2013 Long Island Sound Hypoxia Season Review

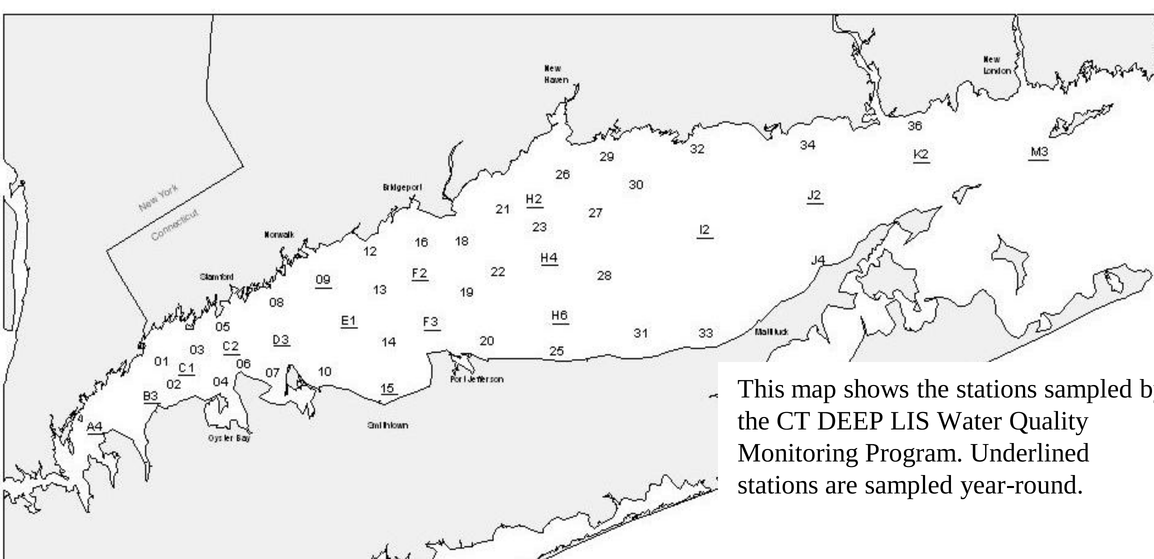
CONNECTICUT DEPARTMENT OF ENERGY & ENVIRONMENTAL PROTECTION
79 ELM STREET, HARTFORD, CT   06106
DANIEL C. ESTY, COMMISSIONER

MONITORING LONG ISLAND SOUND 2013

Program Overview

R/V John Dempsey

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*. These data are used to quantify and identify annual trends and differences in water quality parameters relevant to hypoxia, 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.



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”.

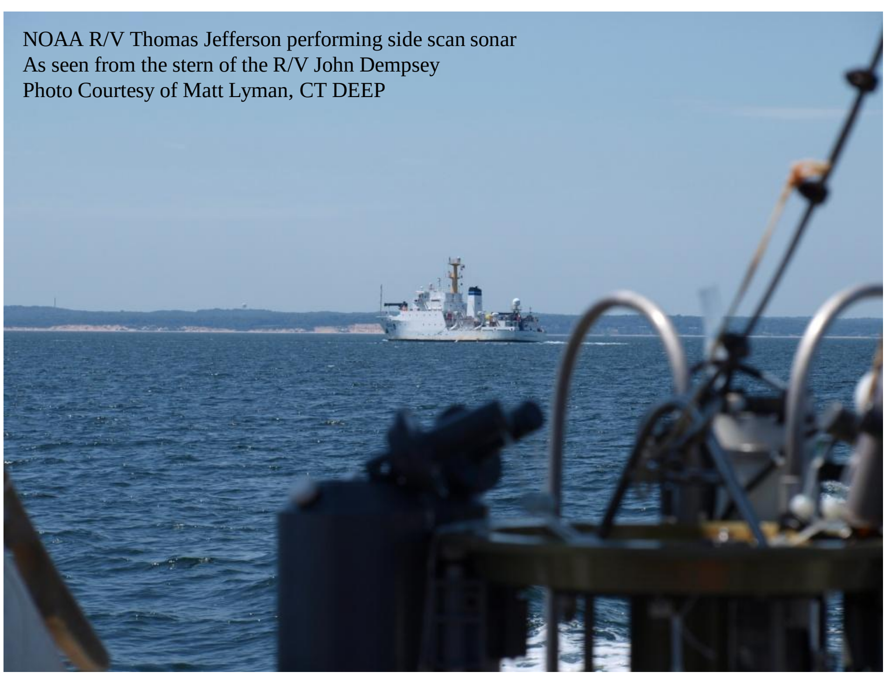
LISICOS monitors water quality parameters (e.g., salinity, temperature, dissolved oxygen, surface waves, photosynthetically available radiation, chlorophyll) and meteorological parameters (e.g., wind speed, direction, barometric pressure, wave height) at up to eight stations across the Sound. Sensors 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.

This report presents a summary of the 2013 *in situ* data collected by CT DEEP. Data from LISICOS are presented with permission for informational purposes.

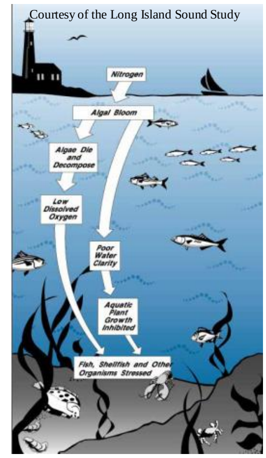
The CT DEEP LIS Water Quality Monitoring Program is synoptic in nature and is intended to characterize water quality conditions at one moment in time over a broad area (the entire Sound). Water column profile data provided by the program are useful for future determinations of volume of hypoxic waters. 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 condition 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.

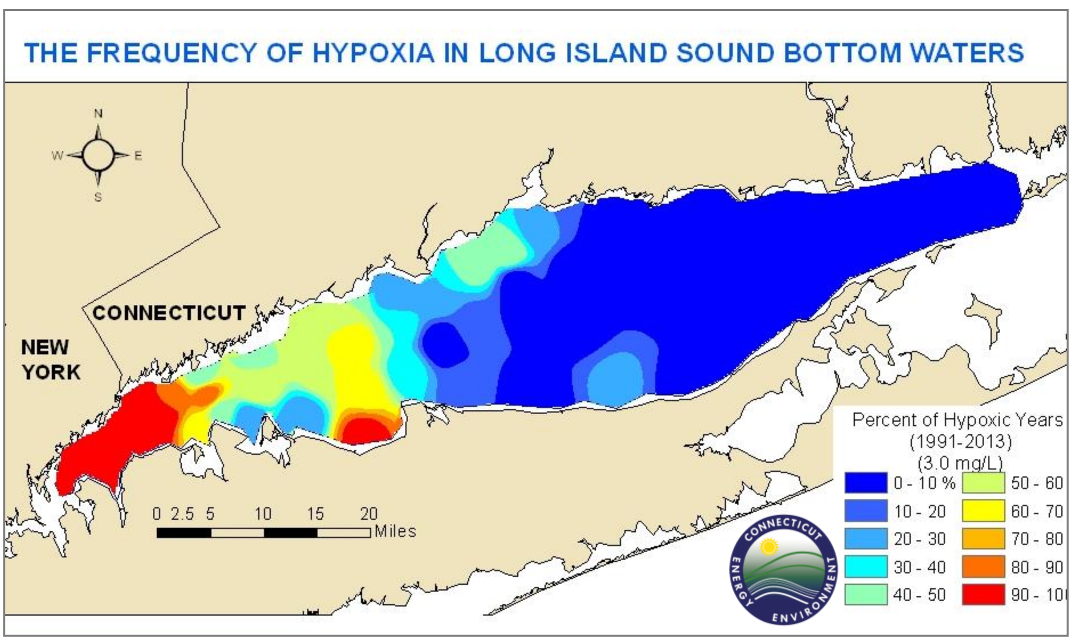

NOAA R/V Thomas Jefferson performing side scan sonar
As seen from the stern of the R/V John Dempsey
Photo Courtesy of Matt Lyman, CT DEEP

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.



How Seriously 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.

2013 Important Facts

CT DEEP conducted eight cruises during the summer of 2013 between 3 June and 9 September. Over the course of the season, ten (10) different stations were documented as hypoxic and of the 259 site visits completed in 2013, hypoxic conditions were found 16 times. Compared to the 22-year averages, 2013 was below average in area and slightly above average in duration. In fact, 2013 had the third smallest area behind 1997 and 1992 (see page 7).

Cruise	Start Date	End Date	Number of stations sampled	Number of hypoxic stations
WQJUN13	6/3/2013	6/5/2013	17	0
HYJUN13	6/21/2013	6/21/2013	23	0
WQJUL13	7/1/2013	7/3/2013	37	0
HYJUL13	7/15/2013	7/17/2013	38	2
WQAUG13	7/29/2013	7/31/2013	40	1
HYAUG13	8/12/2013	8/14/2013	38	10
WQSEP13	8/27/2013	8/29/2013	42	3
HYSEP13	9/9/2013	9/9/2013	24	0

The peak event occurred during the HYAUG13 cruise between 12 and 14 August. The lowest dissolved oxygen concentration (1.34 mg/L) was documented during the HYAUG13 cruise at Station A4. The hypoxia area maps for 2013 appear on pages 10-14.

Based on CT DEEP and NEIWPCC-IEC data

Estimated Start Date	7/8/2013
Estimated End Date	9/7/2013
Duration (days)	62
Maximum Area (mi^2)	80.7

The Long Island Sound Study has defined hypoxia as dissolved oxygen concentrations below 3.0 mg/L. On 25 February 2011, CT DEEP adopted revised water quality standards that specified dissolved oxygen in Class SA and SB waters (applicable to LIS) shall not be less than 3.0 mg/L at anytime.

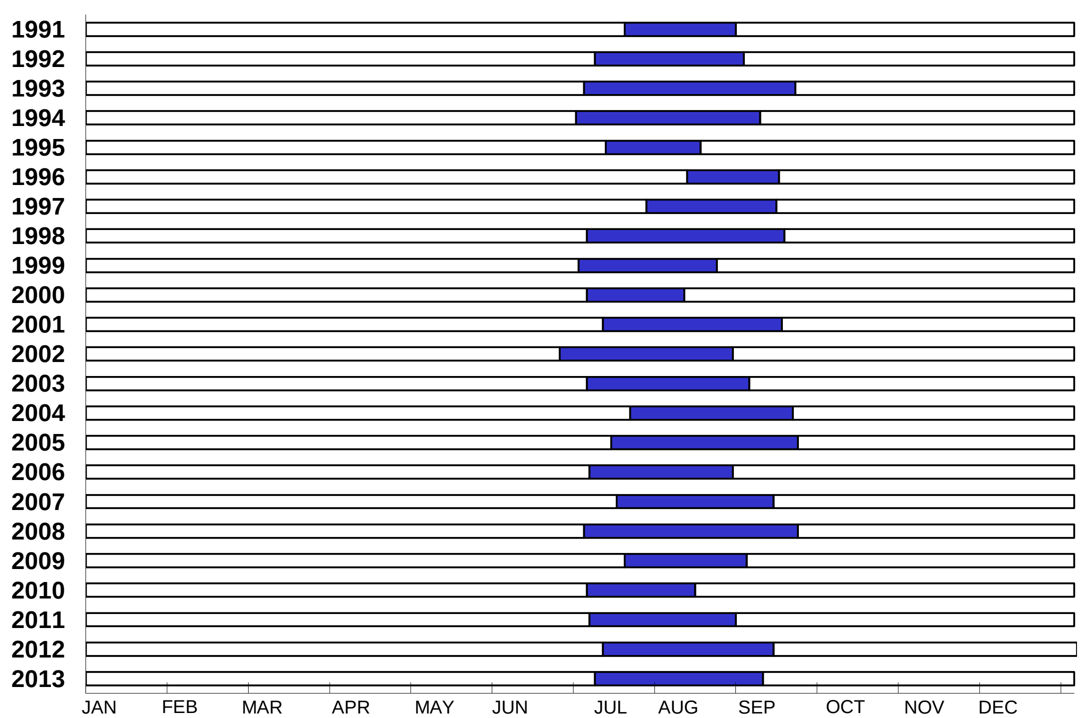
Start date and end date are estimated by plotting CT DEEP and NEIWPCC-IEC data from stations A4 and B3 in Excel using a line with markers chart and then interpolating when the DO concentration drops below/rises above 3.0 mg/L. Due to issues with the sampling vessel, NEIWPCC-IEC was unable to sample on 9/5/13. For the purposes of estimating the end date, the minimum value from the LISICOS Execution Rocks Buoy for that date was used.

