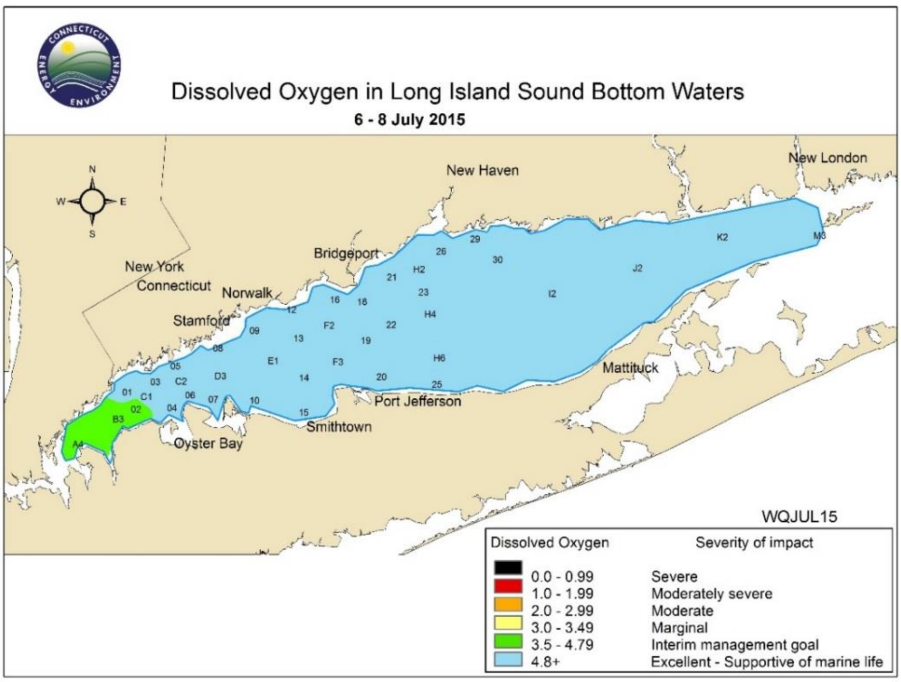
Spring precipitation was below normal for CT and Long Island, resulting in moderate drought conditions across the region. June was wetter than May, but abnormally dry conditions persisted into July and August On the last day of September, a slow moving cold front combined with remnants of a tropical system to bring 1-2 inches of rain to the region. Precipitation continued to be scarce through October and into November 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.

Hypoxia Maps

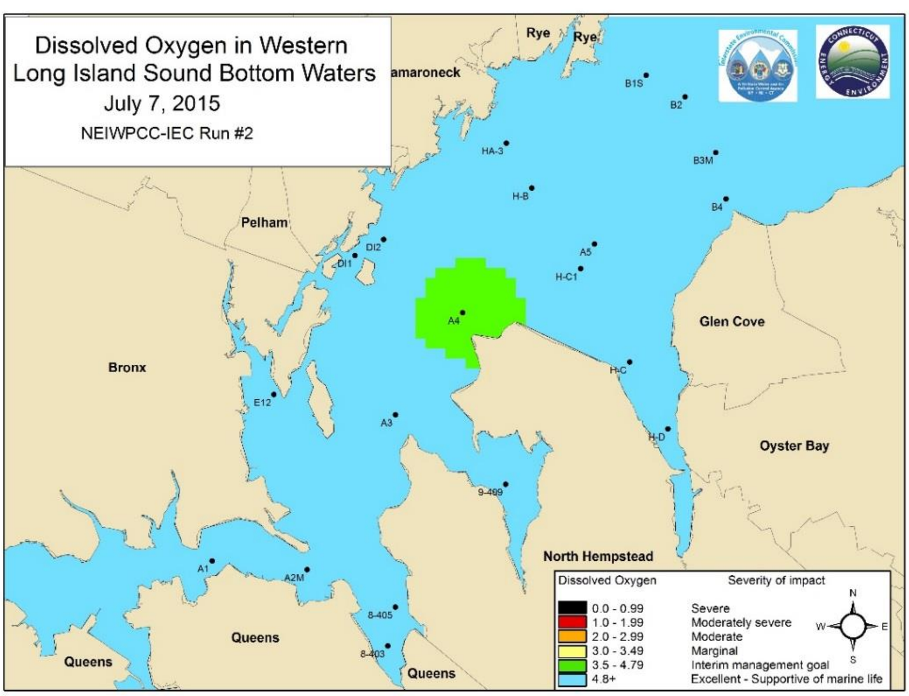
The following maps depict the development of hypoxia based on CT DEEP cruise data through the 2015 season. Data for all surveys are available upon request. NEIWPCC-IEC data were also mapped to provide additional details on hypoxic conditions in the far western Sound. IEC data are considered provisional. IEC data are not utilized to estimate the areal extent of hypoxia.

During the **WQJUN15** and **HYJUN15** survey all stations (CT DEEP and IEC) had DO concentrations **above 4.8 mg/L; therefore, no maps were produced**.



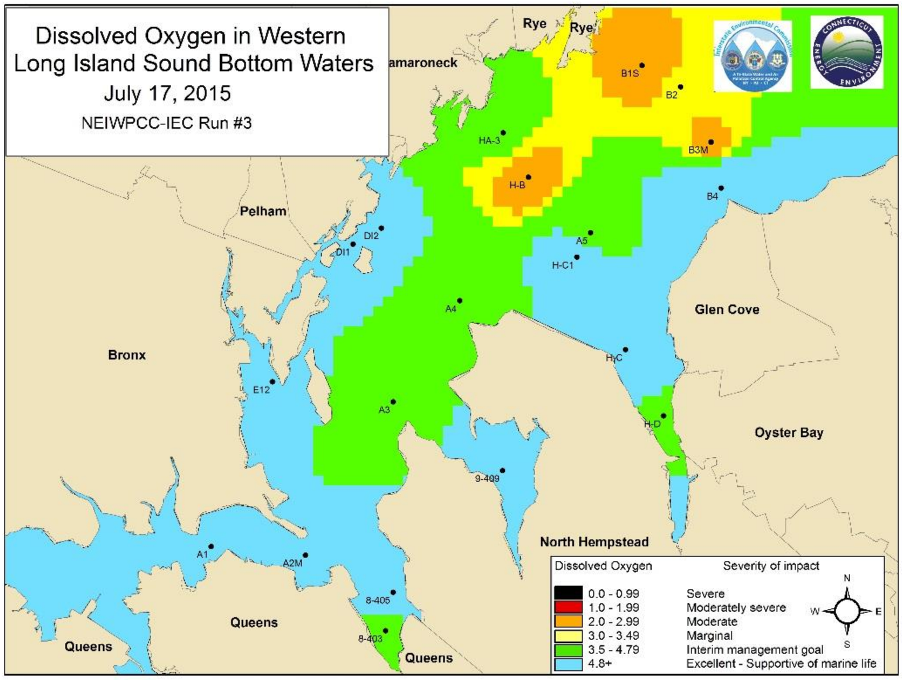
WQJUL15

During the WQJUL15 survey dissolved oxygen concentrations in the bottom waters of LIS were less than 4.8 mg/L at three CT DEEP stations in the far western Narrows- A4, B3, and 02. IEC only found DO concentrations below 4.8 mg/L at Station A4.

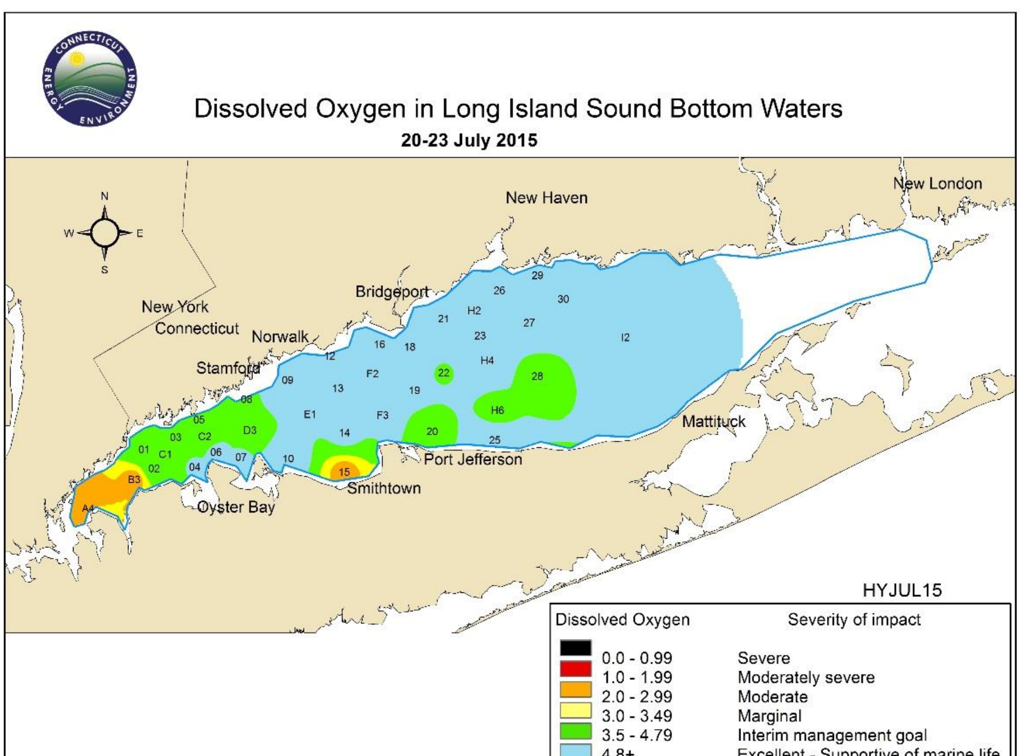


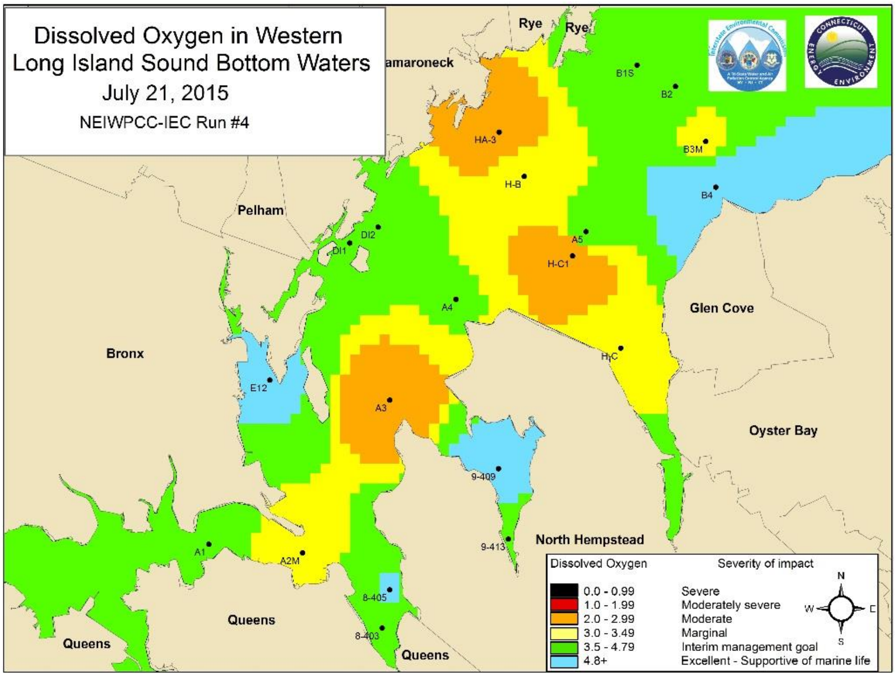
HYJUL15

During IEC Run #3, 11 out of 21 stations exhibited DO concentrations below 4.8 mg/L. Of those, Station B2 was at 3.0 mg/L and three stations were below 3.0 mg/L.



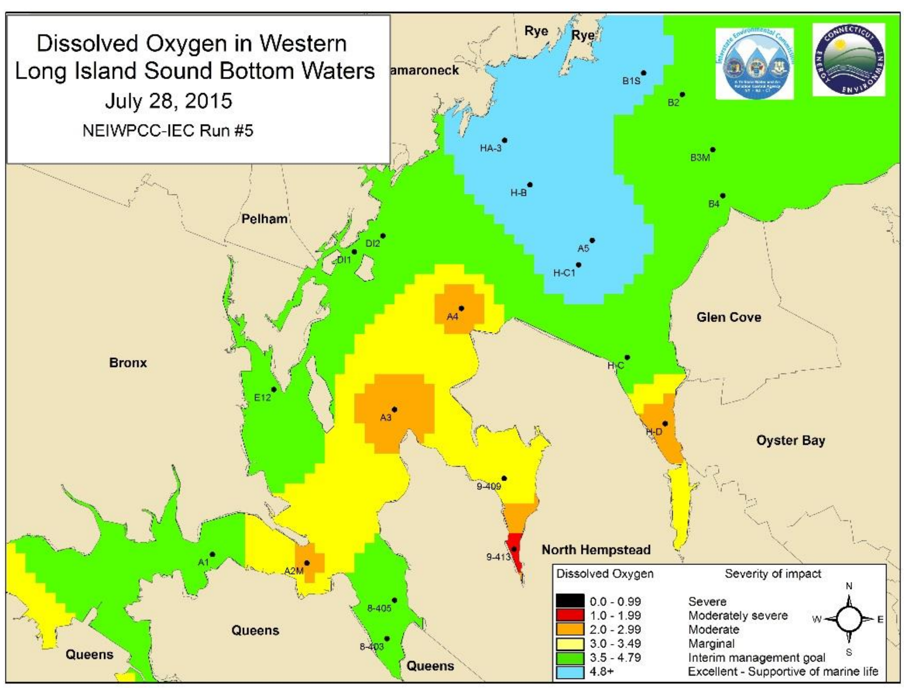
During the HYJUL15 survey, DO concentrations dropped below 4.8 mg/L at 12 stations with three stations below 3.0 mg/L.