Timing and Duration of Hypoxia, 1991 - 2013

The figure and table below display the onset, duration, and end of the hypoxia events from 1991 through 2013 based on the 3.0 mg/L standard.

LISS 3.0 mg/L				
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
Average	July 11	Sept 3	179	55
Deviation	±10 days	±12 days	± 87 mi^2	± 13 days

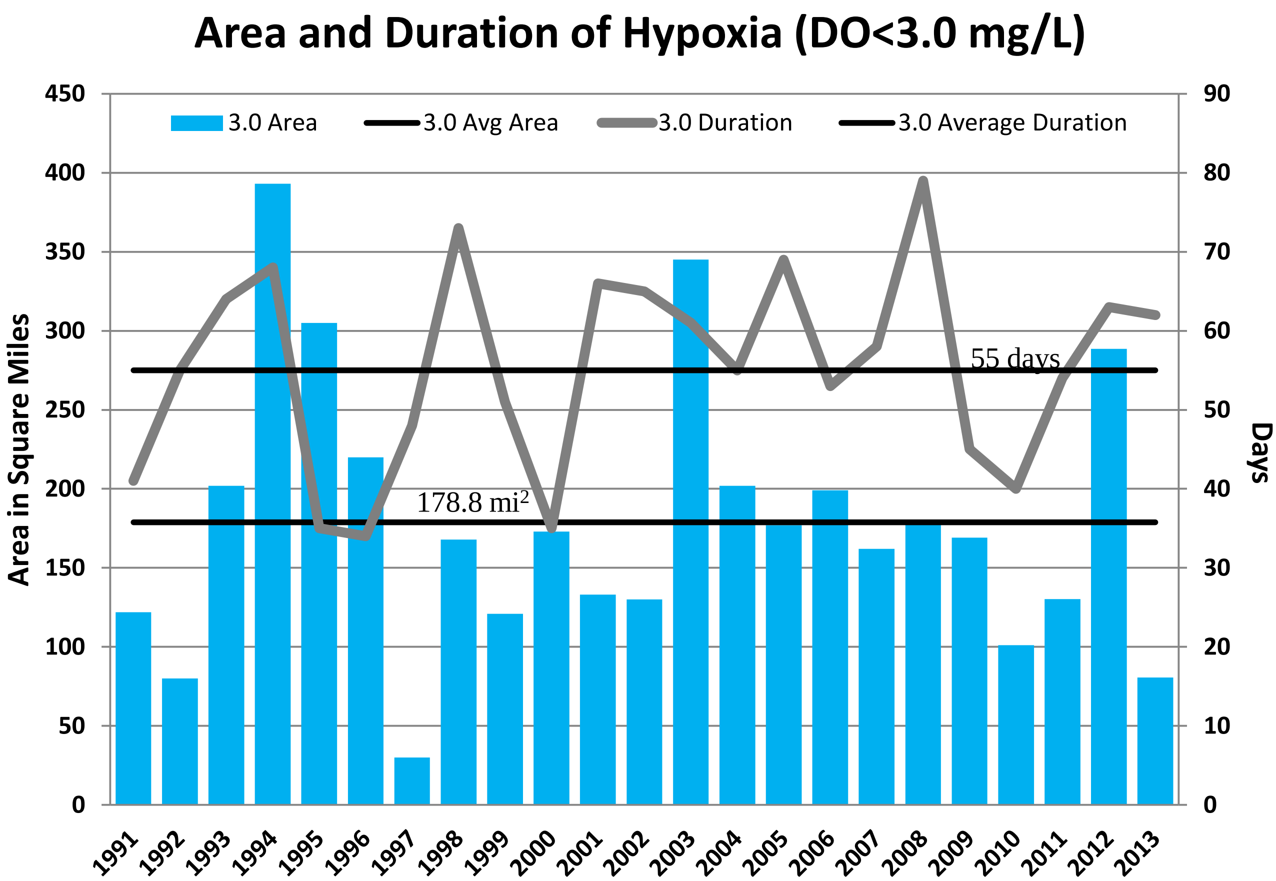
Based on the LISS standard of 3.0 mg/L, the average date of onset was July 11 (± 10 days), the average end date was September 3 (± 12 days), and the average duration was 55 days (± 13 days). The earliest onset of hypoxia (red text) occurred on 25 June 2002 and the latest end date (green text) occurred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



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

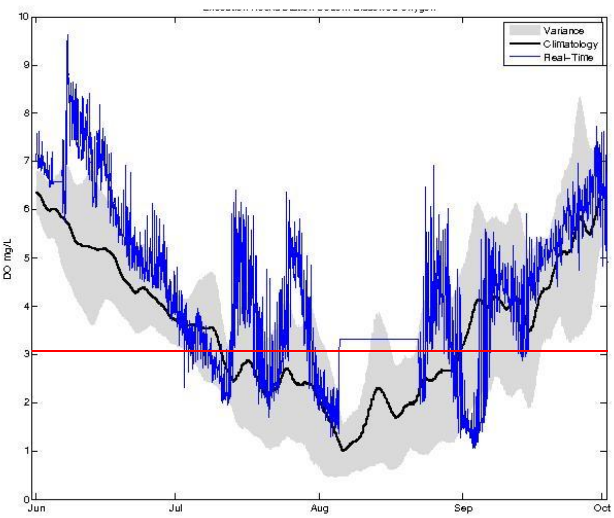


Duration Based on Buoy Data Obtained From the LISICOS Network on 9 October 2013

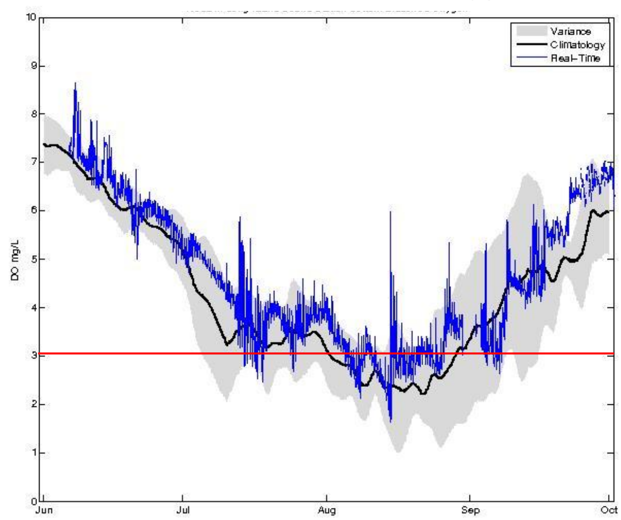
The figures below are from the LISICOS website and depict the 2013 real-time bottom dissolved oxygen data (blue line); the average of the 9 or 12 year dataset, depending on the station (black line); and the variability observed over the historical station record (gray shading).

There were several periods of increased oxygen in the bottom waters that were not captured by CT DEEP surveys and the LISICOS buoys better reflect these reoxygenation events (blue peaks above the red hypoxia threshold line). The Execution Rocks Buoy showed DO concentrations dipped below 3.0 mg/L again on 13 and 14 September (just barely at 2.88 and 2.96 mg/L) and for only a short duration. This results in an end date that is later than CT DEEP's estimated end date.

Execution Rocks Bottom Dissolved Oxygen



Western LIS Bottom Dissolved Oxygen



Based on LISICOS Buoy Data Collected Between 1 June to 9 October

	Execution	Western
Estimated Start Date	7/2/2013	7/14/13
Estimated End Date	9/14/13	9/7/13
Duration below 3.0 mg/L (cumulative days)	23.49	15.21
Duration below 2.0 mg/L (cumulative days)	7.41	0.46
Duration below 1.0 mg/L (cumulative days)	0	0
Minimum DO value (mg/L)	1.05 (3 Sept)	1.63 (14 Aug)
Days with no data	18	11.93

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.***

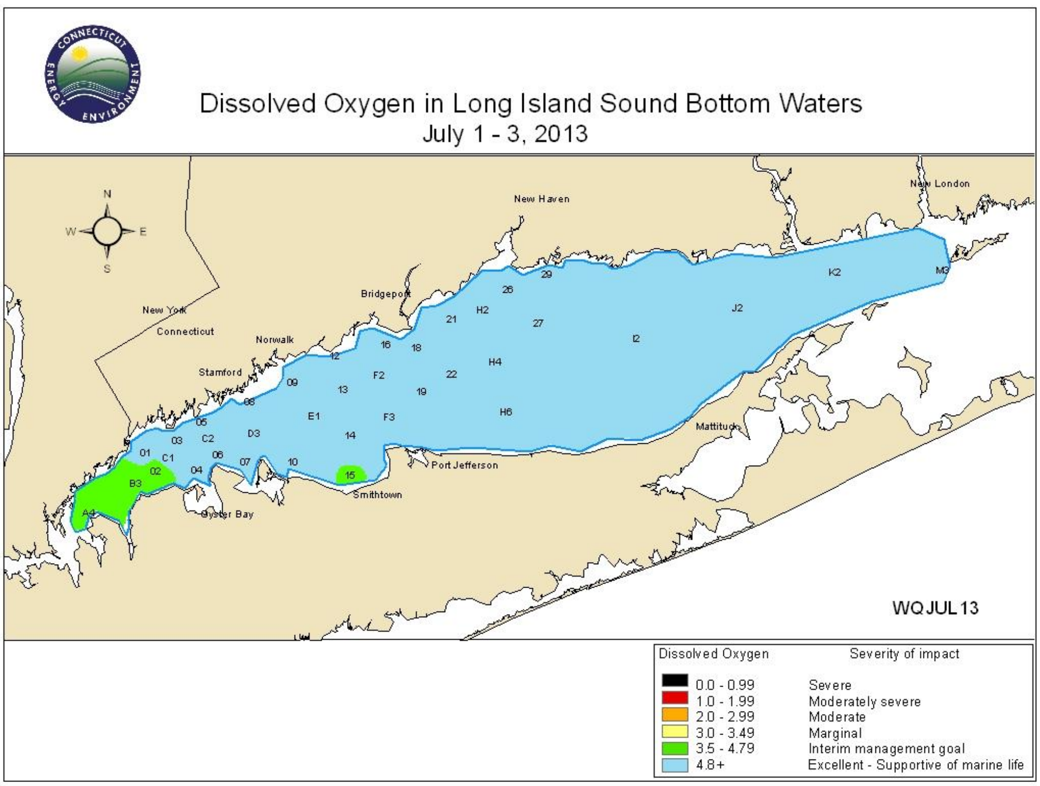
The new ARTG Buoy also exhibited hypoxic conditions with a start date estimated as 7/24/13 and an end date estimated as 9/8/13. The minimum DO was 1.32 mg/L on 8/18.