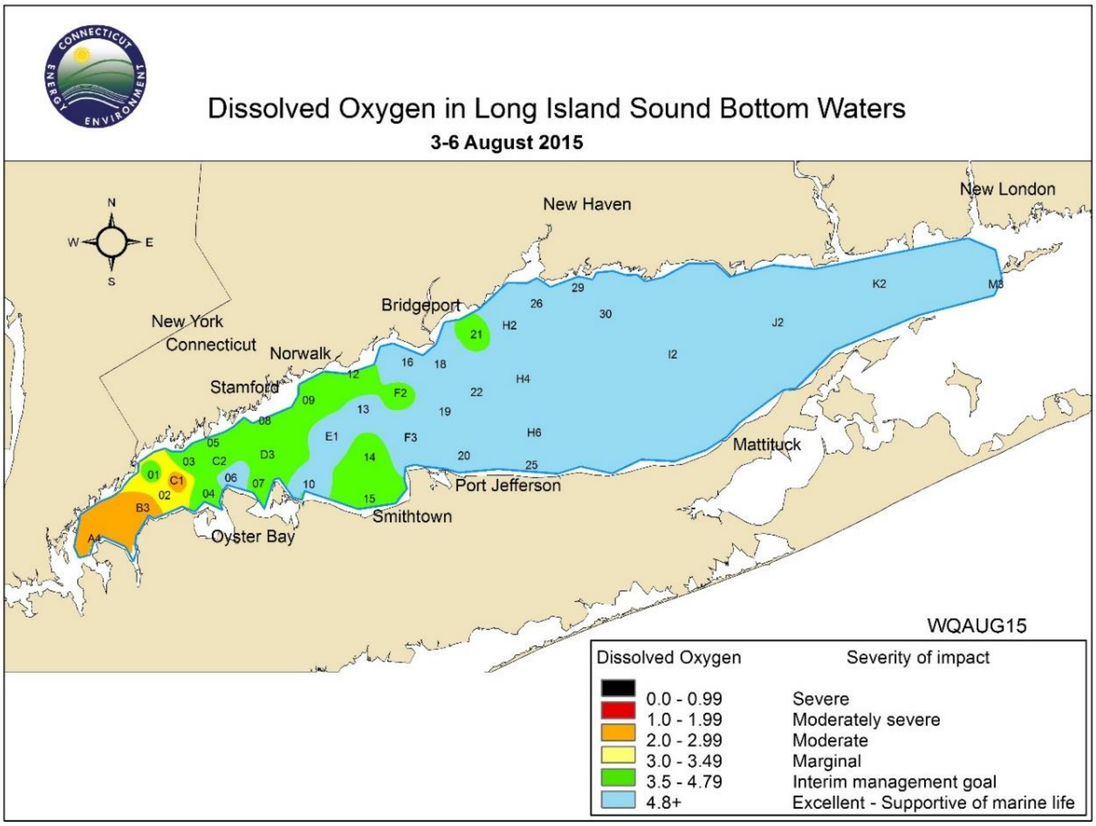
IEC Run #4 occurred two weeks prior to the CTDEEP WQAUG15 survey. At Station A4 the DO was 3.5 mg/L. Station B3 was at 3.3 mg/L. Stations A3, HA-3, and H-C1 dropped below 3.0 mg/L (2.5, 2.7, and 2.1 mg/L, respectively).

IEC Run #5 occurred on 7/28/15, a week prior to the CTDEEP WQAUG15 survey. Sixteen (16) stations were less than 4.8 mg/L. Of those, four were less than 3.5 mg/L and one station, 9-413, was less than 2.0 mg/L. At Station A4 the DO was 2.6 mg/L. Station B3 was at 3.5 mg/L.

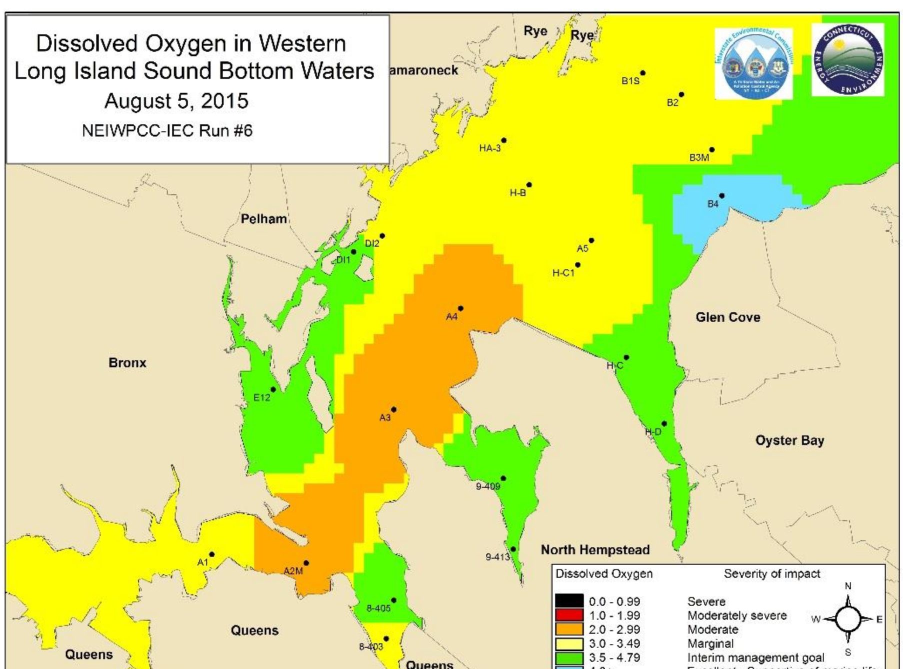


WQAUG15

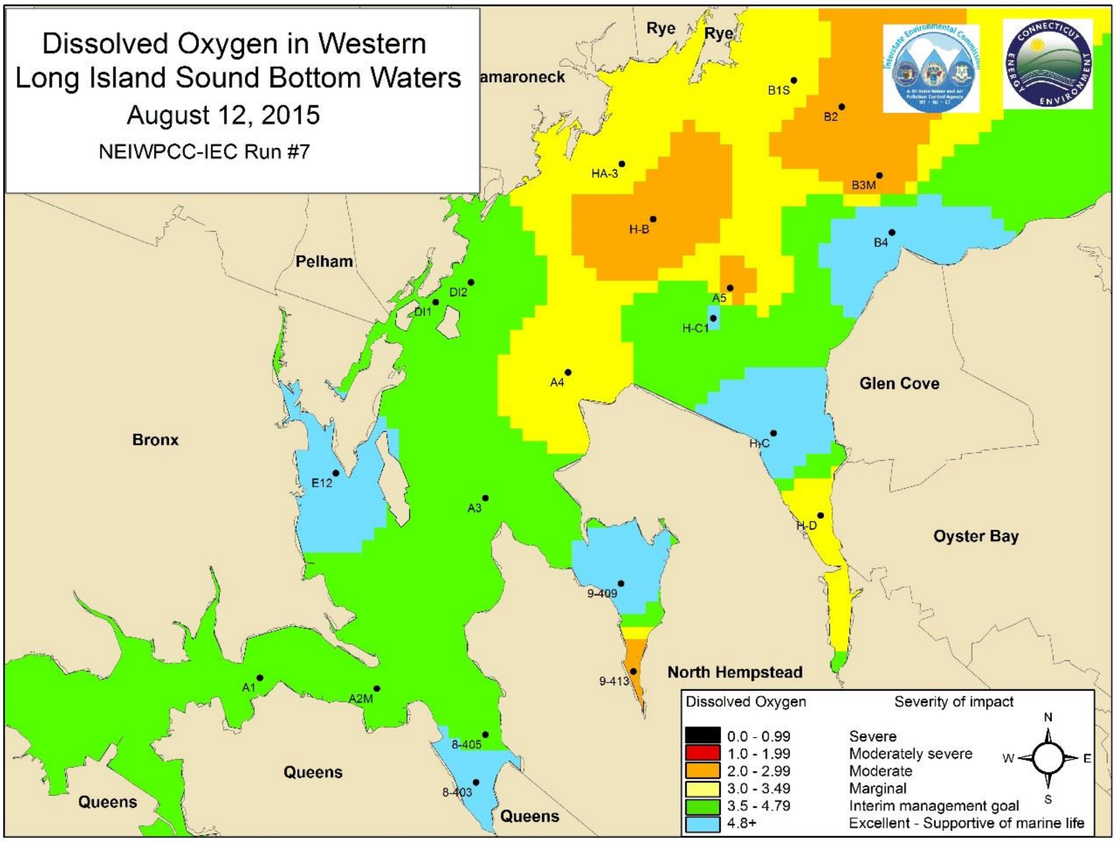
During the WQAUG15 survey, DO concentrations were below 3.0 mg/L at three stations. At Station B3 and A4, concentrations continued to be between 2.0 and 3.0 mg/L. DO concentrations at Station 02 were less than 3.5 mg/L



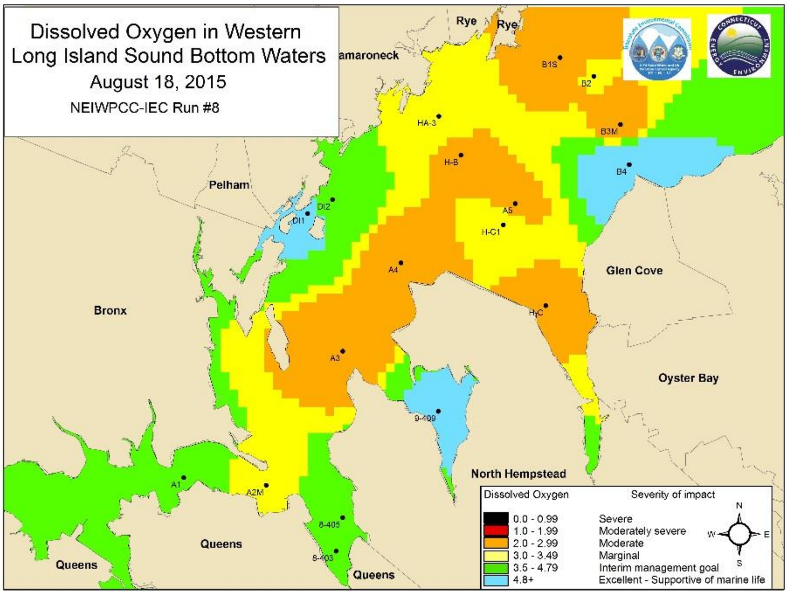
During IEC Run #6 only one station was above 4.8 mg/L. Eleven stations were less than 3.5 mg/L and three stations were less than 3.0 mg/L.



During IEC Run #7 conditions improved slightly with 11 stations exhibiting DO concentrations above 4.8 mg/L. Six stations were less than 4.8 mg/L, 4 stations were less than 3.5 mg/L and five stations were less than 3.0 mg/L.

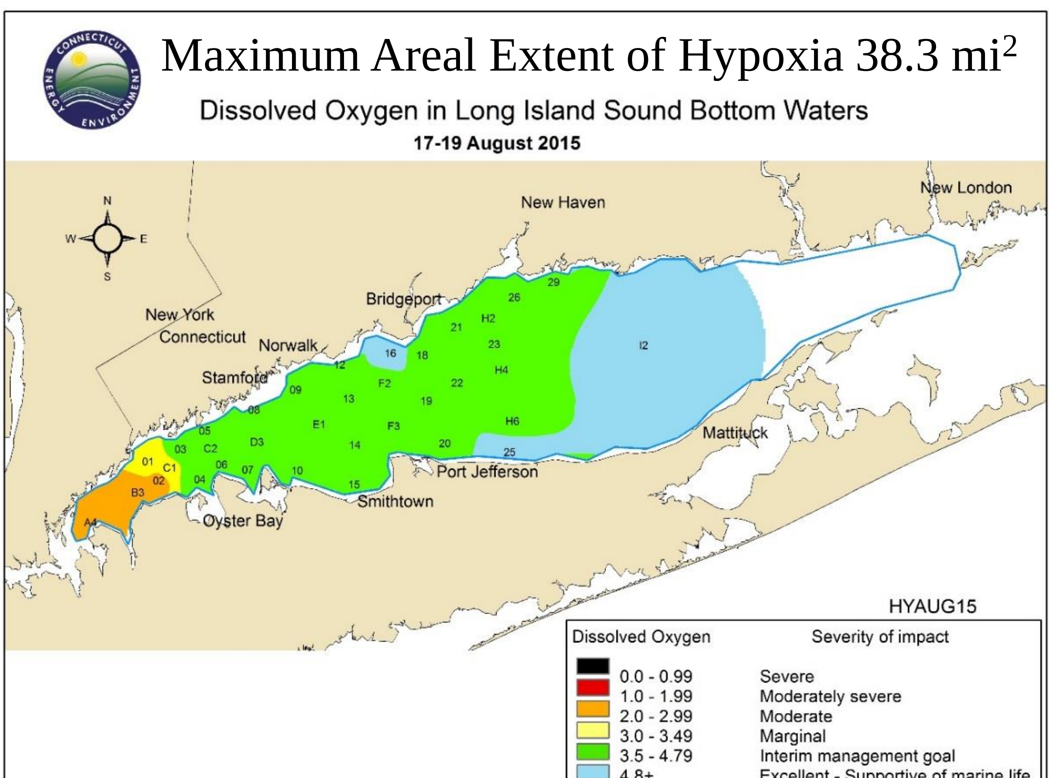


HYAUG15

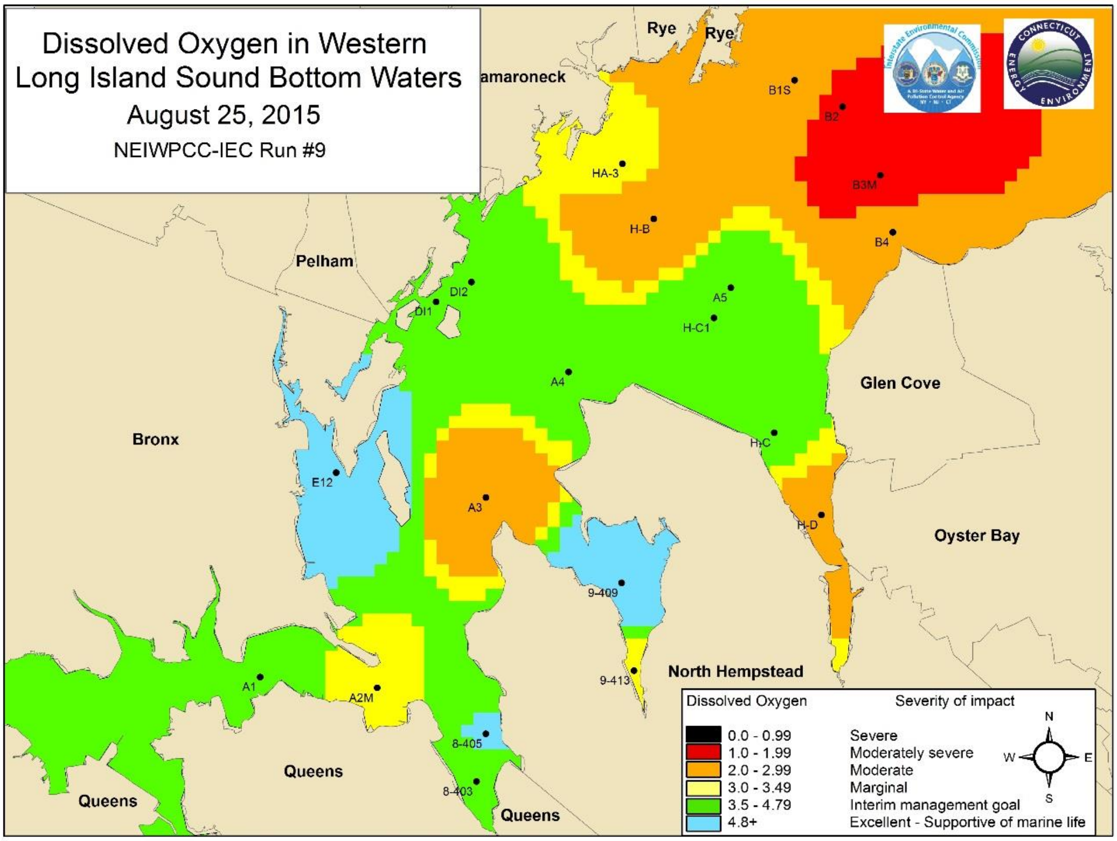


Concentrations degraded for IEC Run #8 with DO at 7 stations measuring less than 3.0 mg/L.

During the HYAUG15 survey DO concentrations across the Sound were less than 3.0 mg/L at 3 stations. Two stations had concentrations between 3.0 and 3.5 mg/L. 28 stations had concentrations between 3.5 mg/L and 4.8 mg/L. This would be the height of the hypoxic event. 2015 had the second lowest areal extent over the course of the 25-year sampling program, with only 1997 having a lower areal extent.

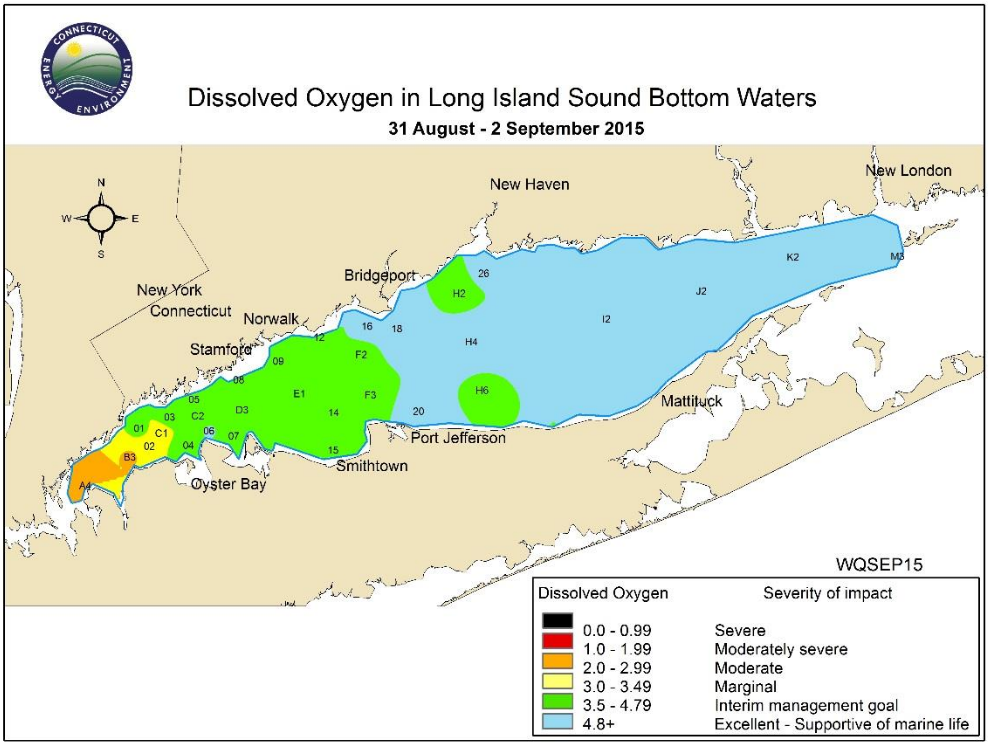


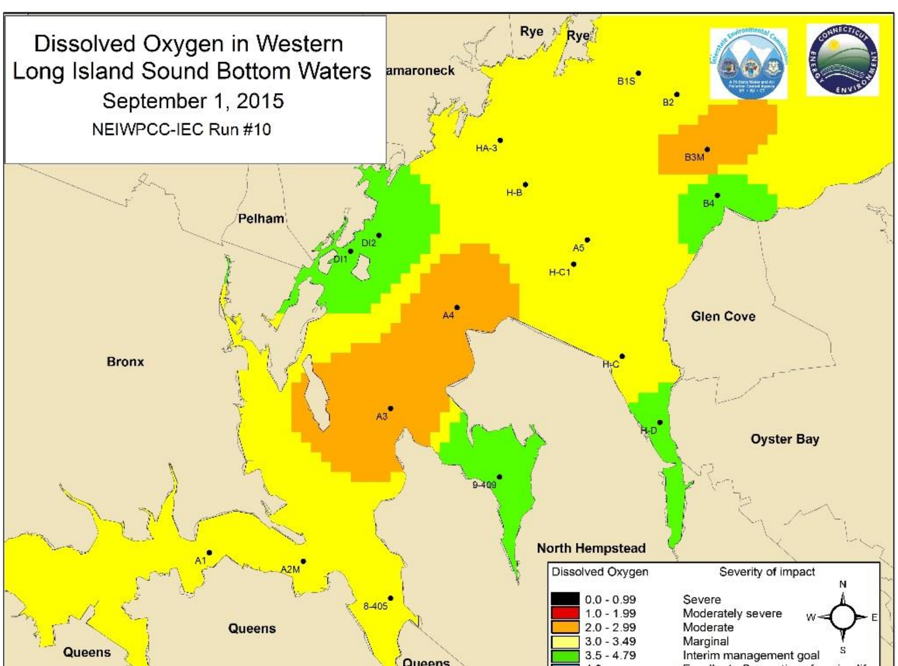
During IEC Run #9 conditions degraded with 2 stations exhibiting DO concentrations below 2.0 mg/L. Five stations were less than 3.0 mg/L, two stations were less than 3.5 mg/L, and eight stations were less than 4.8 mg/L.



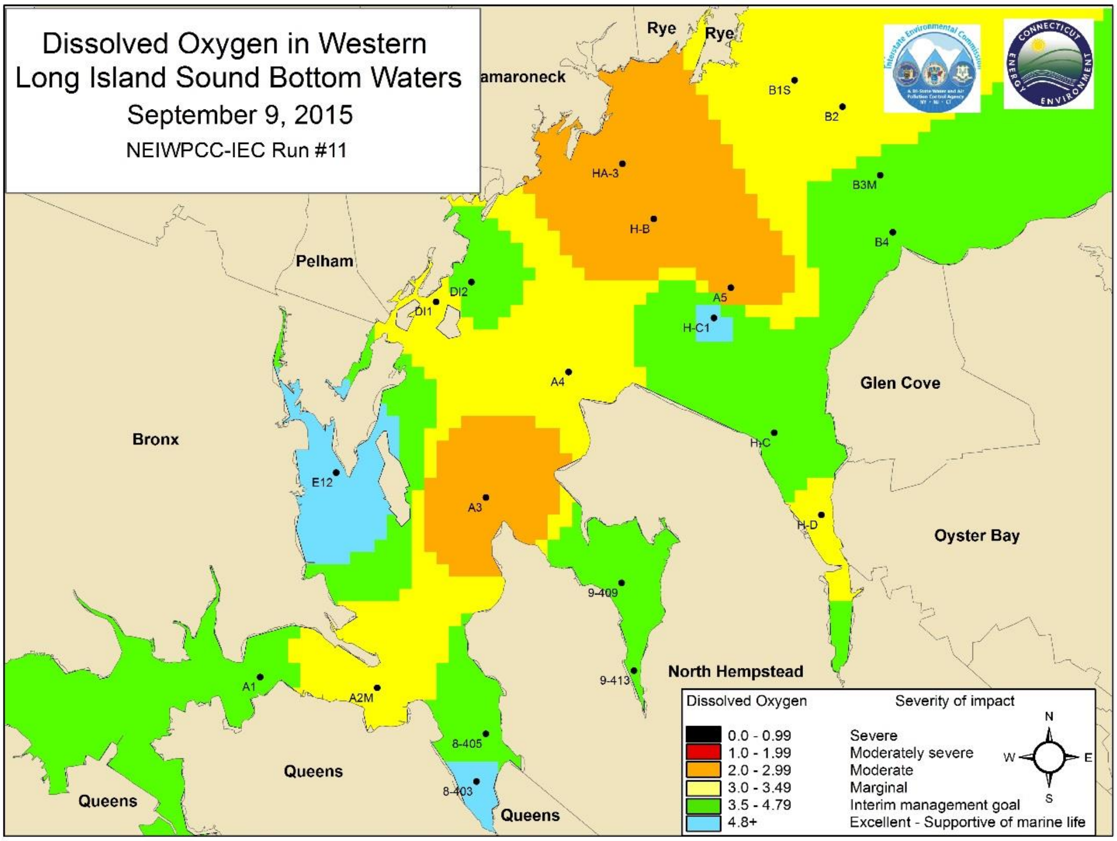
WQSEP15

The WQSEP15 survey and IEC Run #10 found conditions had improved slightly. Concentrations at A4 and B3 were 2.52 and 2.99 mg/L, respectively. Stations C1 and 01were below 3.5 mg/L and 18 stations were below 4.8 mg/L. IEC found similar conditions, with three stations exhibiting concentrations below 3.0 mg/L and nine stations below 3.5 mg/L.