Hypoxia Maps

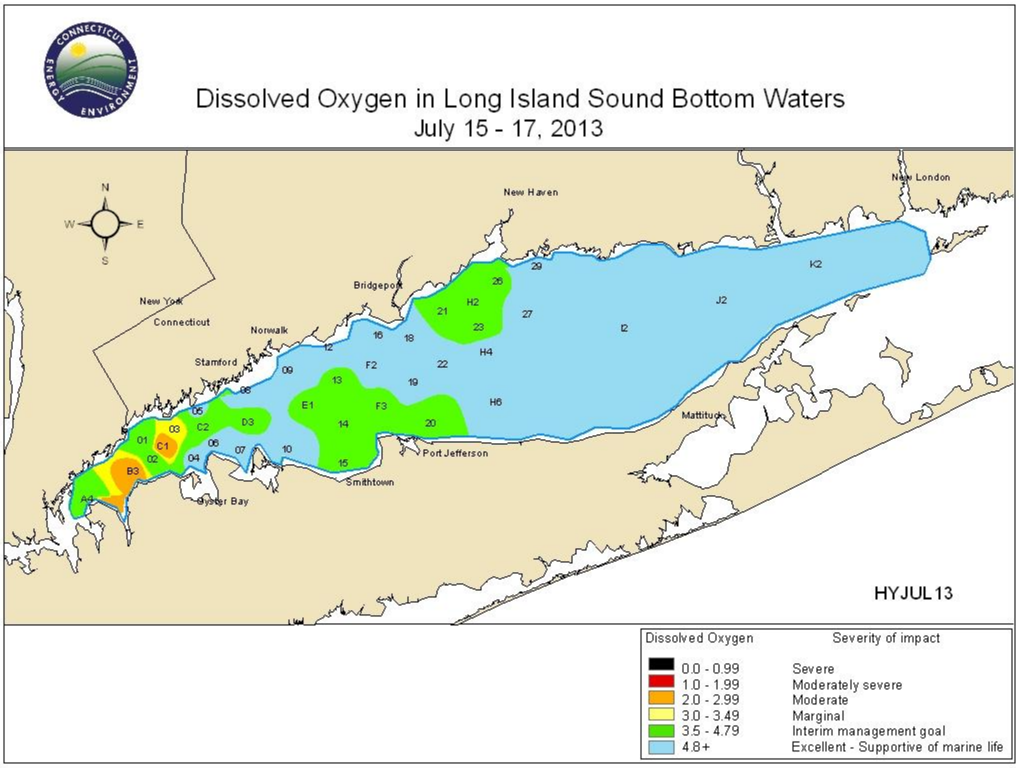
The following maps depict the development of hypoxia based on CT DEEP cruise data through the 2013 season.

During the HYJUN13 survey all stations had DO concentrations above 4.8 mg/L.

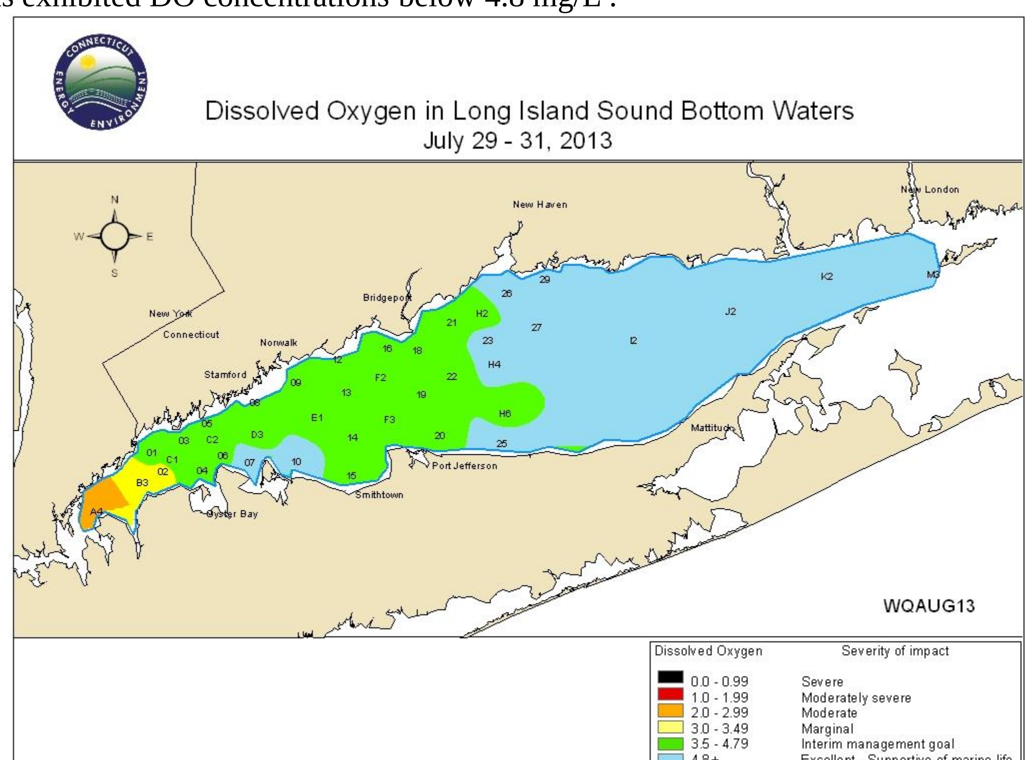
During the WQJUL13 survey DO concentrations were less than 4.8 mg/L at four stations. Data for all surveys are available upon request.



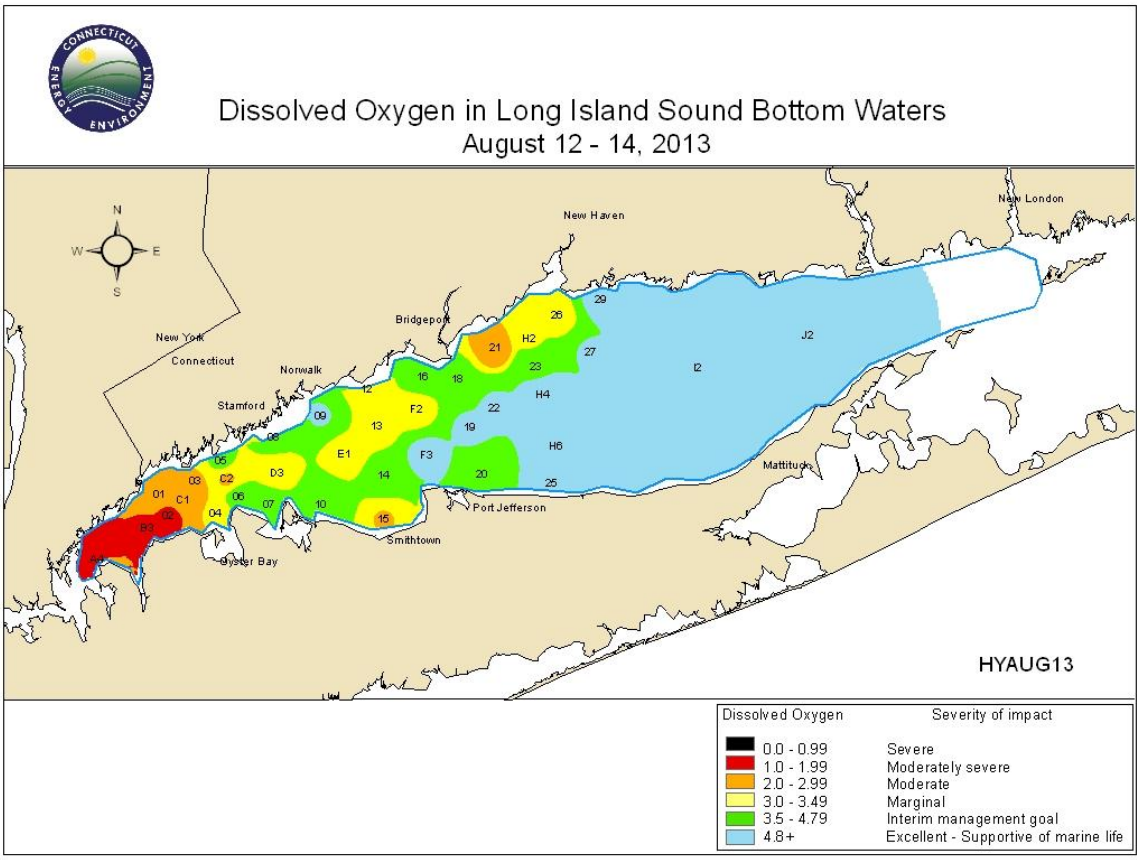
During the HYJUL13 survey, DO concentrations dropped below 4.8 mg/L at 18 stations and of those, one station was below 3.5 mg/L and two stations were below 3. 0 mg/L.



During the WQAUG13 survey, DO concentrations at Station A4 dropped below 3.0 mg/L, while Stations B3 and 02 improved slightly, but were still less than 3.5 mg/L. An additional 25 stations exhibited DO concentrations below 4.8 mg/L .



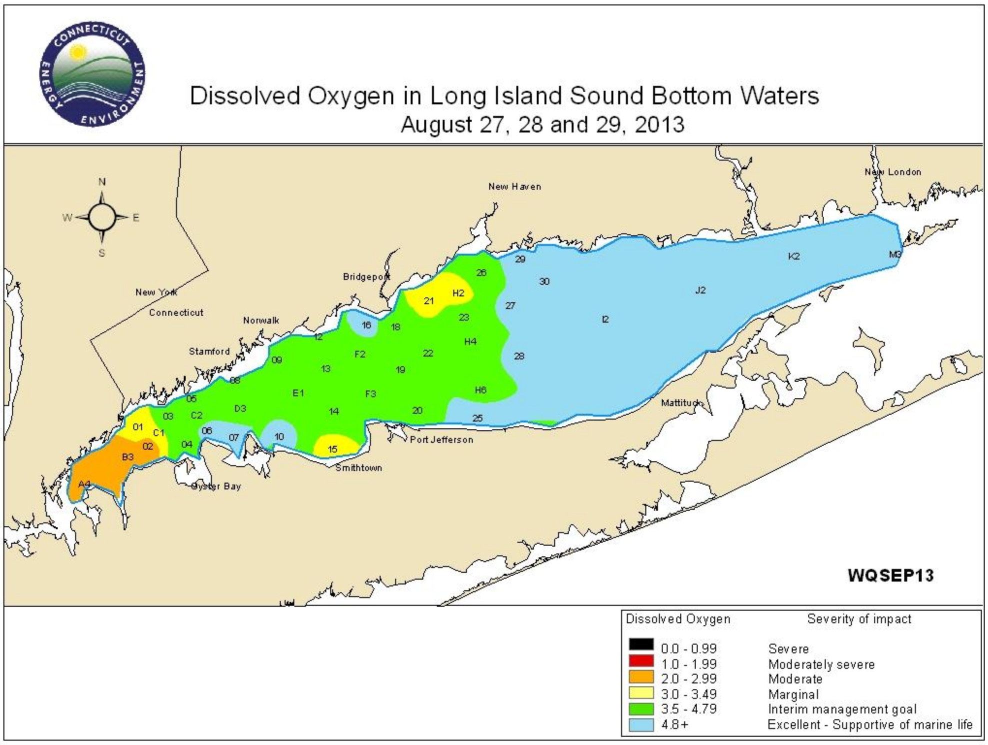
Concentrations continued to decline during the HYAUG13 survey with three stations exhibiting DO concentrations below 2.0 mg/L and six stations below 3.0 mg/L. Additionally, eight stations had concentrations below 3.5 mg/L and ten stations were below 4.8 mg/L. Conditions in 2013 were better than in 2012 when the DO concentration at Station A4 was below 1 mg/L and 23 stations were below 3.0 mg/L. 2013 had the third lowest areal extent over the course of the 22-year sampling program, with only 1991 and 1997 having lower areal extents.