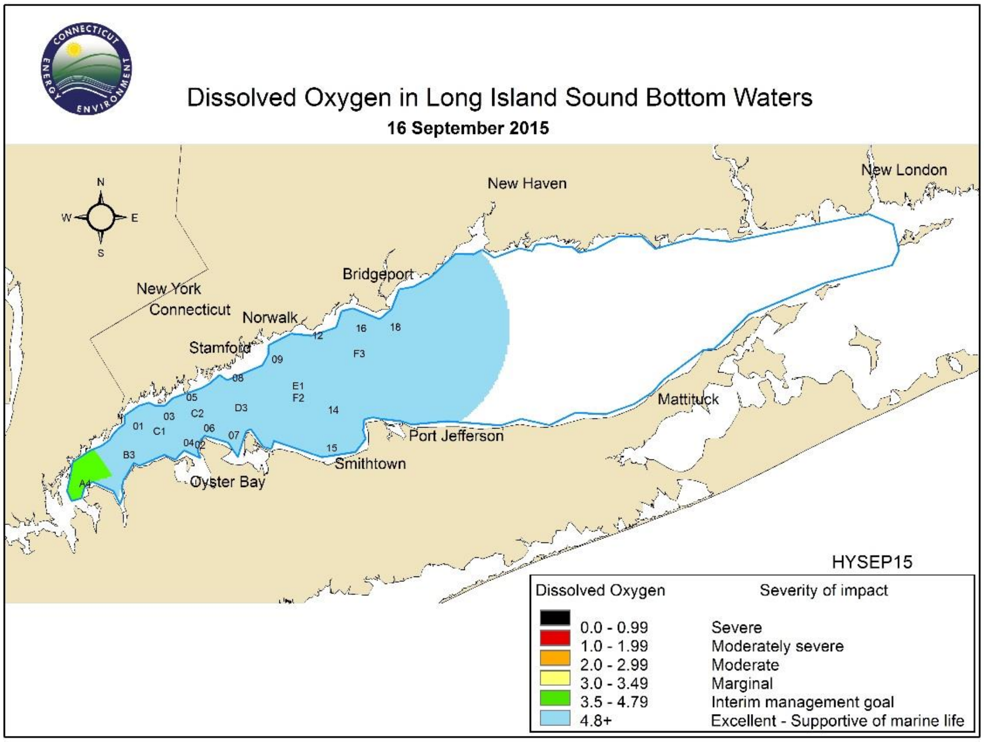


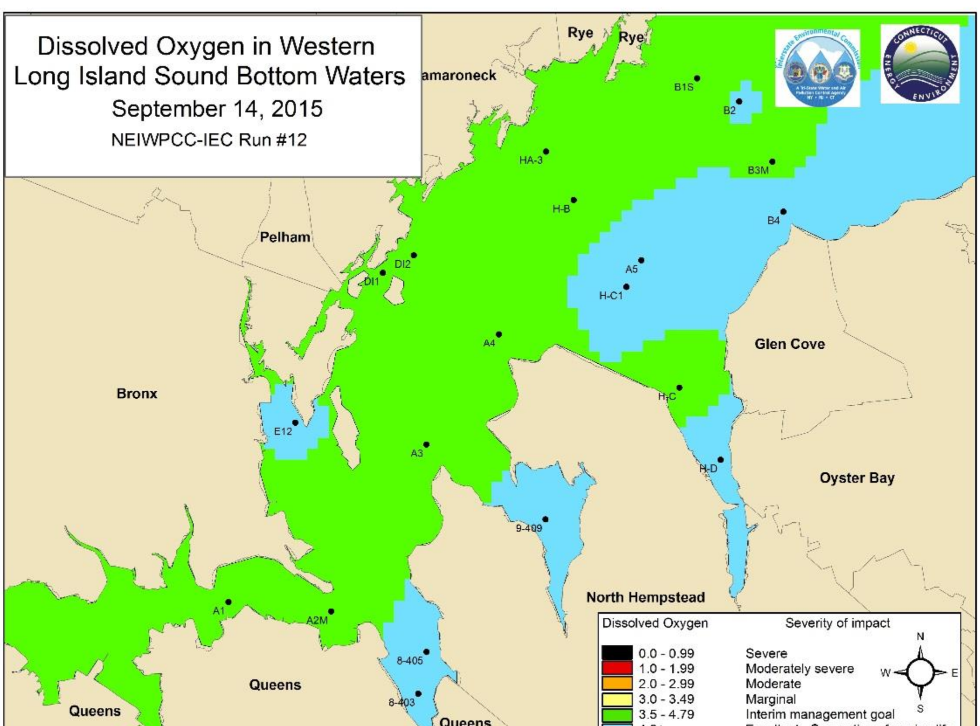
During IEC Run #11 conditions improved slightly. Four stations had DO concentrations less than 3.0 mg/L, six stations were less than 3.5 mg/L, and eight stations were less than 4.8 mg/L.



HYSEP15

Conditions rebounded for the HYSEP15 survey with only one CT DEEP station exhibiting DO concentrations below 4.8 mg/L (A4). IEC sampled two days prior to CT DEEP and found 11 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 14 September.

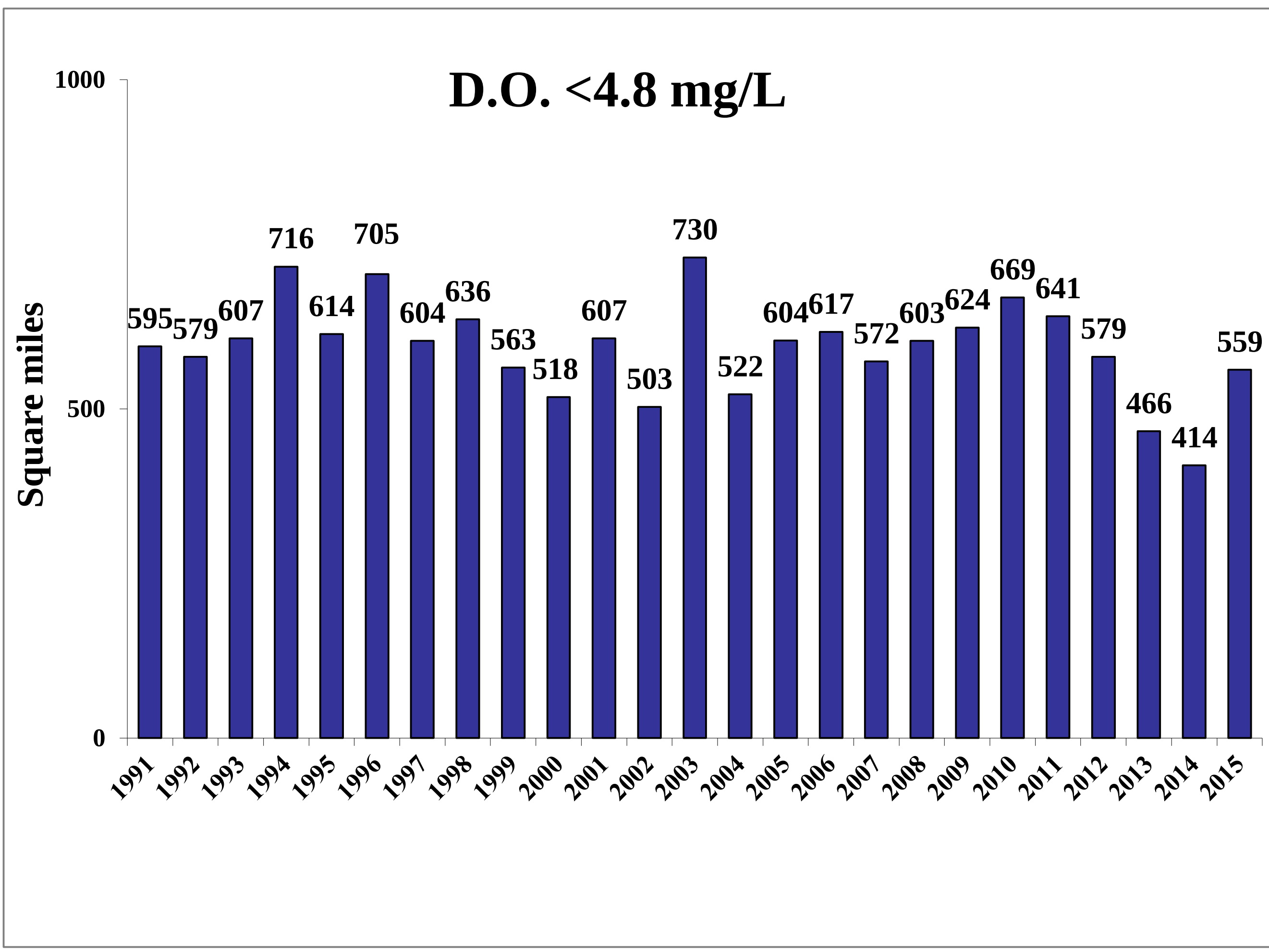




Area of Dissolved Oxygen Below the Chronic Criterion for Growth and Protection of Aquatic Life for LIS

Aquatic organisms are harmed based on a combination of minimum oxygen concentration and duration of the low DO excursion. CT DEEP established Dissolved Oxygen Chronic Exposure Criteria based on research and data collected by the EPA. 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 2015, the maximum area below 4.8 mg/L occurred during the HYAUG15 survey and was estimated at 559 square miles. From 1991-2015, the area affected by concentrations less than 4.8 mg/L averages 593.9 square miles and varies slightly from 414 to 730 square miles.

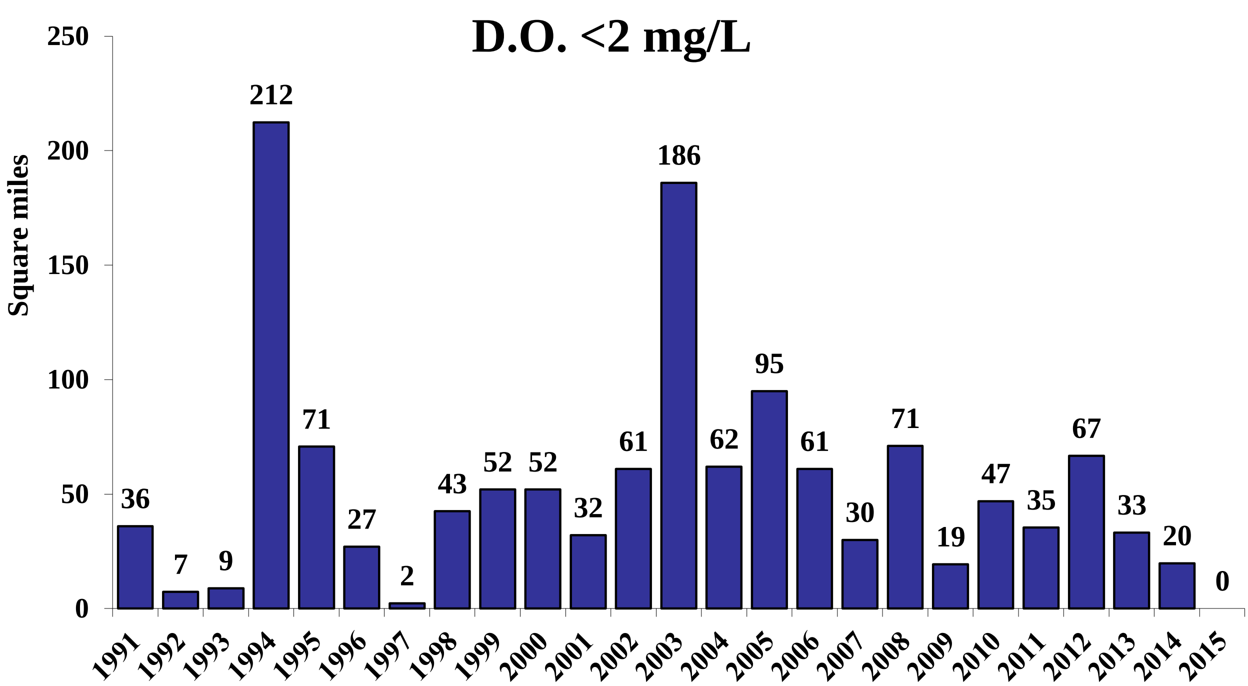


Severe Hypoxia

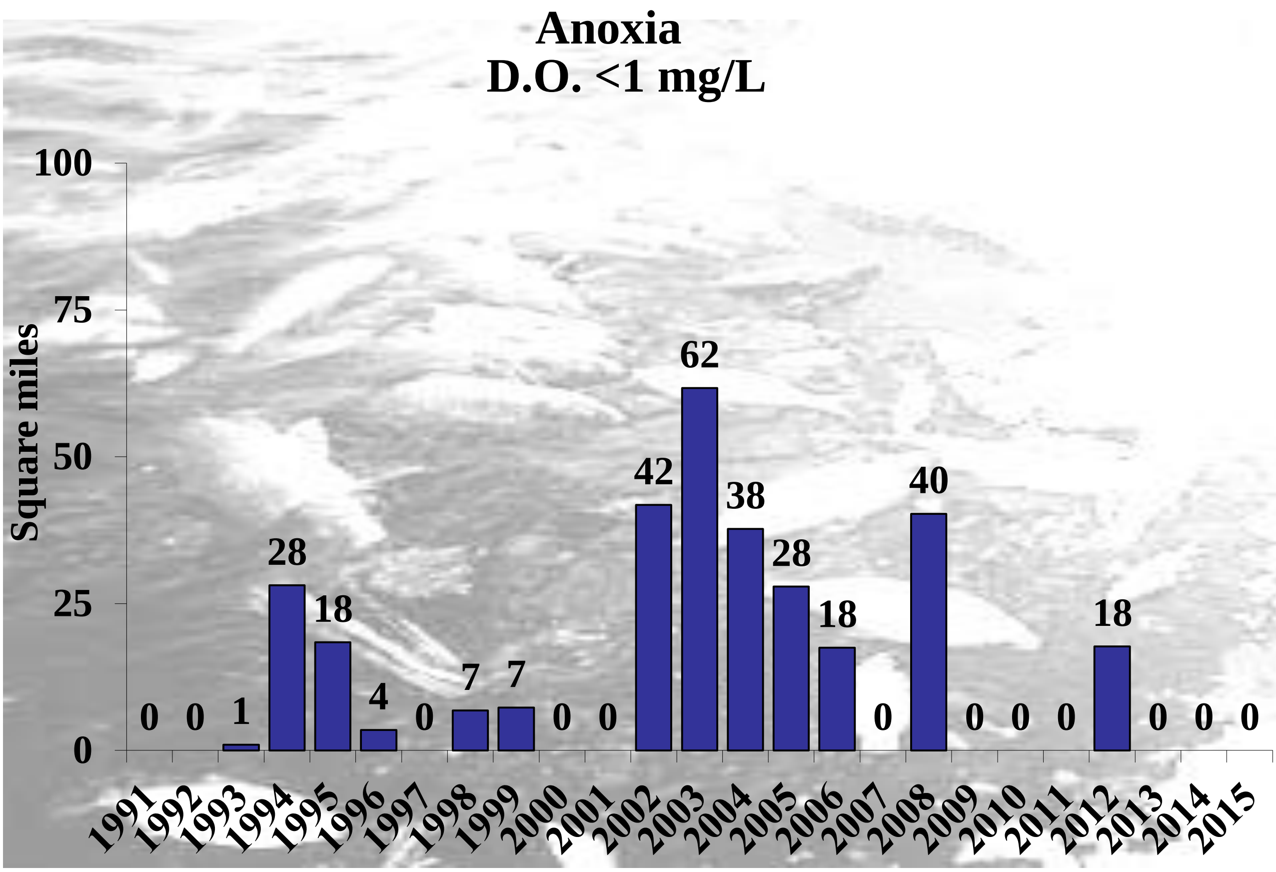
The Long Island Sound Study provides information on LIS Hypoxia for inclusion in EPA's *Report on the Environment* (http://www.epa.gov/ncea/roe/) which reports on "the best available indicators of information on national conditions and trends in air, water, land, human health, and ecological systems…". 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. Based on CT DEEP data, in 2015, bottom water dissolved oxygen concentrations were all greater than 2.0 mg/L (i.e., area <2.0 mg/L= 0 mi^2). The average area with concentrations less than 2.0 mg/L, calculated from 1991-2015, is 53.2 mi^2. Based on the LISICOS Execution Rocks data there were 22.25 cumulative days below 2.0 mg/L.

For comparisons, the 30-year average size of the hypoxic zone in the northern Gulf of Mexico is roughly 5312 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 2015 hypoxic zone covered 6474 mi^2 (16760 km^2) and was larger than 2014 (http://www.gulfhypoxia.net/Research/Shelfwide%20Cruises/2015/PressRelease2015.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 12 of the twenty-five years there was no anoxia reported by CT DEEP. The greatest area with DO 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 1991-2015 is 12.4 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, 2014, and 2015 anoxic conditions were not documented by CT DEEP, IEC or LISICOS.

HABITAT IMPAIRMENT ASSOCIATED WITH HYPOXIA

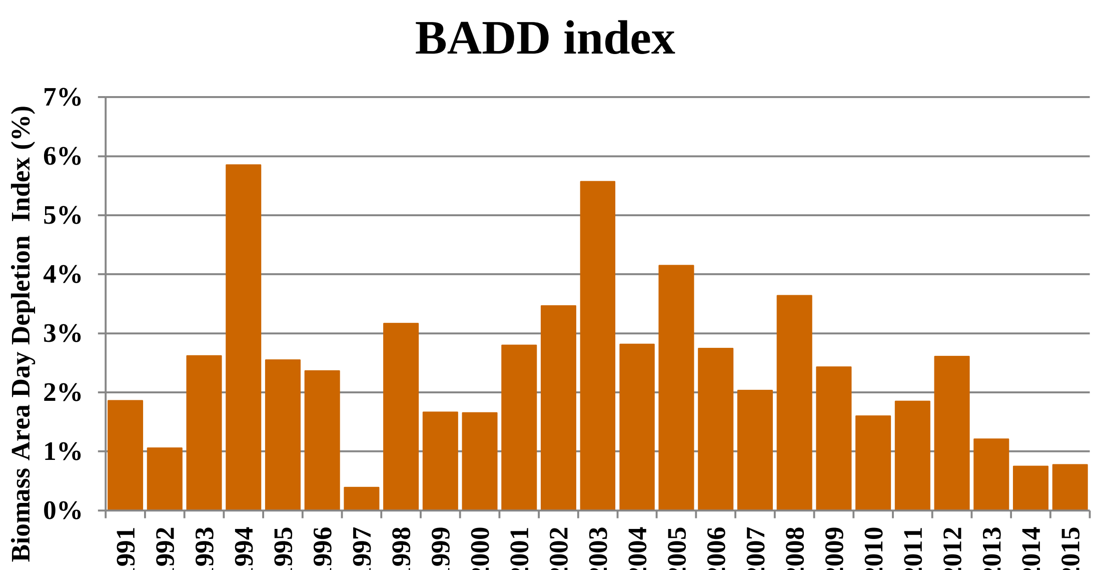
For Long Island Sound, DO levels below 3 mg/L are considered hypoxic, causing mobile animals to leave and sessile animals to die or be physically or behaviorally impaired. However, DO can become limiting below 4.8 mg/L for sensitive fish species, such as whiting and scup, while more tolerant species, such as butterfish, bluefish, lobster and Atlantic herring, are not affected until DO falls below 2 mg/L.

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. 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.

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, hypoxia spread over 1,000 km^2 (395 $miles^2$) for the entire season, resulting in a BADD index of almost 6%. In 2015, the BADD index was 0.77%.

-Penny Howell, Fisheries Biologist, CT DEEP Marine Fisheries Division, CT Wildlife Article, July/August 2014

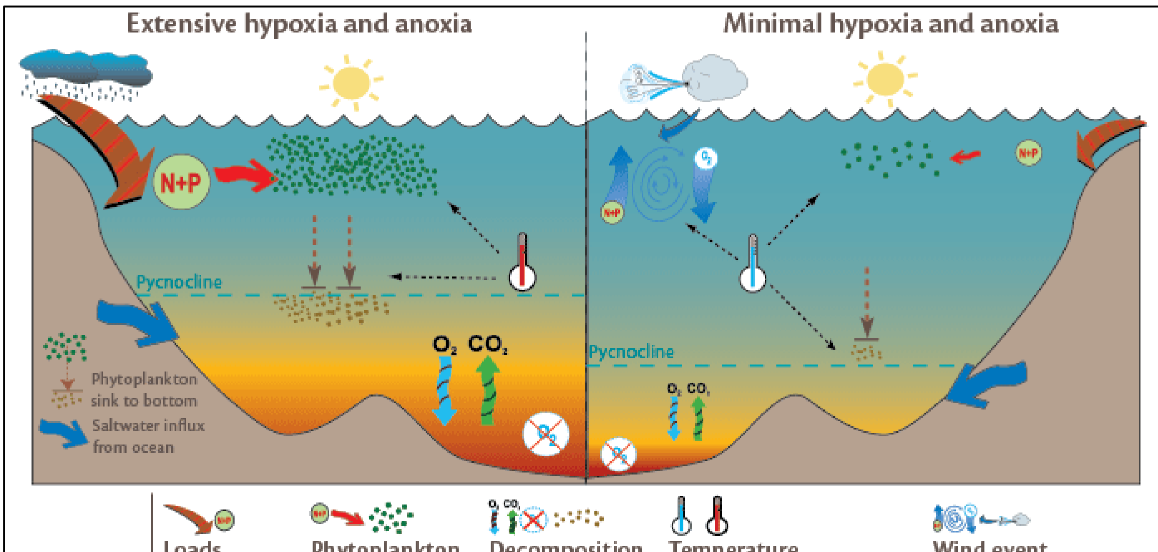


Simpson, David G., Kurt Gottschall, and Mark Johnson. 1995. Cooperative interagency resource assessment (Job 5). In : A study of marine recreational fisheries in Connecticut, CT DEP Marine Fisheries Office, PO Box 719, Old Lyme, CT 06371, p 87-135.

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.



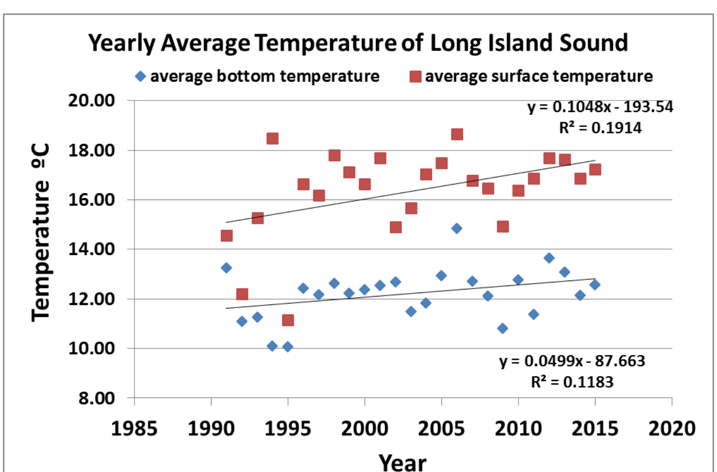
	Loads	Phytoplankton	Decomposition	Temperature	Wind event
Large amount of low dissolved oxygen	Large nitrogen and phosphorus loads	Elevated nutrients cause large phytoplankton blooms	High oxygen consumption by decaying phytoplankton	Warm water a) Stimulates decomposition b) Stratifies water column c) 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

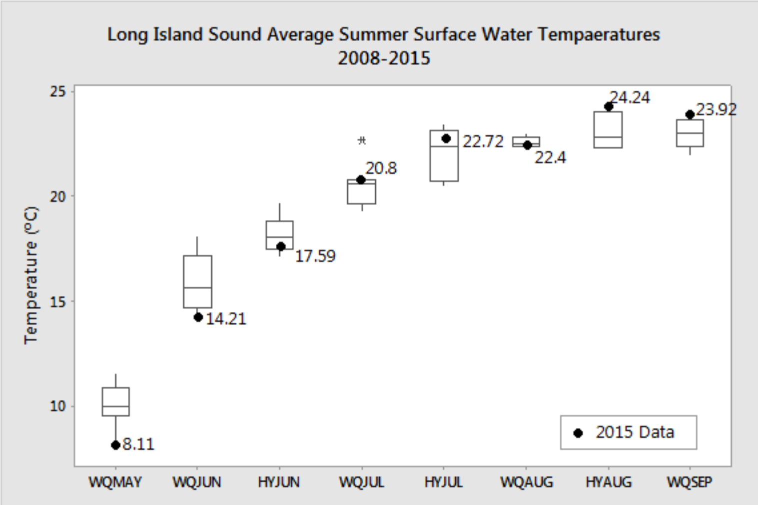
2015 Water Temperature Data

2015 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.

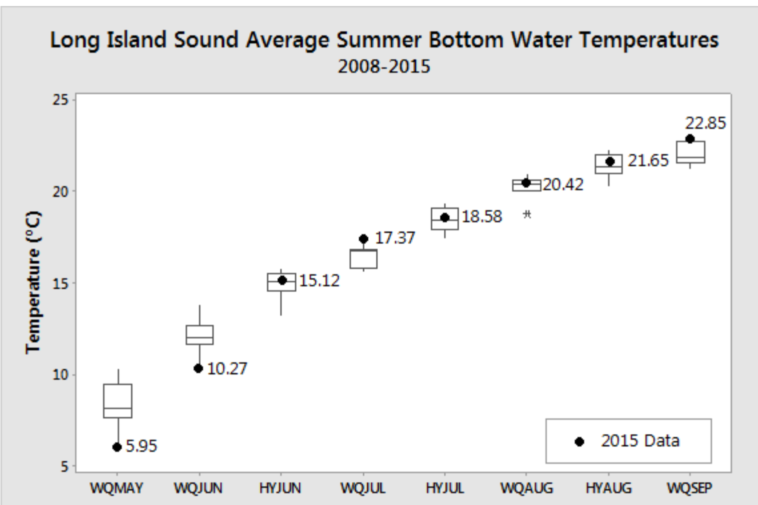
Cruise	2015 Max	1991-2015 Max	2015 Min	1991-2015 Min	2015 Average	1991-2015 Average
WQJAN	5.397	9.311	1.243	0.500	3.442	4.432
WQFEB	3.176	6.748	-0.462	-1.325	0.889	2.062
CHFEB	No Survey	4.464	No Survey	-0.288	No Survey	2.219
WQMAR	0.871	6.611	**-1.189**	**-1.189**	-0.602	2.198
CHMAR	No Survey	6.575	No Survey	0.113	No Survey	3.519
WQAPR	2.652	10.072	**0.650**	**0.650**	1.418	4.622
WQMAY	11.122	14.145	**4.517**	**4.517**	6.403	8.506
WQJUN	17.140	21.436	**8.027**	**8.027**	11.183	12.701
HYJUN	19.289	22.458	12.415	11.116	15.139	15.825
WQJUL	23.054	25.336	14.460	11.639	18.092	17.404
HYJUL	25.672	27.493	15.759	15.038	19.735	19.320
WQAUG	**29.985**	**29.985**	18.788	14.018	20.905	20.530
HYAUG	**26.492**	**26.492**	20.582	18.678	22.260	21.686
WQSEP	25.555	25.857	21.176	16.390	23.011	21.772
HYSEP	**23.835**	**23.835**	22.428	19.533	23.131	21.806
WQOCT	20.060	21.571	17.925	14.161	18.962	19.201
WQNOV		16.601		10.467		13.899
WQDEC		12.712		0.000		9.114



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 1991-2015.



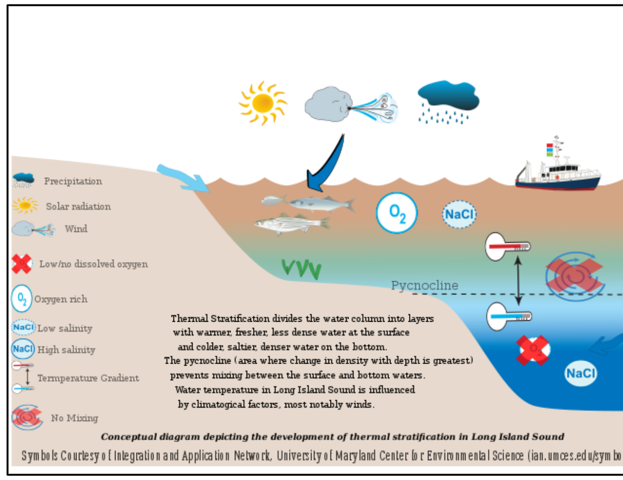
Water temperatures in 2015 mimicked air temperatures with May and June averages below the 2008-2015 mean and August and September being above.



While box plots were not prepared using winter water temperature data, February, March and April were certainly cold; 2015 was the first time in at least nine years that the R/V John Dempsey was iced in at Milford Harbor.