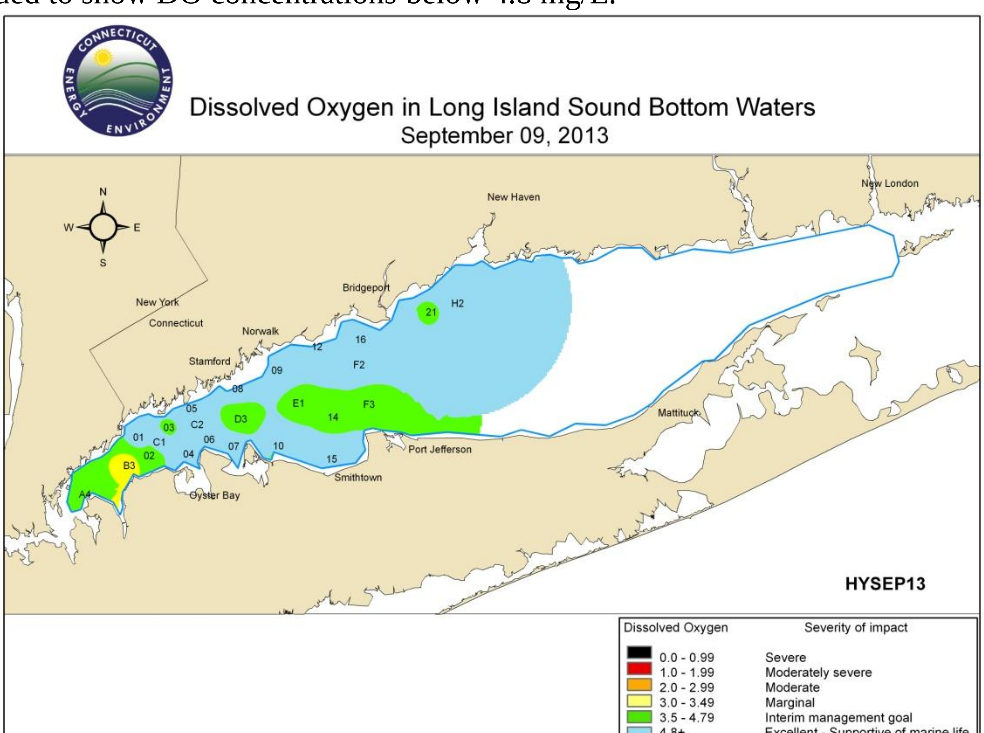
Maximum Areal Extent (80.7 mi^2) of Hypoxia

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

The WQSEP13 survey found conditions improving, with no stations exhibiting DO concentrations below 2.0 mg/L. Three stations still had concentrations less than 3.0 mg/L and five stations had concentrations less than 3.5 mg/L.



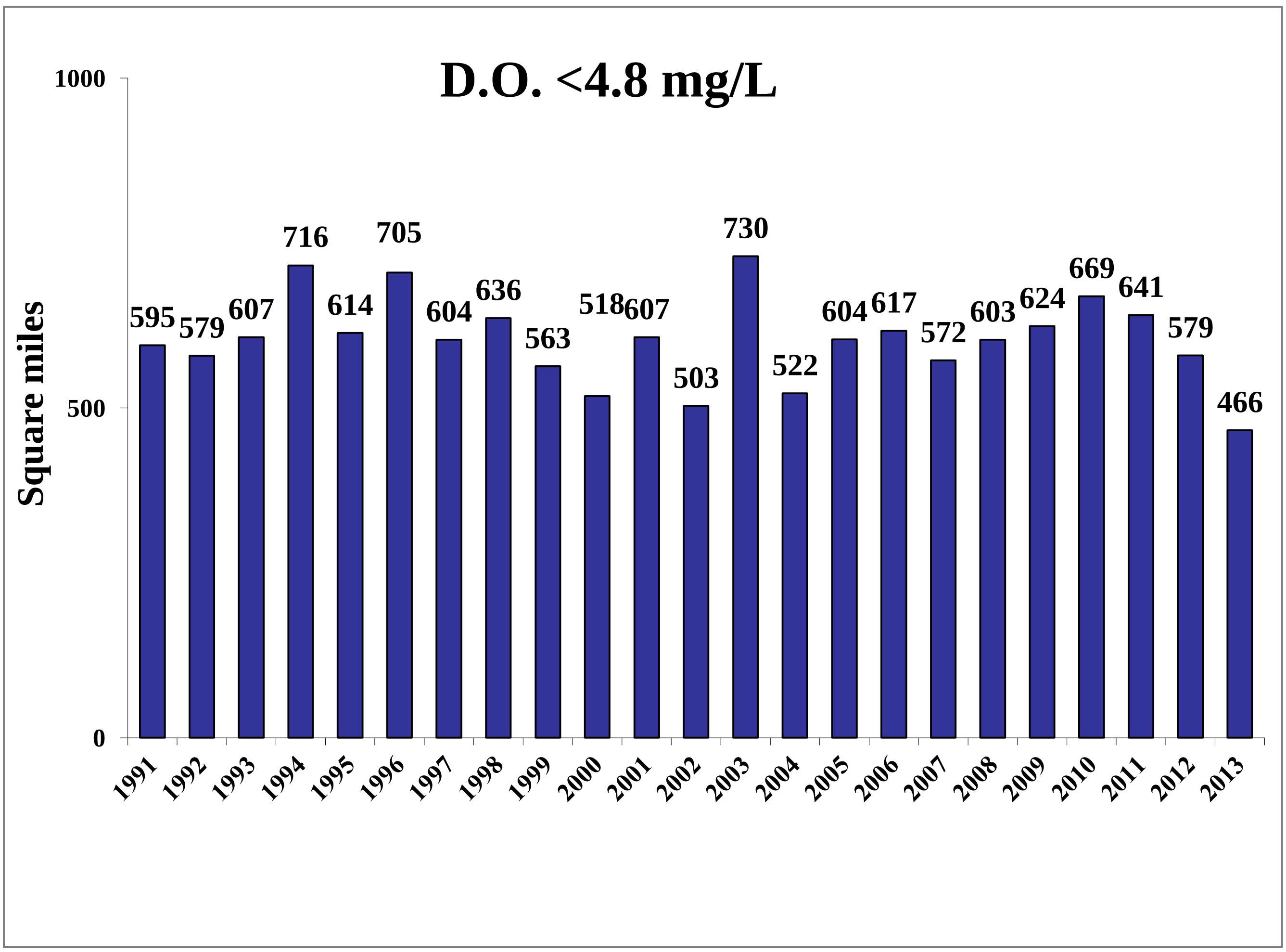
Conditions continued to improve through the HYSEP13 survey with only one station exhibiting DO concentrations below 3.5 mg/L (B3). Eight additional stations continued to show DO concentrations below 4.8 mg/L.



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 2013, the maximum area occurred during the WQSEP13 survey and was estimated at 466 square miles and was the lowest over the 22-year sampling program. From 1991-2013, the area affected by concentrations less than 4.8 mg/L averages 603.2 square miles and varies slightly from 466 to 730 square miles.

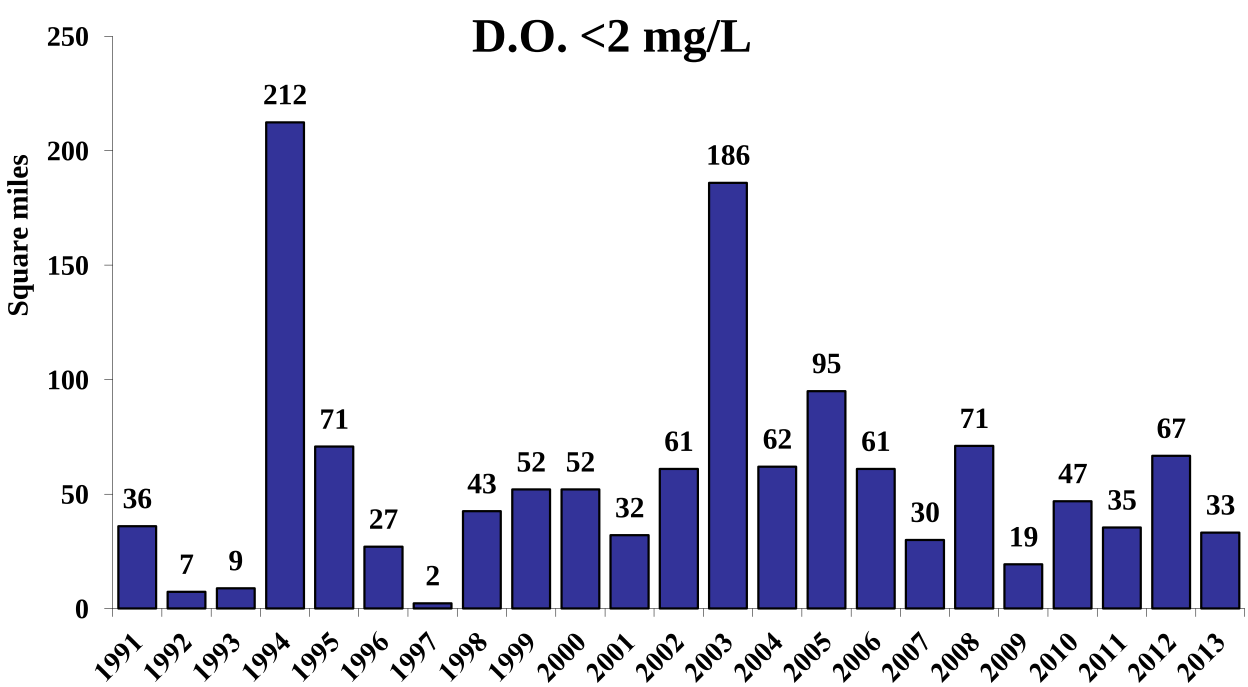


Severe Hypoxia

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.

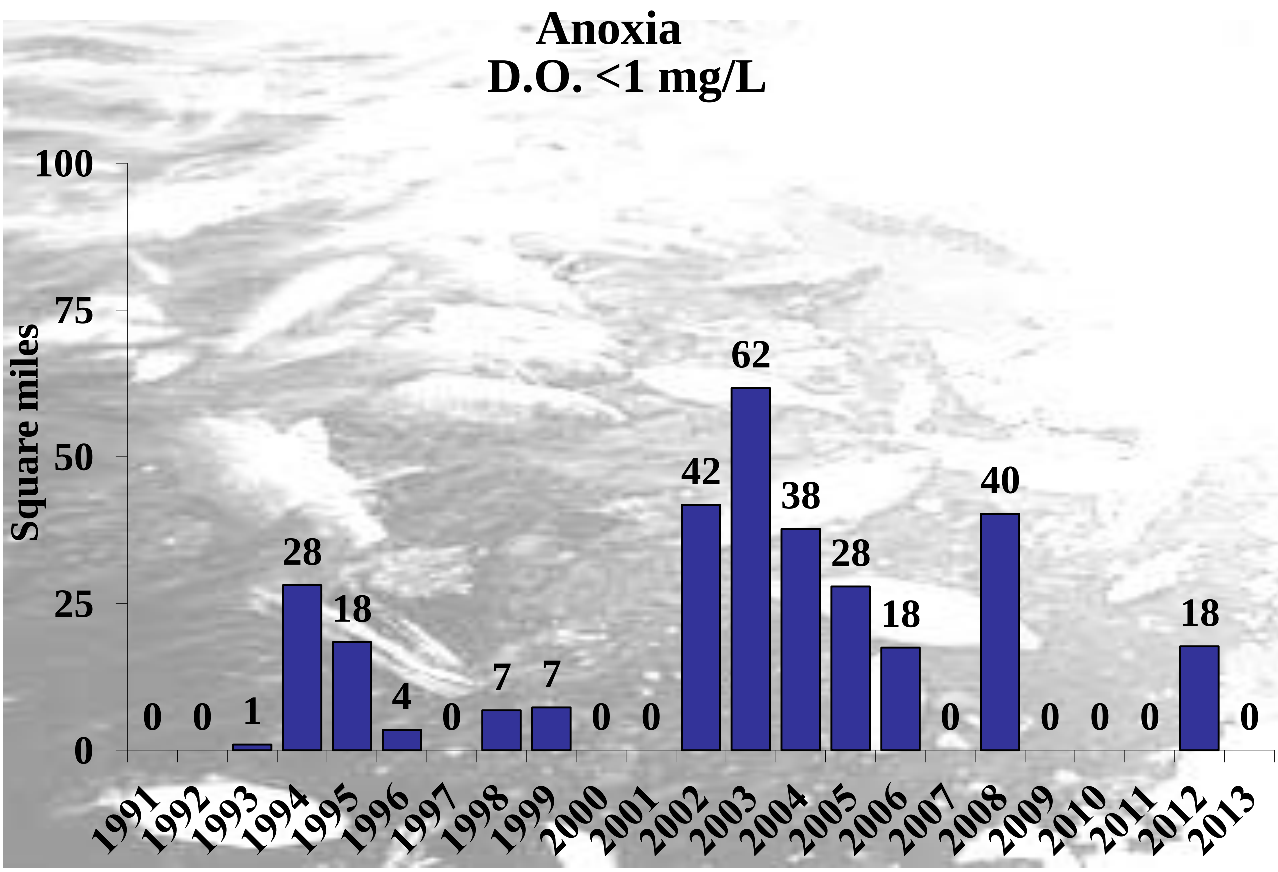
This chart illustrates the maximum area of bottom waters of Long Island Sound with concentrations less than 2 mg/L. In 2013, the maximum area of LIS affected by severe hypoxia was 33.2 mi^2, a decrease from 2012. The average area, calculated from 1991-2013, is 58.1 mi^2. Based on CT DEEP data there were 15 days when DO was less than 2.0 mg/L. Based on the LISICOS Execution Rocks data there were 4.73 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 2013 hypoxic zone covered 5837.9 mi^2 (15,120 km^2) and was one of the largest areas on record exceeding the long -term average (http://www.gulfhypoxia.net/Research/Shelfwide%20Cruises/2013/PressRelease2013.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.