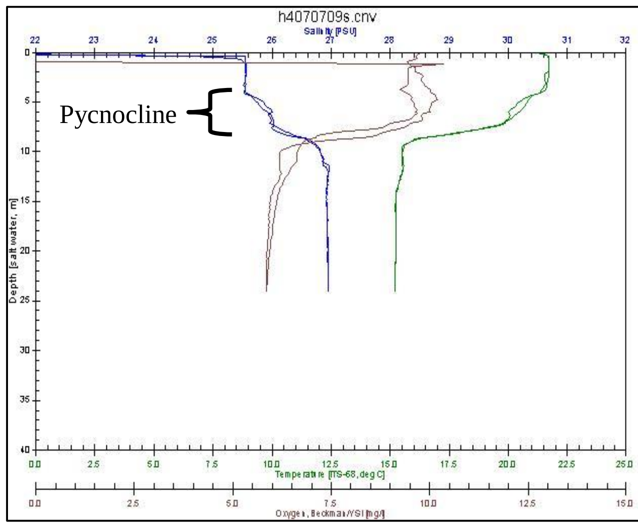
Delta T and Stratification

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

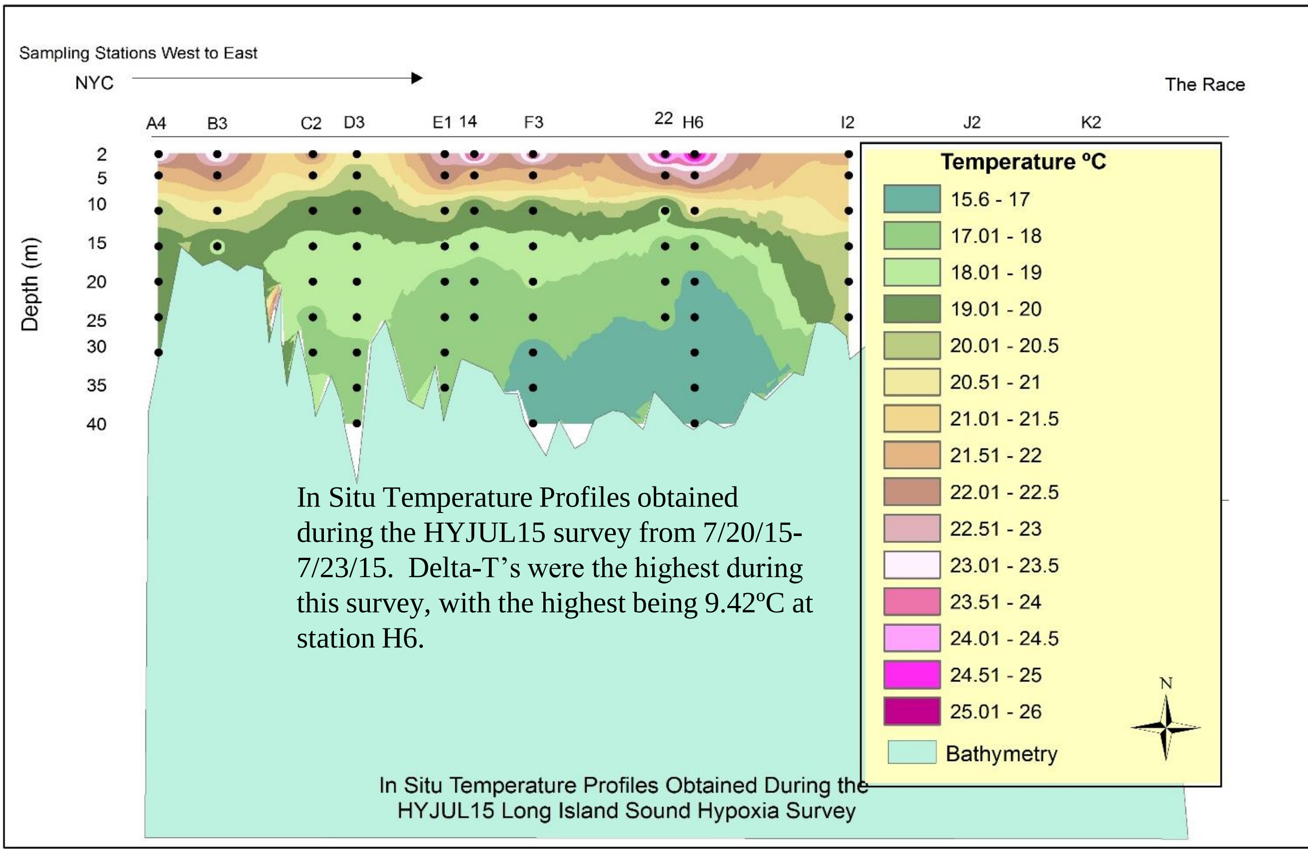


Conceptual diagram depicting the development of thermal stratification in Long Island Sound

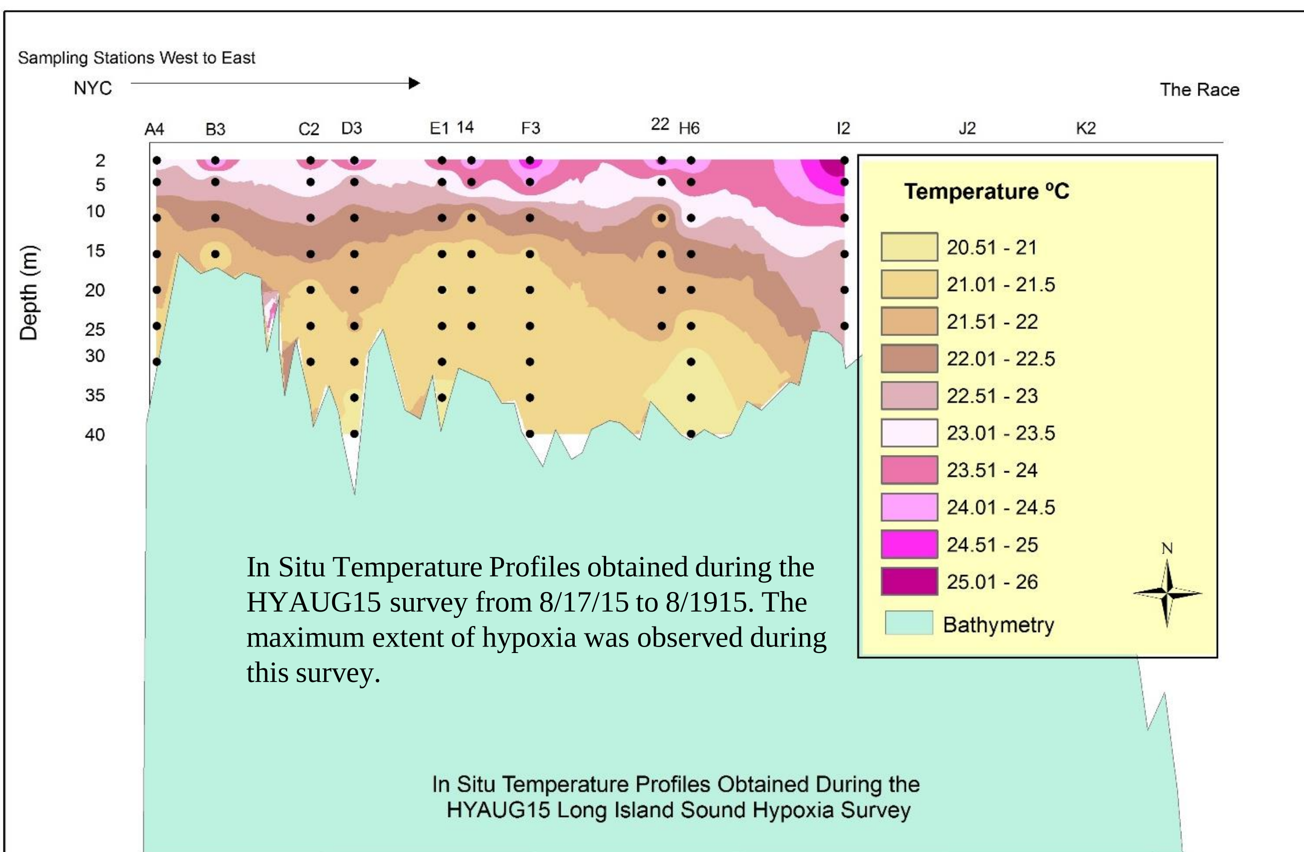
Symbols Courtesy of Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols)



The temperature graphs on page 30 show computer interpolations along the west-east axis of LIS generated from profile data collected during two CT DEEP surveys. During the HYJUL15 survey, surface water temperatures had warmed to an average of 22.72ºC while the bottom water remained cooler around an average of 18.57ºC. This set up the largest differences in temperatures between the surface and bottom waters with Delta-T’s between 0.97 and 9.42ºC. The second graph shows how the water column was thermally stratified during the HYAUG15 survey when hypoxic conditions were at their worst. The temperature area maps on page 31 show how the Delta T’s varied over the course of the summer sampling season. Delta T’s increased from the WQAPR15 survey through the HYJUL15 survey, setting up the stratification and leading to the maximum extent of hypoxia in late 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 0.1ºC, allowing the oxygenated surface waters to mix through to the bottom, leading to the end of the hypoxic event. The maps also show how the Delta T varies spatially. The western Sound typically 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. This year the Central Sound had the highest Delta T’s.

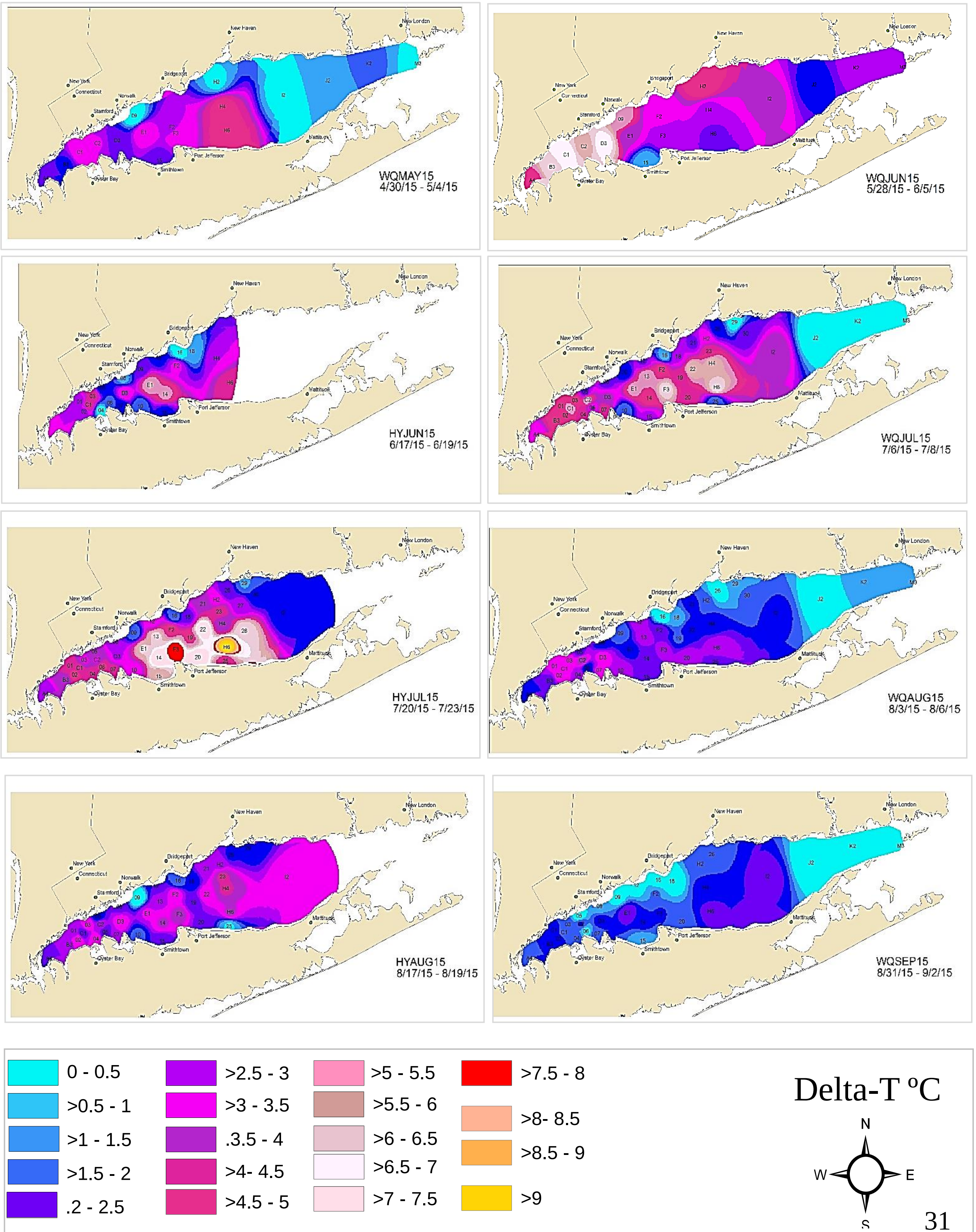


In Situ Temperature Profiles obtained during the HYJUL15 survey from 7/20/15-7/23/15. Delta-T's were the highest during this survey, with the highest being 9.42ºC at station H6.



In Situ Temperature Profiles obtained during the HYAUG15 survey from 8/17/15 to 8/1915. The maximum extent of hypoxia was observed during this survey.