According to the Northeast Regional Climate Center, (www.nrcc.cornell.edu/page_summaries.html) August 2013 was cooler than normal, although the three prior months were above normal across the Northeast. Additionally, precipitation was above normal for the summer period (June-August) with both Connecticut and New York receiving about 5 inches more than their averages.

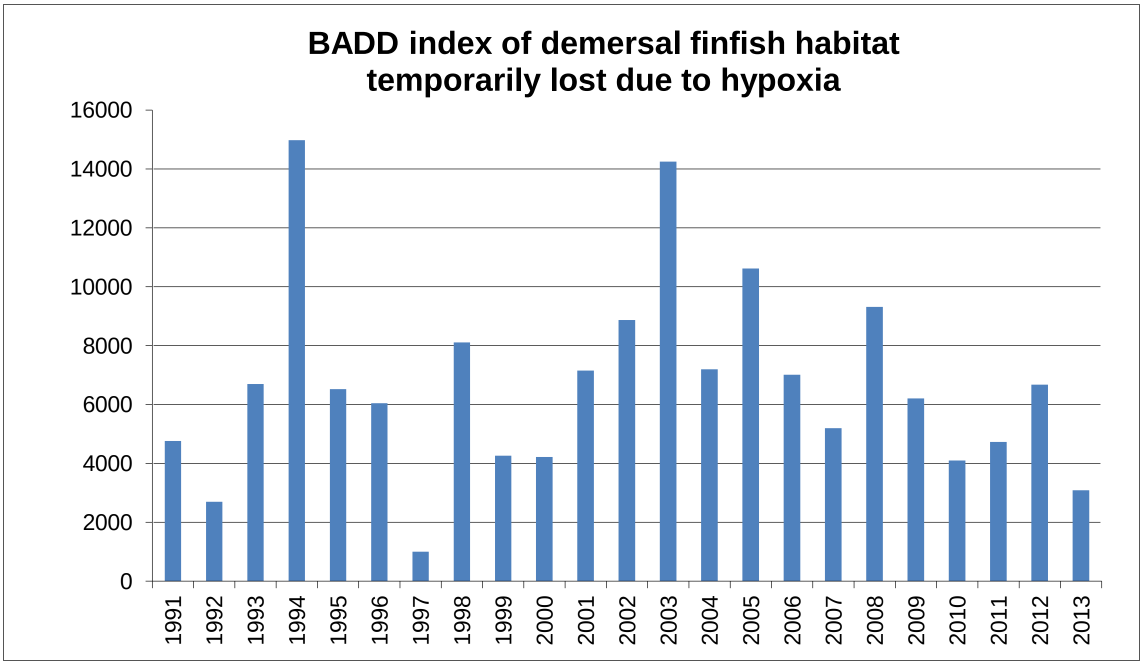


For management purposes the Long Island Sound Study defines anoxia as DO concentrations less than 1 mg/L. In ten of the twenty-two years there was no anoxia reported by CT DEEP. The greatest area with D.O. below 1 mg/L observed in LIS, based on ~biweekly sampling by CT DEEP, was during the summer of 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, anoxic conditions were not documented by 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 8 July – 7 September (62 d). The index is then expressed as a percentage of the available area-days (sample area 2,723 km^2 x 62 d, or 168,826 area-days).

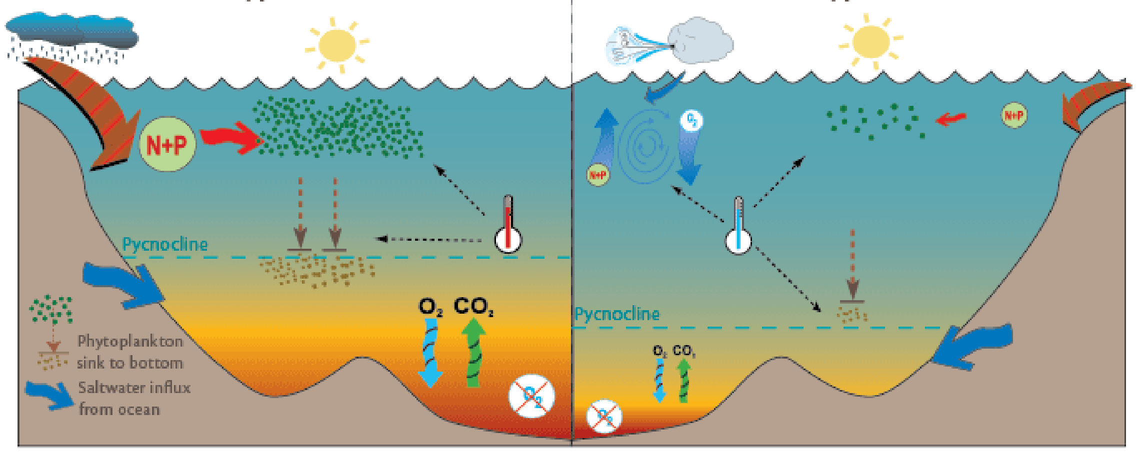


Simpson, David G., Kurt Gottschall, and Mark Johnson. 1995. Cooperative interagency resource assessment (Job 5). In : A study of marine recreational fisheries in Connecticut, CT DEP Marine Fisheries Office, PO Box 719, Old Lyme, CT 06371, p 87-135.

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 22.) 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.



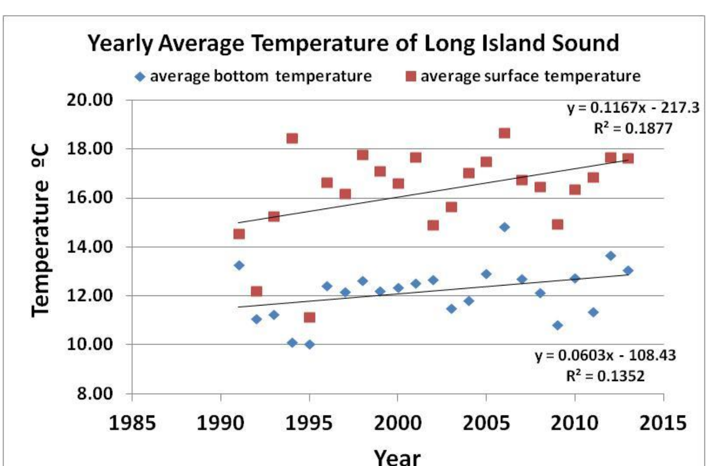
	Loads	Phytoplankton	Decomposition	Temperature	Wind event
Large amount of low dissolved oxygen	Large nitrogen and phosphorus loads	Elevated nutrients cause large phytoplankton blooms	High oxygen consumption by decaying phytoplankton	Warm water a) Stimulates decomposition b) Stratifies water column c)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

2013 Water Temperature Data

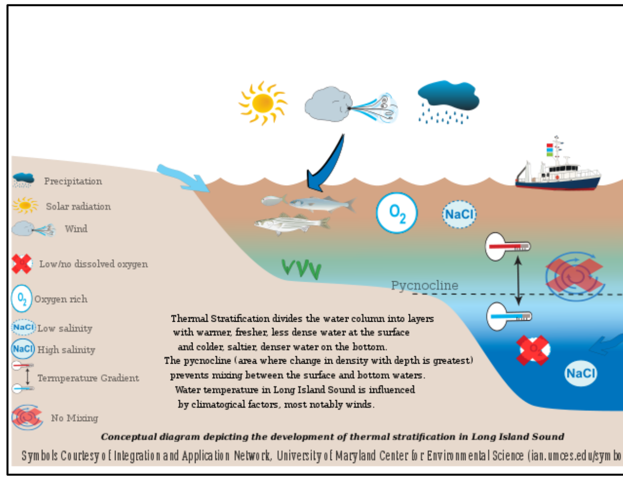
2013 maximum, minimum, and average water temperature (ºC) data are summarized below. Data are integrated across Long Island Sound (i.e., all stations and all depths) and are displayed by cruise. Data were obtained using the CT DEEP Sea Bird Sea Cat Conductivity, Temperature, Depth (CTD) profiler.

Cruise	2013 Max	1991-2012 Max	2013 Min	1991-2012 Min	2013 Average	1991-2012 Average
WQJAN	6.582	9.311	4.281	0.500	5.272	4.556
WQFEB	5.289	6.748	1.861	-1.325	3.230	2.158
CHFEB	2.448	4.464	1.803	0.678	1.965	2.447
WQMAR	4.025	6.611	2.211	-0.783	2.901	2.399
CHMAR	No Survey	6.575	No Survey	0.113	No Survey	3.519
WQAPR	5.667	10.072	3.516	1.309	4.207	4.863
WQMAY	10.987	14.145	6.955	5.054	8.527	8.621
WQJUN	18.945	21.436	11.768	8.239	13.312	12.769
HYJUN	21.204	22.458	13.780	11.116	16.915	15.837
WQJUL	22.773	25.336	14.535	11.639	18.085	17.400
HYJUL	27.493	27.493	16.902	15.038	19.911	19.332
WQAUG	24.649	27.067	18.857	14.018	21.230	20.492
HYAUG	23.348	25.517	20.183	18.678	21.545	21.661
WQSEP	24.535	25.031	19.476	16.390	22.036	21.678
HYSEP	22.990	23.484	21.247	19.533	21.911	21.639
WQOCT	20.722	21.571	17.702	14.161	19.696	19.141
WQNOV		16.601		10.467		13.837
WQDEC		12.712		4.655		9.205



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 1991-2013.

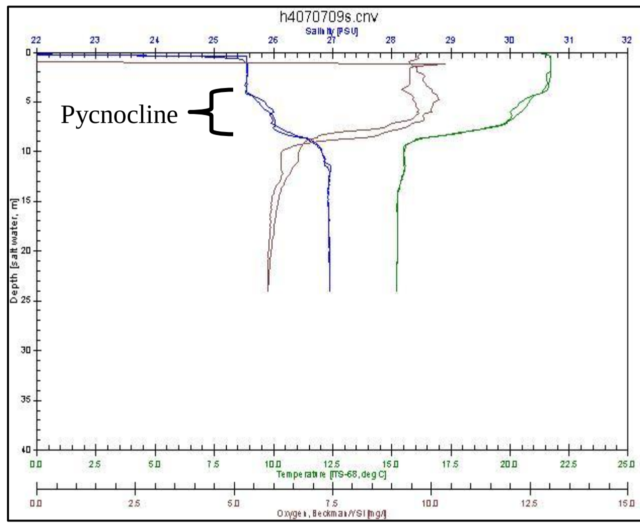
Delta T and Stratification



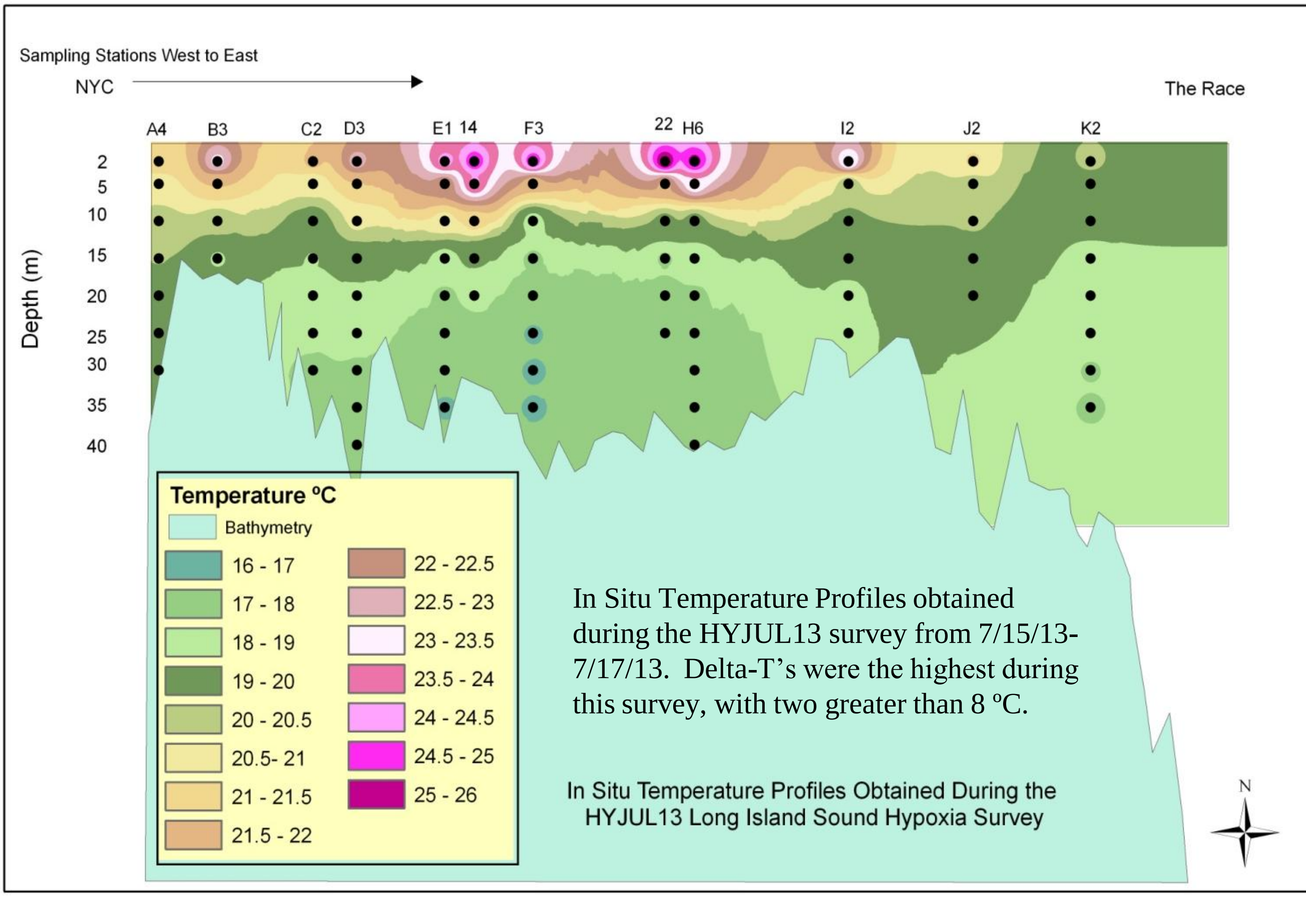
Conceptual diagram depicting the development of thermal stratification in Long Island Sound

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

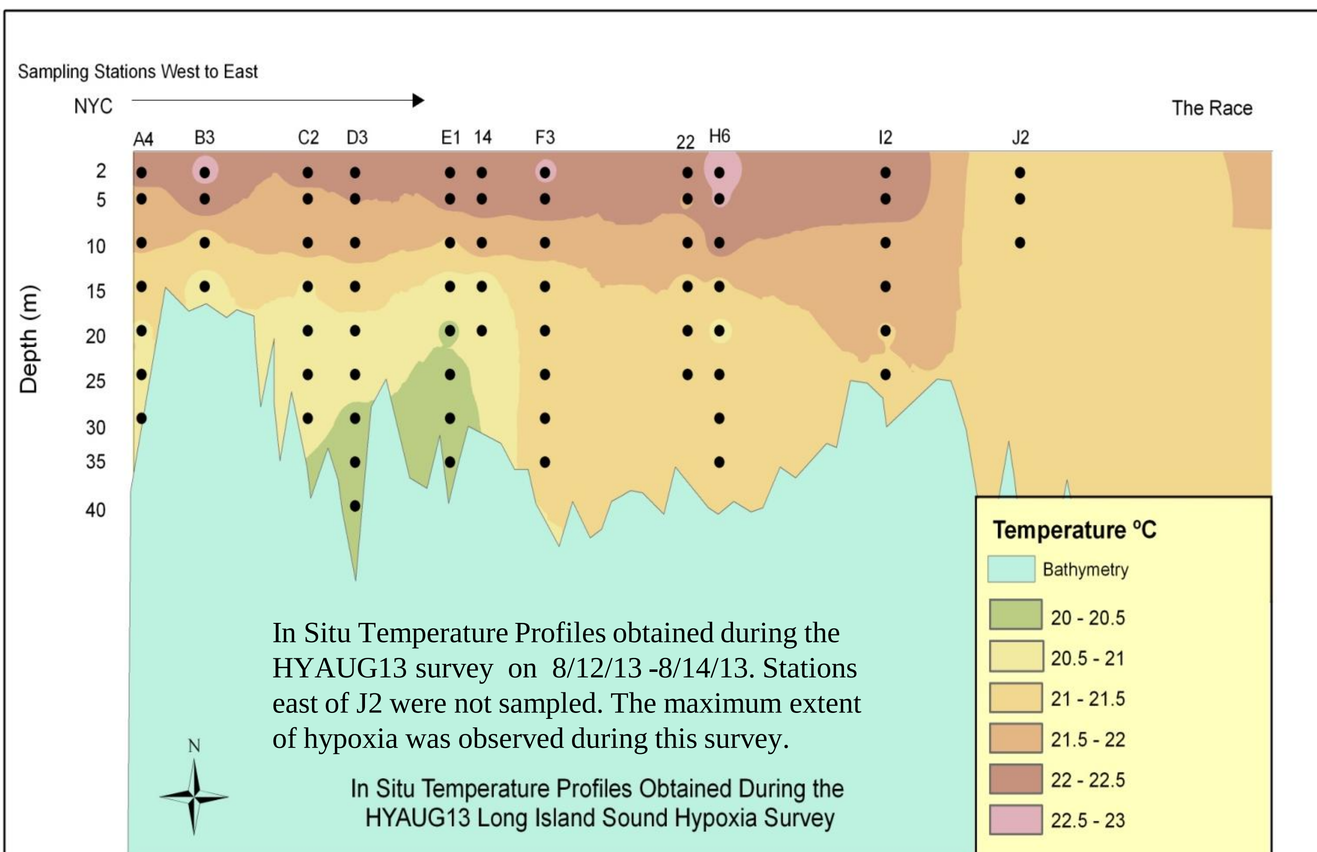
The temperature difference between the bottom waters and the surface waters is known as "Delta T". This Delta T, along with salinity differences, creates a density difference, or "density gradient" resulting in a separation or "stratification" of water layers that hinders the oxygenated surface waters 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



The temperature graphs on page 21 show computer interpolations along the west-east axis of LIS generated from profile data collected during two CT DEEP surveys. During the HYJUL13 survey, surface water temperatures had warmed to an average of 23 ºC while the bottom water remained cooler around an average of 19ºC. 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 the HYAUG13 survey when hypoxic conditions were at their worst. The graphs on page 22 show how the Delta T's varied over the course of the summer sampling season. Delta T's increased from the WQAPR13 survey through the WQAUG13 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 ºC over much of the Sound. Delta T's continued to decrease during the HYSEP13 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 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.

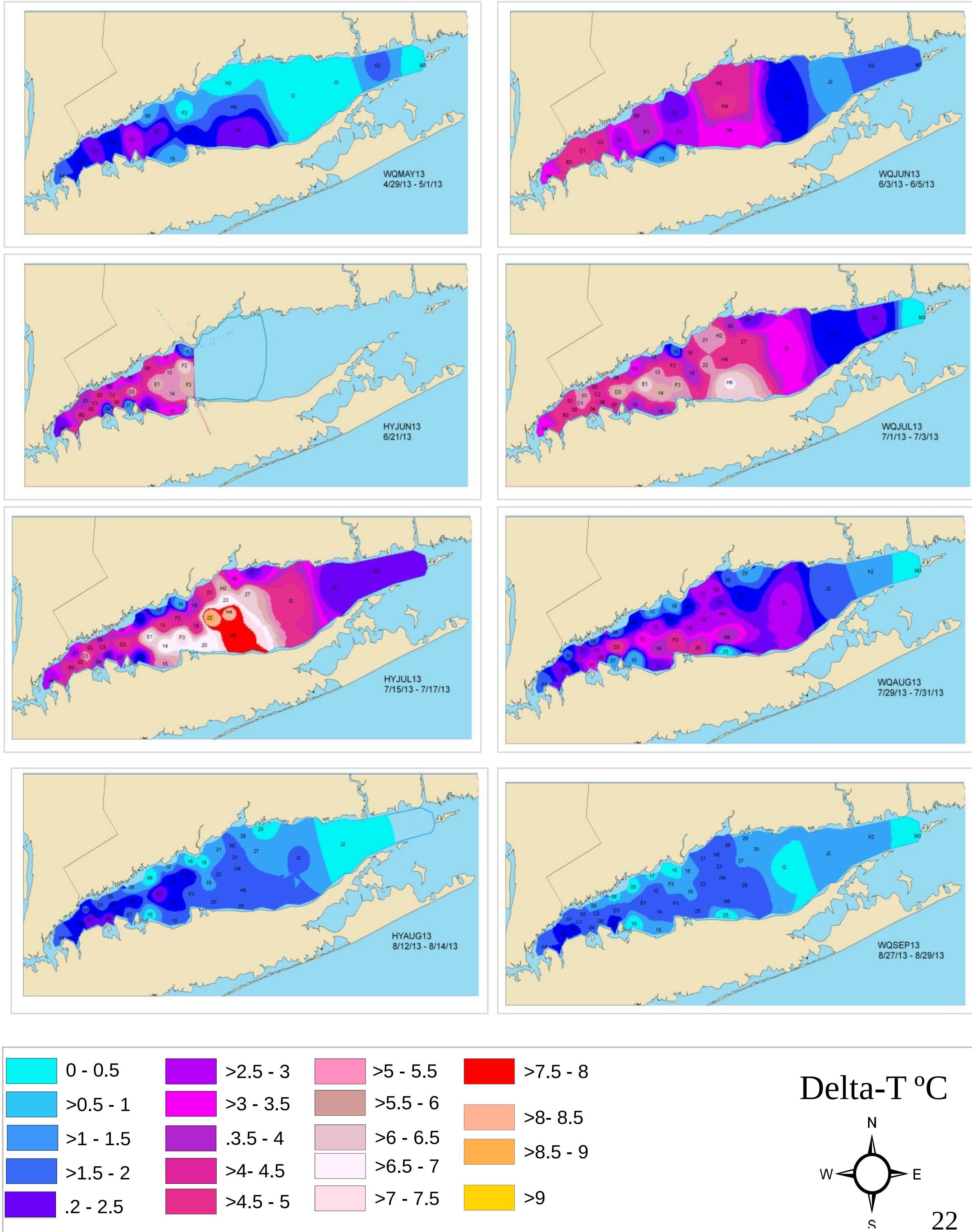


In Situ Temperature Profiles obtained during the HYJUL13 survey from 7/15/13-7/17/13. Delta-T's were the highest during this survey, with two greater than 8 ºC.



In Situ Temperature Profiles obtained during the HYAUG13 survey on 8/12/13 -8/14/13. Stations east of J2 were not sampled. The maximum extent of hypoxia was observed during this survey.