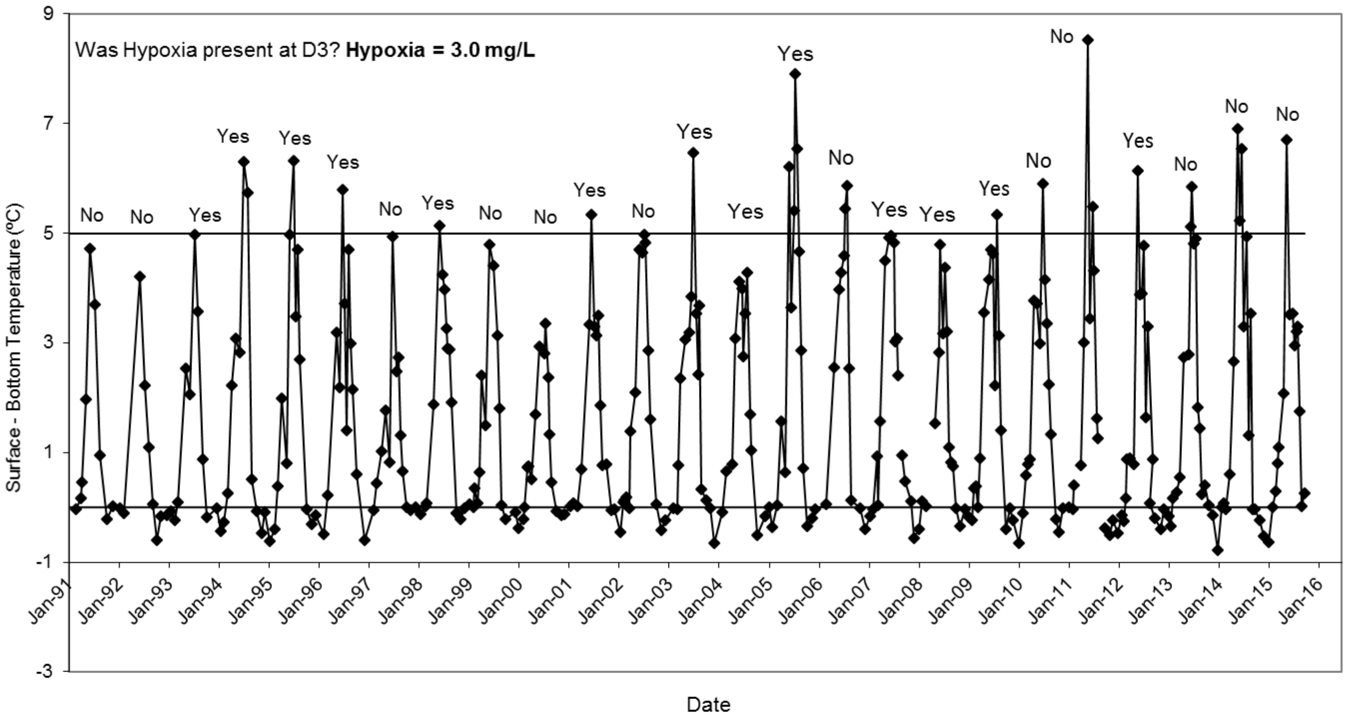
2015 Delta-T Maps



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, **2015 had the lowest winter temperature recorded**, 2014 had the highest summer temperature, 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
2015	**-1.1**	24.23	6.71	38.3

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 2015.

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). In 2015, the maximum Delta T at D3 was 6.71ºC and the station was not hypoxic (lowest DO 3.5 mg/L).

Salinity

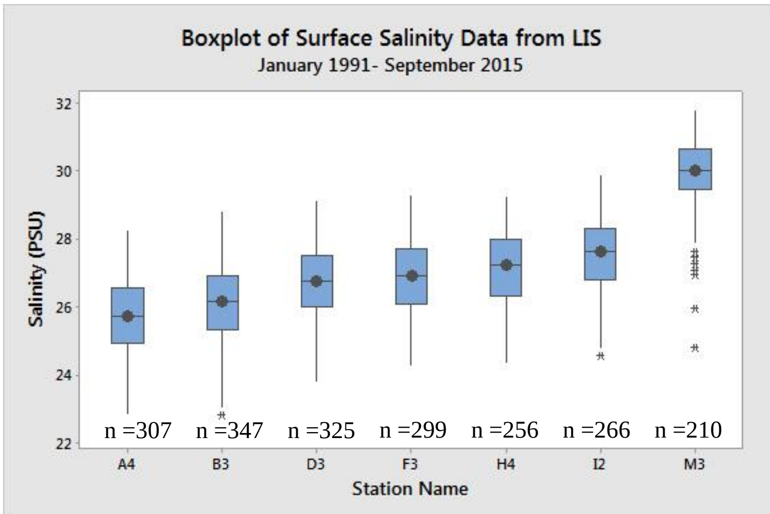
Salinity is a measure of the dissolved salts content of seawater. It is usually expressed in practical salinity units (PSU). Salinity levels across Long Island Sound vary from 23 PSU in the Western Sound at Station A4 to 33 PSU in the eastern Sound at Station M3. The Thames, Connecticut, and Housatonic rivers are the major sources of freshwater entering the Sound. Summary statistics for salinity data collected from seven stations across the Sound from 1991-2015 are presented in the tables below. Data collected this year are also presented separately.

		1991-2015 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	317	23.823	28.727	26.403	26.445	0.0515	0.916	0.839
B3	365	24.259	28.926	26.669	26.685	0.0479	0.916	0.839
D3	342	24.912	29.215	27.296	27.425	0.0471	0.871	0.759
F3	318	25.153	29.432	27.652	27.714	0.0474	0.846	0.716
H4	277	25.508	29.7	27.804	27.915	0.0494	0.823	0.677
I2	298	25.762	29.985	28.11	28.221	0.048	0.829	0.687
M3	250	28.608	32.622	30.635	30.616	0.0459	0.726	0.527

		2015 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	12	26.396	27.615	27.1	27.042	0.0998	0.346	0.12
B3	12	26.82	28.037	27.315	27.236	0.105	0.364	0.133
D3	12	27.208	28.592	27.863	27.764	0.132	0.458	0.21
F3	9	27.611	28.982	28.324	28.296	0.168	0.505	0.255
H4	12	27.611	29.348	28.271	28.163	0.134	0.463	0.215
I2	11	27.688	29.277	28.6	28.752	0.16	0.529	0.28
M3	9	30.567	31.869	31.143	30.952	0.149	0.447	0.2

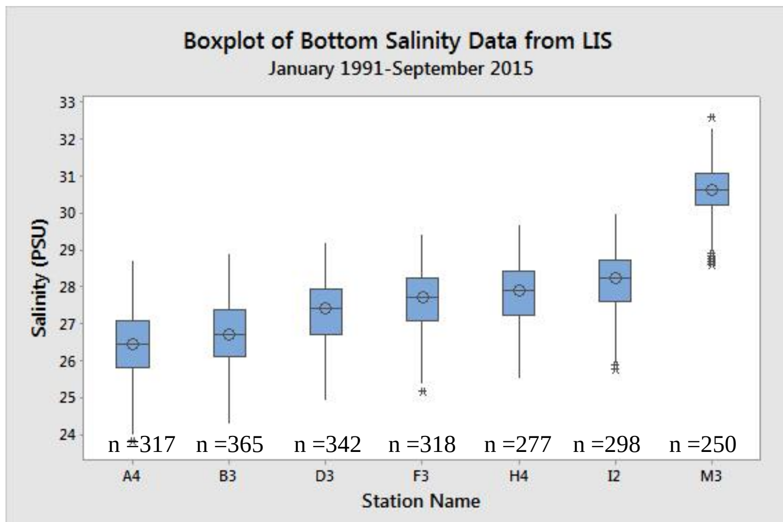
		1991-2015 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	307	22.833	28.278	25.723	25.733	0.0595	1.042	1.086
B3	347	22.8	28.84	26.107	26.17	0.0572	1.065	1.134
D3	325	23.772	29.146	26.731	26.768	0.058	1.045	1.092
F3	299	24.246	29.307	26.875	26.911	0.0617	1.067	1.139
H4	256	24.315	29.262	27.136	27.224	0.066	1.055	1.114
I2	266	24.56	29.909	27.541	27.637	0.0623	1.017	1.034
M3	210	24.789	31.837	29.968	30.03	0.0717	1.039	1.08

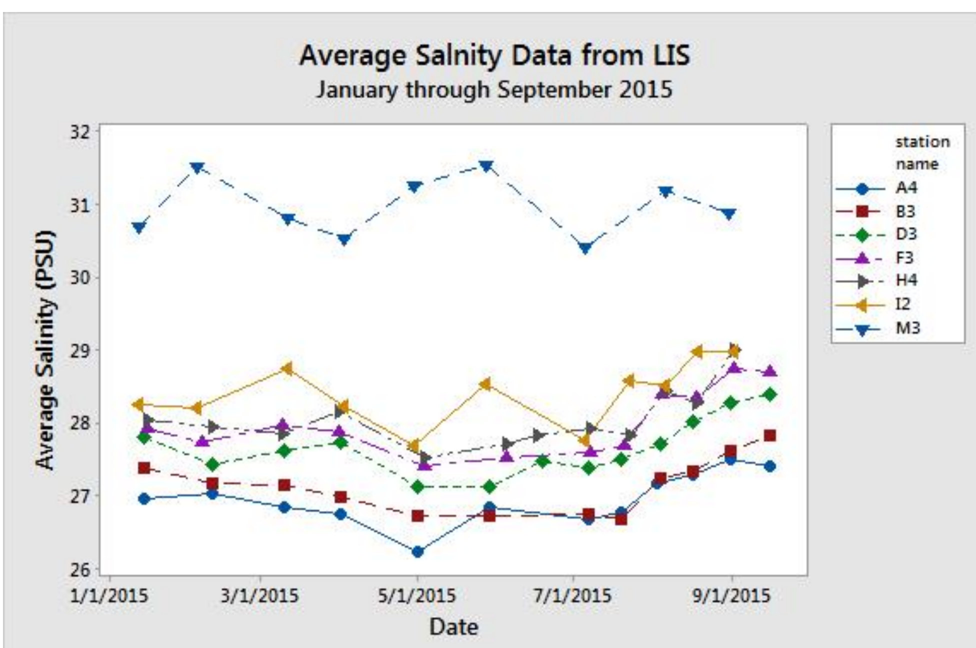
		2015 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	12	25.642	27.247	26.506	26.542	0.155	0.536	0.288
B3	12	26.195	27.558	26.798	26.854	0.136	0.471	0.222
D3	13	26.482	28.235	27.317	27.251	0.129	0.466	0.217
F3	11	26.838	28.625	27.462	27.33	0.161	0.534	0.285
H4	11	27.201	28.355	27.627	27.5	0.114	0.378	0.143
I2	10	27.584	28.599	28.004	28.017	0.105	0.333	0.111
M3	9	29.639	31.177	30.4	30.442	0.166	0.499	0.249



This box plot, based upon data collected during CT DEEP surveys from January 1991 – September 2015, 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- September 2015 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.

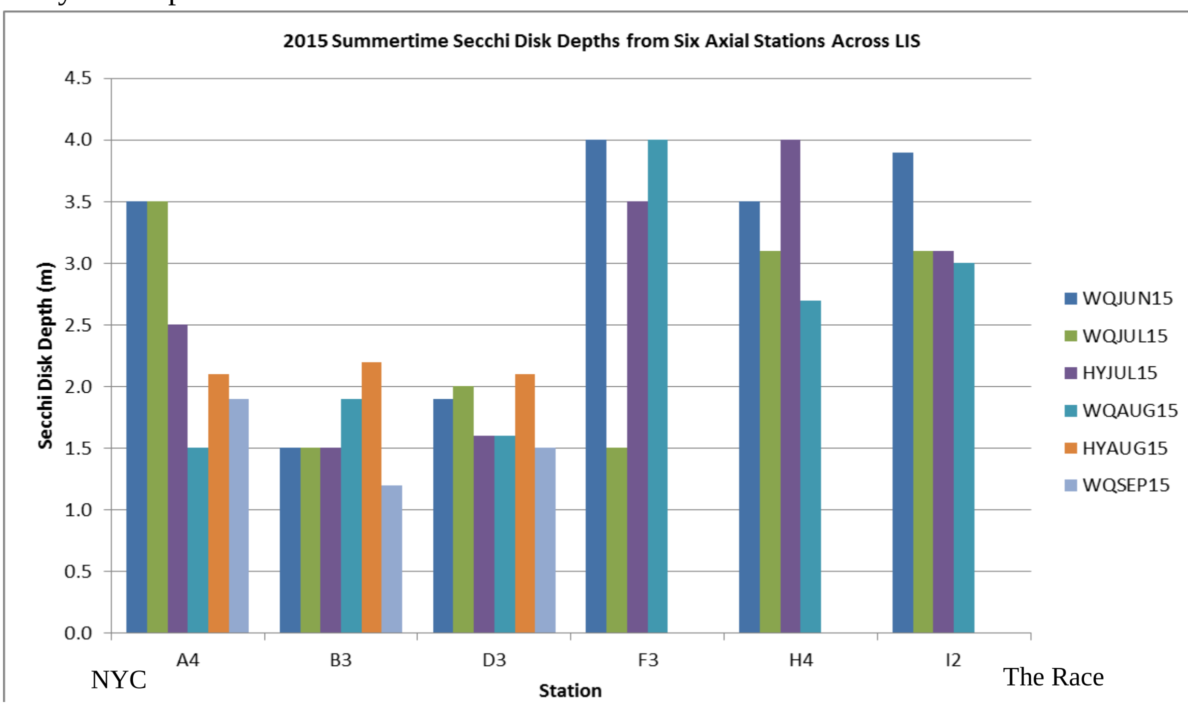




This plot illustrates the temporal variability of the mean salinity values by station from January-September 2015.

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, 3368 measurements have been entered into our database; of those 2,035 are from the 17 stations sampled annually. The 2000-2015 average Secchi depth is 2.4 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 2015.