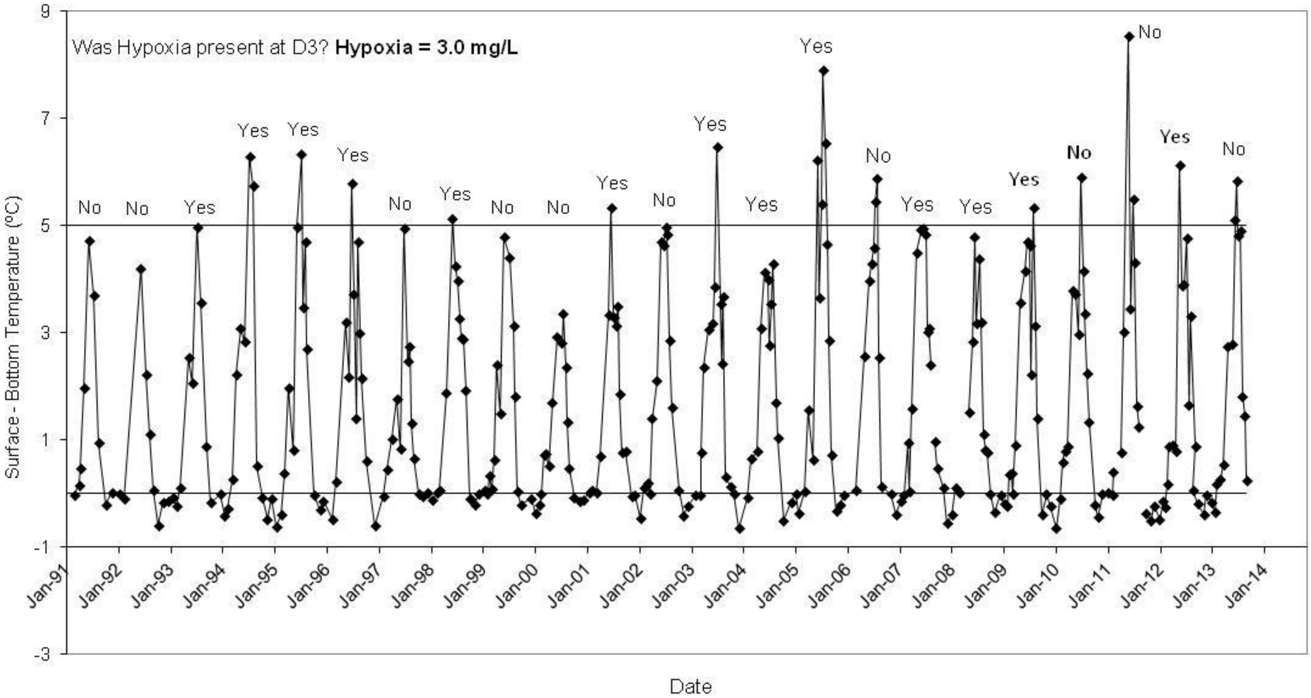
2013 Delta-T Maps



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	24.15	5.85	80.7

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 2013.

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).

Salinity

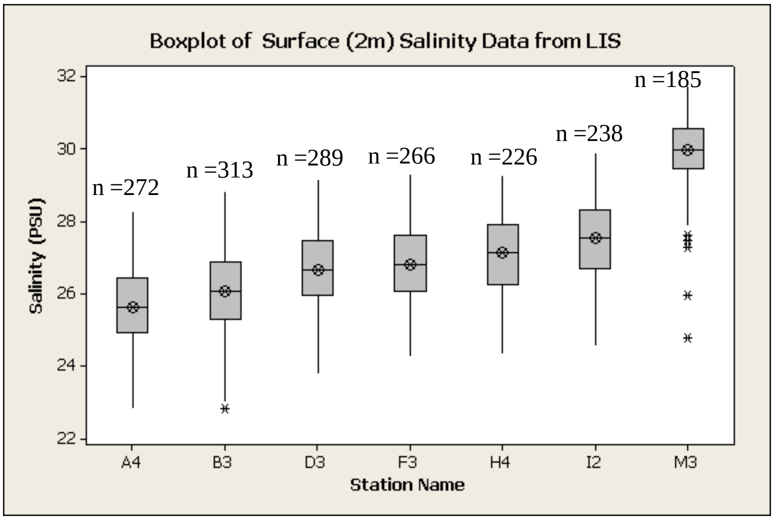
Salinity is a measure of the dissolved salts content of seawater. It is usually expressed in practical salinity units (PSU). Salinity levels across Long Island Sound vary from 23 PSU in the Western Sound at Station A4 to 33 PSU in the eastern Sound at Station M3. The Thames, Connecticut, and Housatonic rivers are the major sources of freshwater entering the Sound. Summary statistics for salinity data collected from seven stations across the Sound from 1991-2012 are presented in the tables below. Data collected this year are also presented separately.

		1991-2012 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	282	23.823	28.727	26.335	26.32	0.0554	0.93	0.864
B3	330	24.259	28.926	26.613	26.573	0.051	0.926	0.857
D3	307	24.912	29.215	27.244	27.355	0.0505	0.885	0.783
F3	286	25.153	29.432	27.602	27.628	0.0506	0.855	0.731
H4	245	25.508	29.7	27.749	27.765	0.0538	0.842	0.709
I2	269	25.762	29.985	28.065	28.122	0.051	0.837	0.701
M3	225	28.608	32.622	30.596	30.566	0.0479	0.719	0.517

		2013 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	11	26.044	27.656	26.841	26.839	0.159	0.526	0.277
B3	11	26.316	28.001	27.092	27.097	0.173	0.573	0.329
D3	11	27.047	28.282	27.543	27.438	0.125	0.415	0.173
F3	10	27.254	28.481	27.854	27.824	0.138	0.437	0.191
H4	9	27.168	28.562	28.036	28.008	0.146	0.438	0.192
I2	9	27.444	28.948	28.158	27.971	0.171	0.513	0.263
M3	8	30.204	31.891	31.057	31.05	0.255	0.721	0.52

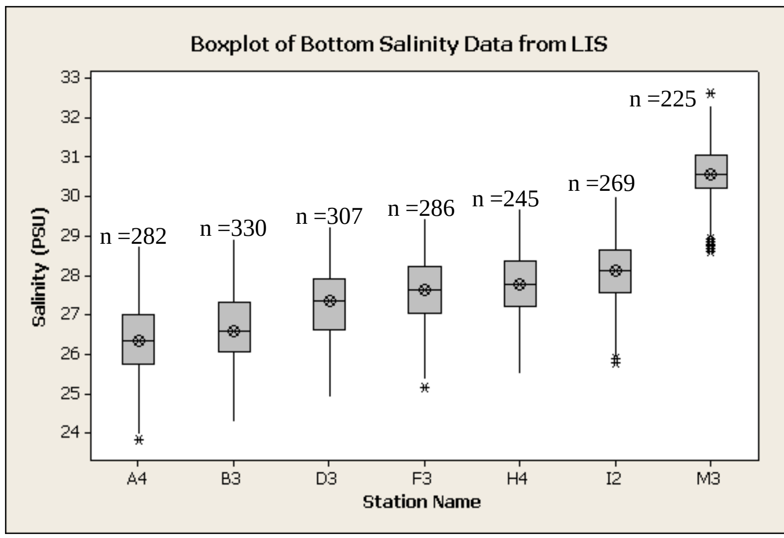
		1991-2012 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	272	22.833	28.278	25.643	25.623	0.0631	1.041	1.084
B3	313	22.8	28.84	26.044	26.067	0.0604	1.068	1.14
D3	289	23.772	29.146	26.671	26.638	0.062	1.053	1.109
F3	266	24.246	29.307	26.823	26.818	0.0656	1.07	1.145
H4	226	24.315	29.262	27.071	27.122	0.0713	1.072	1.15
I2	238	24.56	29.909	27.488	27.521	0.0672	1.036	1.073
M3	185	24.789	31.758	29.948	29.985	0.0738	1.004	1.008

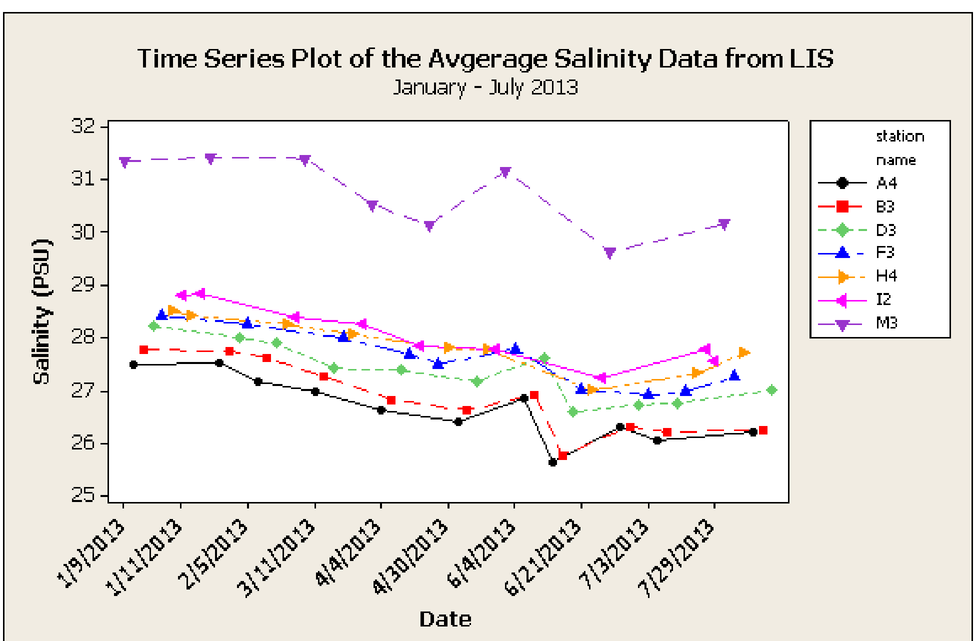
		2013 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	10	24.208	27.35	26.082	26.067	0.312	0.986	0.972
B3	11	24.832	27.602	26.462	26.397	0.249	0.827	0.684
D3	11	25.69	28.071	27.011	27.125	0.241	0.8	0.641
F3	10	25.285	28.318	27.002	27.054	0.296	0.935	0.874
H4	9	26.184	28.506	27.524	27.766	0.275	0.824	0.679
I2	9	26.438	28.722	27.748	27.834	0.276	0.827	0.684
M3	8	29.18	31.215	30.282	30.205	0.269	0.762	0.581



This box plot, based upon data collected during CT DEEP surveys from January - July 2013 (n=377, includes BOLD09 survey), 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- July 2013 (n=377, includes BOLD09 survey), 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.

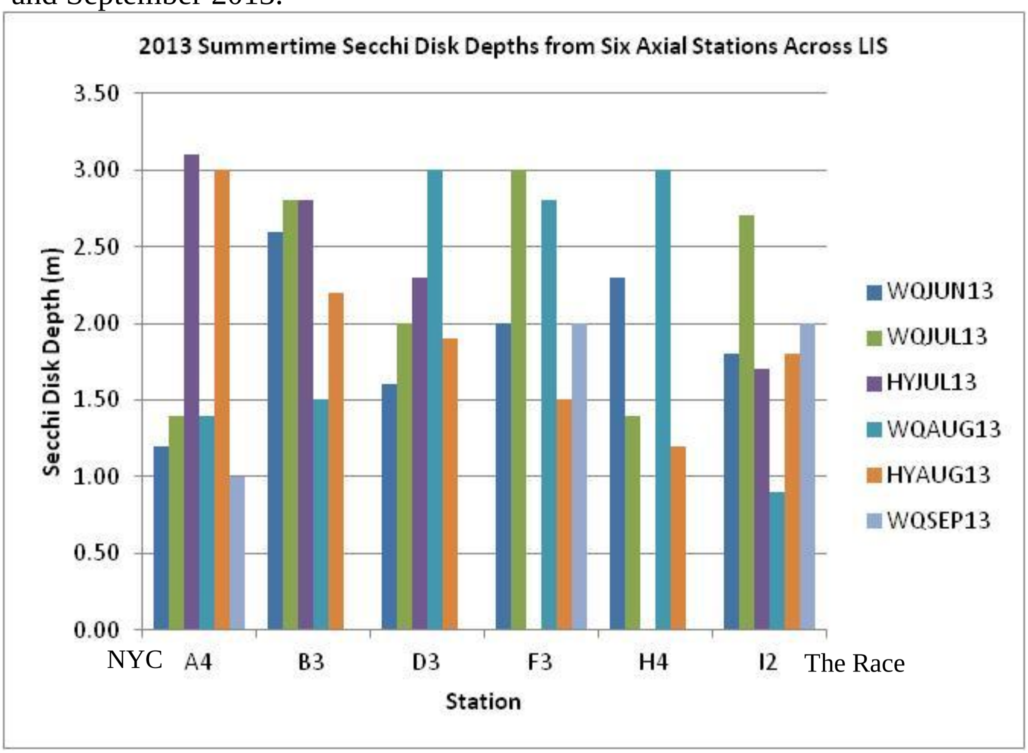




This time series plot illustrates the temporal variability of the mean salinity values by station from January- July 2013 (WQAUG13 survey).