2014 data

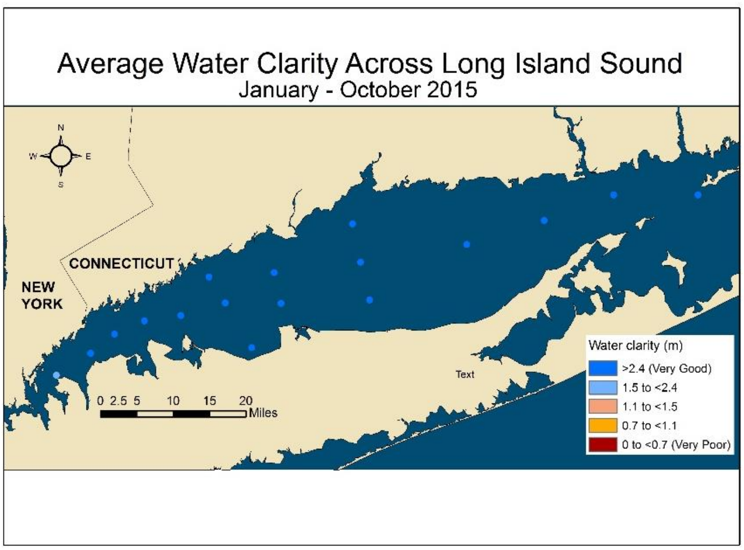
- **Average Secchi Disk Depth: 2.83 m (n=294)**
- **Minimum Secchi Disk Depth: 1.0 m on multiple dates/stations**
- **Maximum Secchi Disk Depth: 5.1 m at Station 09 during the WQAPR14 cruise**

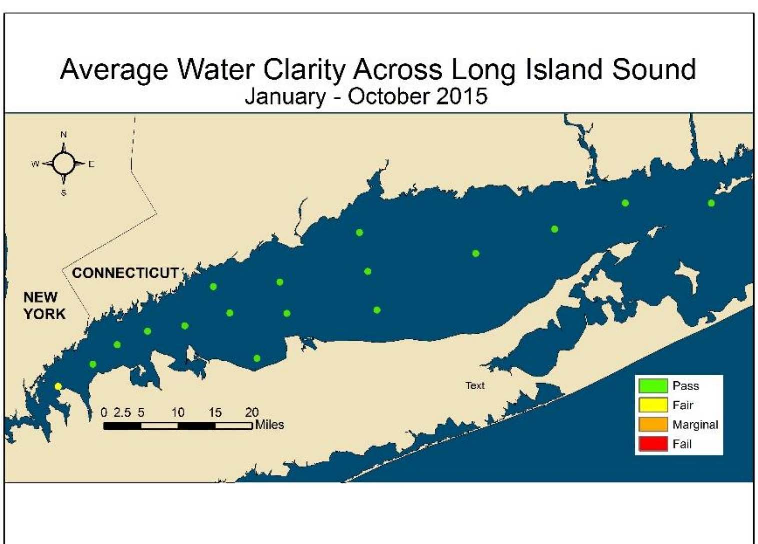
2015 data

- **Average Secchi Disk Depth: 2.71 m (n=269)**
- **Minimum Secchi Disk Depth: 1.0 m at Station K2 during the WQJAN15 cruise**
- **Maximum Secchi Disk Depth: 5.0 m at Stations H4 during the WQSEP15 cruise**

The Integration and Application Network at the University of Maryland Center for Environmental Science prepared a Report Card for Long Island Sound (based on 2013 data) that was released to the public in 2015 (http://ecoreportcard.org/report-cards/long-island-sound/). One of the indicators included in the Report Card is water clarity (Secchi disk depth).

The newly released Long Island Sound Comprehensive Conservation and Management Plan has identified improving water clarity as a goal to support healthy eelgrass communities. Water clarity is one of the major factors affecting eelgrass health and therefore extent. The CCMP states "For the purposes of this goal, "improved" is defined as an increase in the overall numeric criterion for water clarity in the Long Island Sound water quality report card by at least half letter grade (e.g., B to B+) between the initial 2015 report card evaluation and the evaluation conducted in 2035.





CT DEEP created maps similar to that found in the Report Card using the 2015 average Secchi depth data (January-October) from our 17 monthly water quality monitoring stations. Average Secchi depths across the Sound ranged from 1.95 m at Station A4 to 3.93 m at Station M3. Water clarity seems to have improved slightly from 2013 when the average Secchi depth at A4 was 1.71 m and at M3 was 3.24 m. However, recall that 2015 was abnormally dry. Therefore, the improved water clarity may simply be the result of decreased precipitation and fewer suspended solids entering the water column.

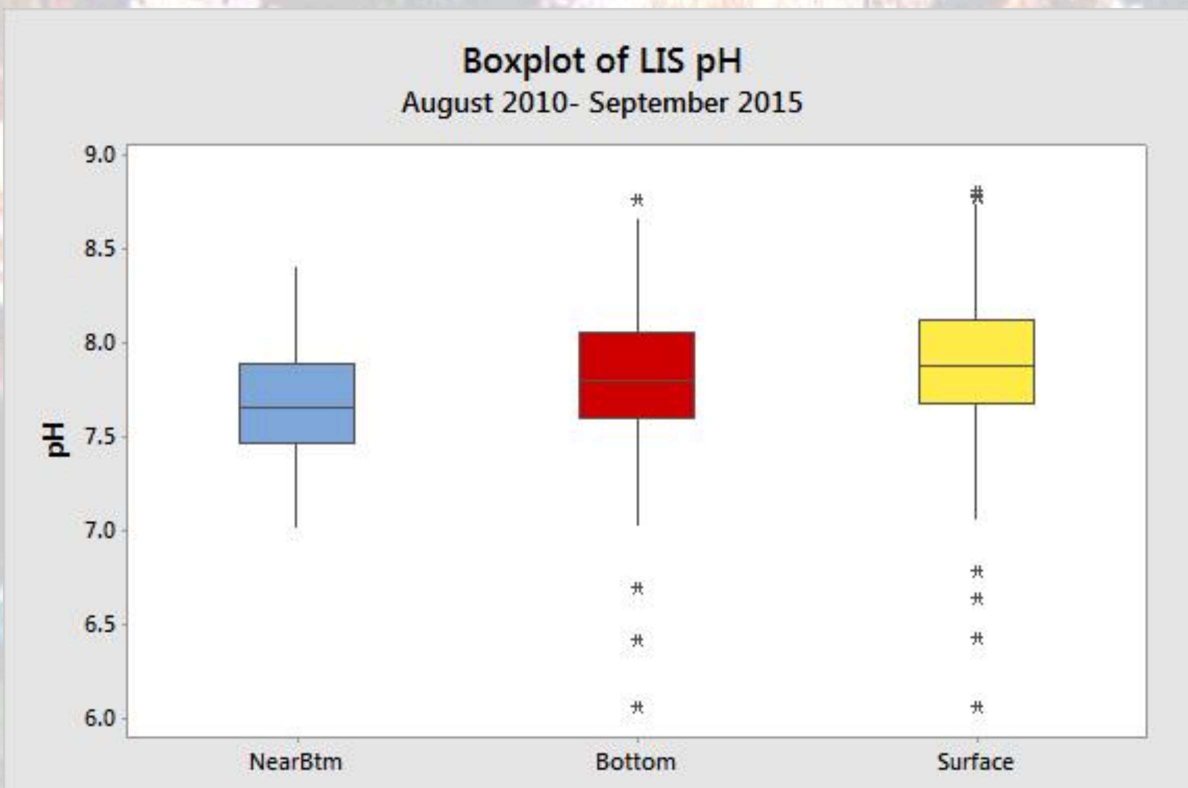
Criteria Threshold (m)	Overall Score Calculation
< 0.7	Fail (0%)
0.7-1.1	Marginal (33.3%)
1.1-2.4	Fair (66.7%)
> 2.4	Pass (100%)

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 HYSEP15 survey are summarized below.

	n	Maximum	Minimum	Mean	Median	SE Mean	StDev	Variance	Q1	Q3
Near Btm	1188	8.415	7.003	7.6754	7.6585	0.00792	0.2729	0.0745	7.461	7.885
Bottom	1242	8.762	6.061	7.8202	7.7985	0.00885	0.312	0.0974	7.593	8.0563
Surface	1896	8.806	6.066	7.896	7.877	0.00659	0.287	0.0824	7.68	8.12



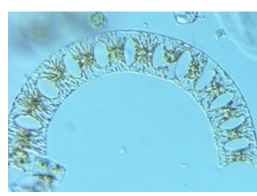
Chlorophyll a

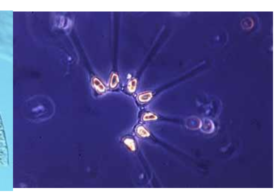
Chlorophyll is a pigment found in plants that gives them their green color. It allows plants to absorb light from the sun and convert it to chemical energy during photosynthesis. In photosynthesis carbon dioxide and water are combined to produce sugar giving off oxygen as a byproduct. Microscopic plants, 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.





Unfortunately, April –October chlorophyll a data are not yet available from UConn. As a result, we are unable to evaluate the timing of the spring bloom or compare the chlorophyll concentrations to the thresholds put forth in the Long Island Sound Report Card.

National Coastal Condition Assessment Sampling 2015

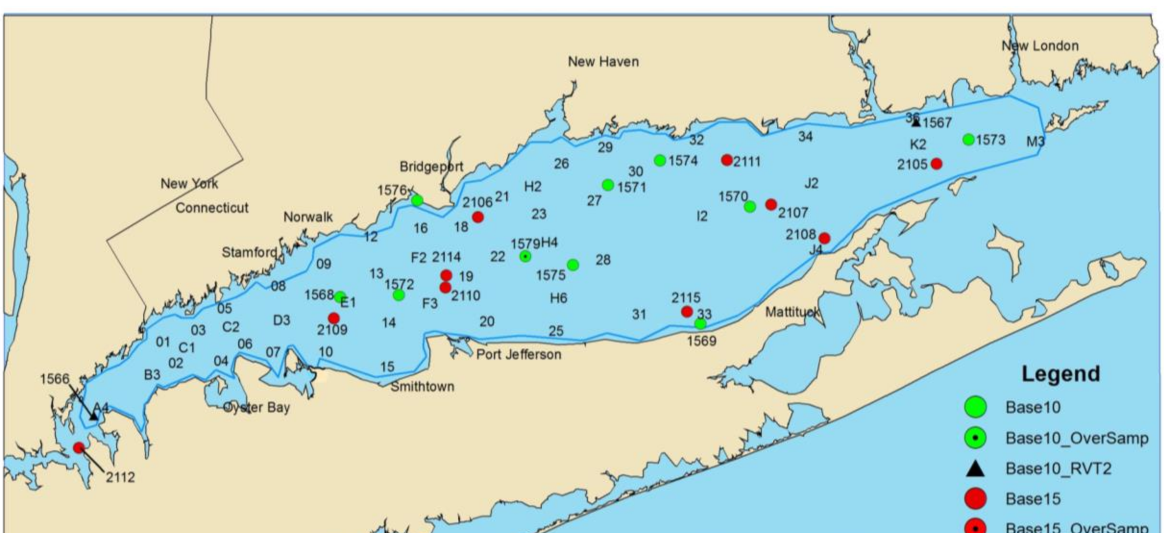
In 2015, CTDEEP participated in the NCCA, which is an EPA statistical survey on the condition of our Nation's marine water.

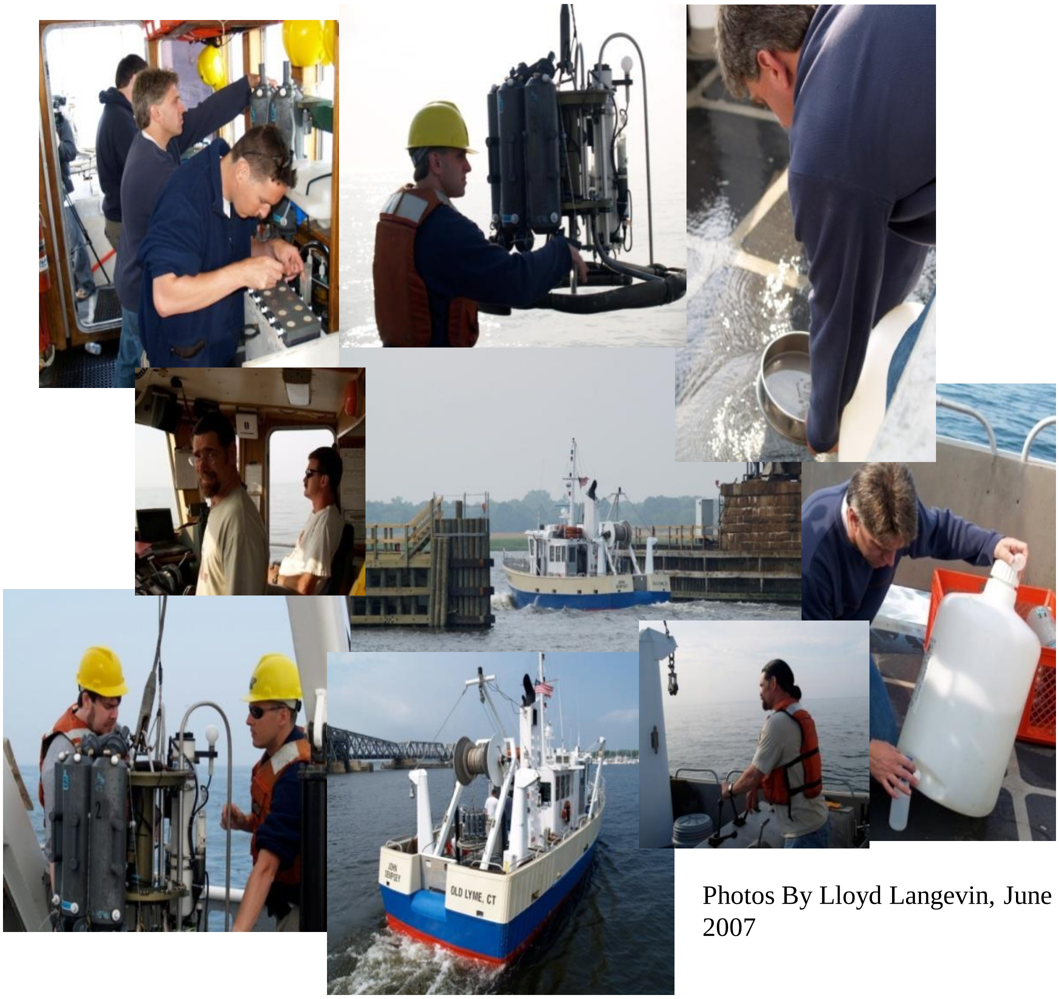
The survey aims to address two key questions:

- What percent of the Nation's coastal waters are in good, fair, and poor condition for key indicators of water quality, ecological health, and recreation?
- What is the relative importance of key stressors such as nutrients and contaminated sediments?

CTDEEP sampled 22 sites for water quality, sediment quality, benthic community condition, and fish tissue contaminants.

Additional information on the surveys can be found on EPA's website: http://www2.epa.gov/national-aquatic-resource-surveys/national-coastal-condition-assessment.





Photos By Lloyd Langevin, June 2007

Acknowledgements

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