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, 2740 measurements have been entered into our database; of those 1,621 are from the 17 stations sampled annually. The 2000-2013 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 2013.



2012 data

- **Average Secchi Disk Depth: 2.36 m (n=268)**
- **Minimum Secchi Disk Depth: 1.0 m on multiple dates/stations**
- **Maximum Secchi Disk Depth: 4.0 m at Station F3 during the WQJUL12 cruise**

2013 data

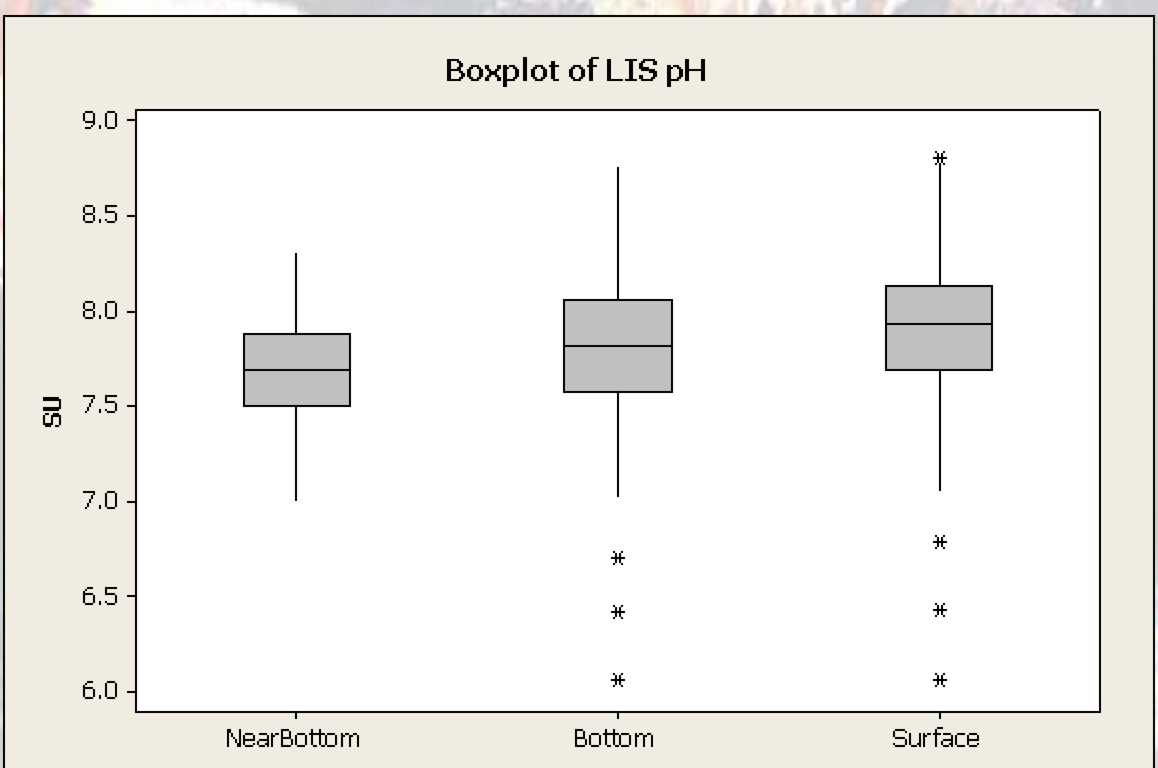
- **Average Secchi Disk Depth: 2.33 m (n=260)**
- **Minimum Secchi Disk Depth: 0.9 m at Station A4 during the WQAUG13 cruise**
- **Maximum Secchi Disk Depth: 4.2 m at Stations J2 during the WQAPR13 cruise**

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 WQSEP13 survey are summarized below.

	n	Maximum	Minimum	Mean	Median	SE Mean	StDev	Variance
Near Btm	722	8.315	7.003	7.6807	7.6915	0.00935	0.2513	0.0632
Bottom	727	8.762	6.061	7.8195	7.815	0.0119	0.3218	0.1036
Surface	1116	8.806	6.066	7.9059	7.932	0.00869	0.2905	0.0844



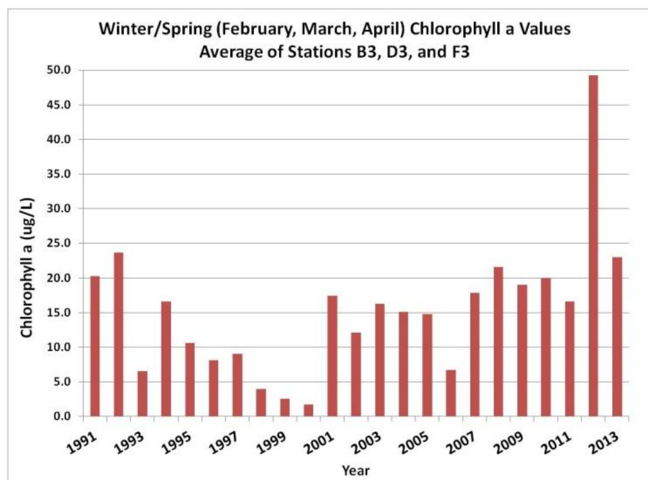
Chlorophyll a

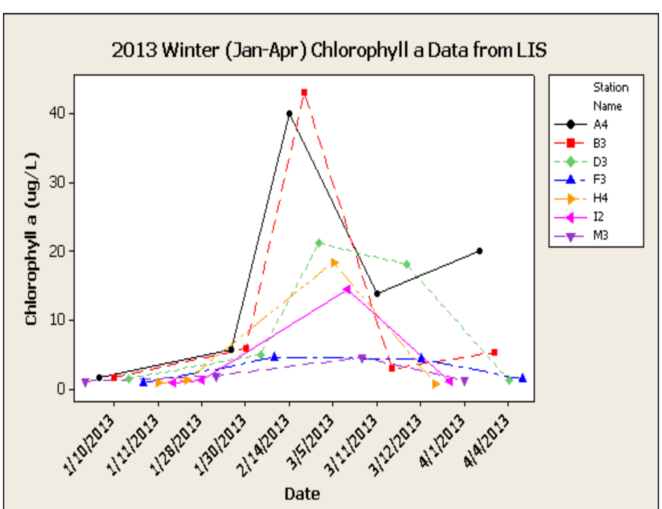
Chlorophyll is a pigment found in plants that gives them their green color. It allows plants to absorb light from the sun and convert it to chemical energy during photosynthesis. In photosynthesis carbon dioxide and water are combined to produce sugar giving off oxygen as a byproduct. Microscopic plants,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

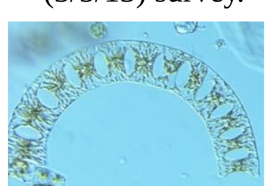
Chlorophyll a concentrations are measured *in situ* using the CTD fluorometer as well as through the collection of grab samples using Niskin bottles. The grab samples are brought back into the onboard lab, filtered, and then sent to UConn for analysis.

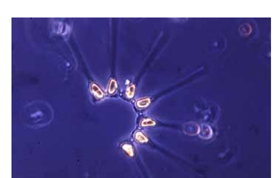
The spring phytoplankton bloom occurs in Long Island Sound between February and April. Historically high levels of chlorophyll a in the western Sound during this time have been linked to summertime hypoxia conditions. Grab sample data from stations B3, D3, and F3 during the spring months are averaged together and then plotted to show the spring bloom conditions in the western Sound.

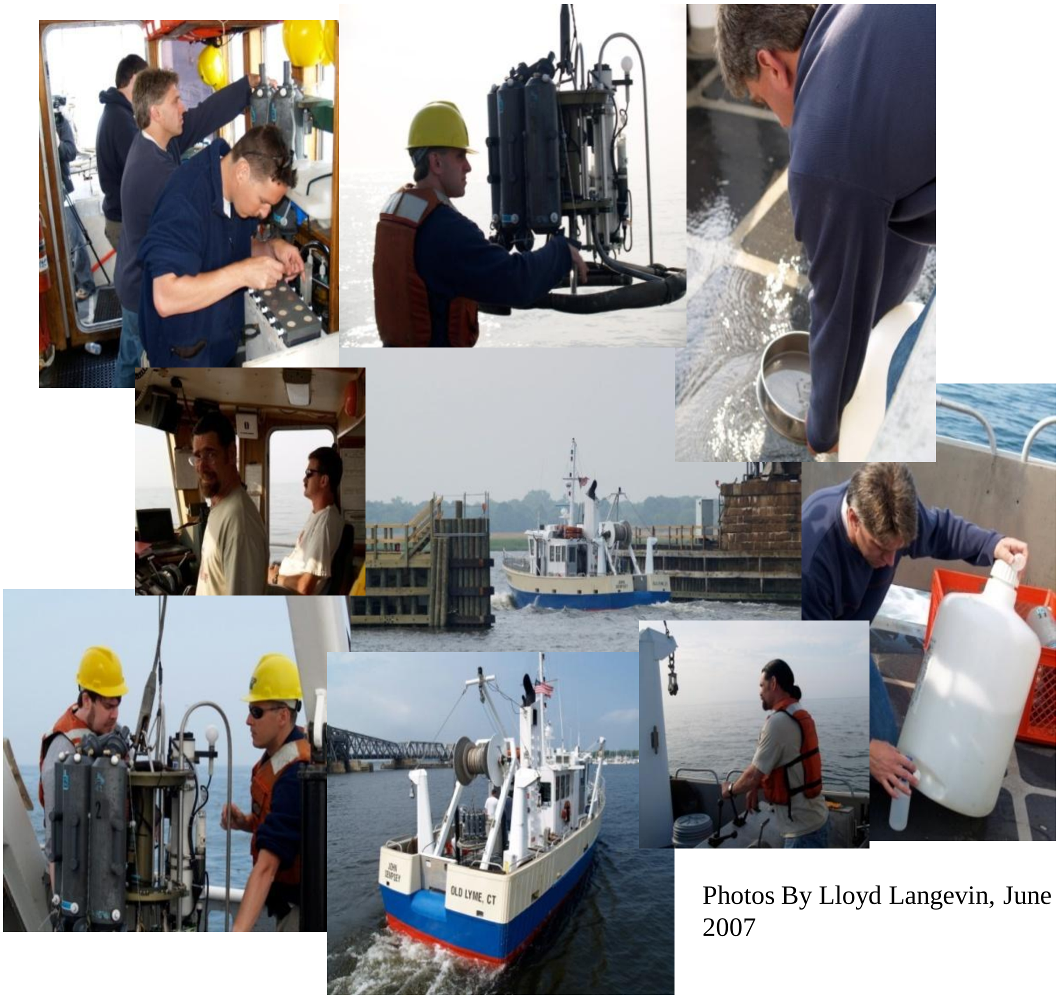




This time series plot illustrates the temporal variability of the surface chlorophyll a values (grab samples) by station from January-April 2013. The spring bloom was captured during the special CHFEB13 (2/14/13) survey and extended into the WQMAR13 (3/5/13) survey.







Photos By Lloyd Langevin, June 2007

Acknowledgements

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