2012 Long Island Sound Hypoxia Season Review

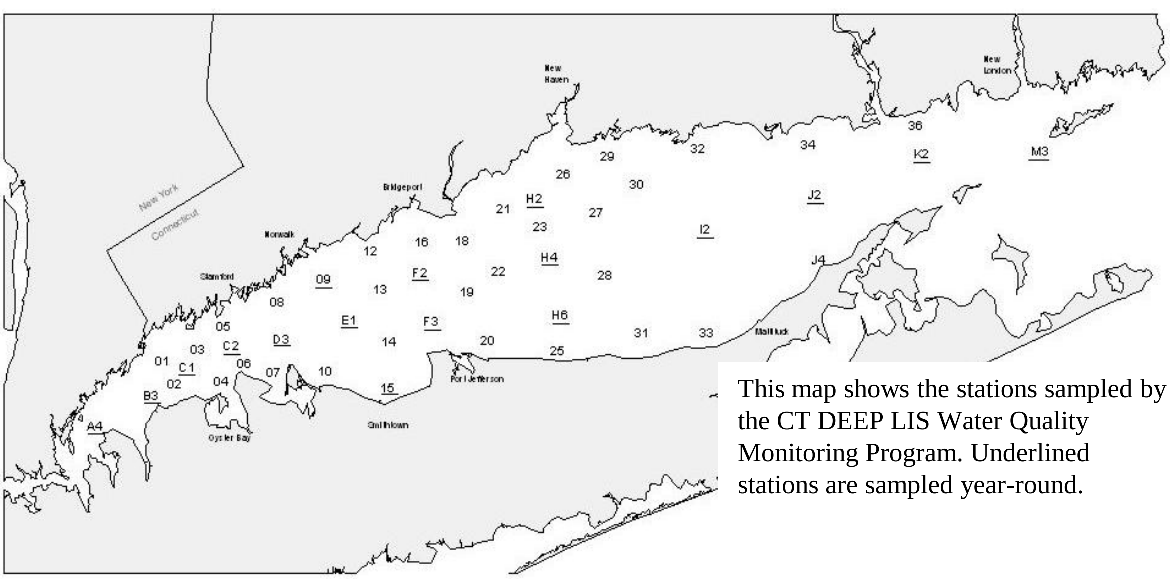
CONNECTICUT DEPARTMENT OF ENERGY & ENVIRONMENTAL PROTECTION
79 ELM STREET, HARTFORD, CT 06106
DANIEL C. ESTY, COMMISSIONER

MONITORING LONG ISLAND SOUND 2012

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".

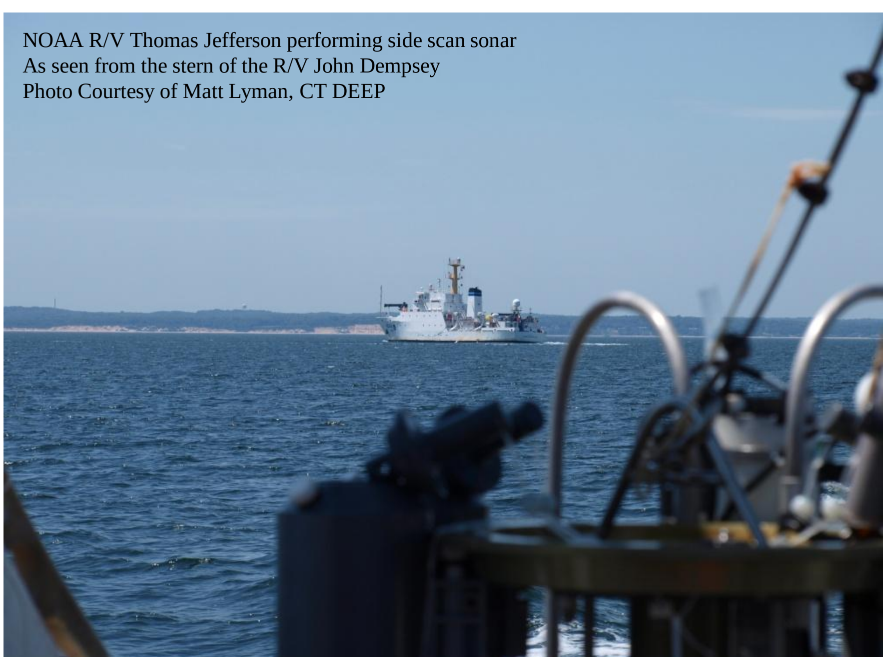
LISICOS monitors water quality parameters (e.g., salinity, temperature, dissolved oxygen, surface waves, photosynthetically available radiation, chlorophyll) and meteorological parameters (e.g., wind speed, direction, barometric pressure, wave height) at up to eight stations across the Sound. Sensors 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 2012 *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.

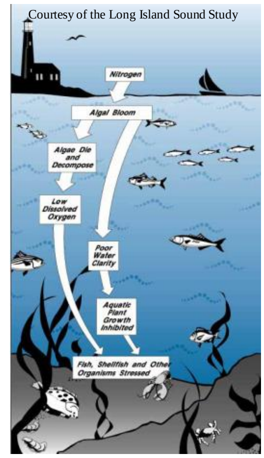
The LISICOS water quality sensors are attached to fixed locations and provide a holistic view of the conditions over a long span of time (i.e., continuous data from one station). The LISICOS continuously recording buoys have shown instances where vertical mixing within the water column raises the DO 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.

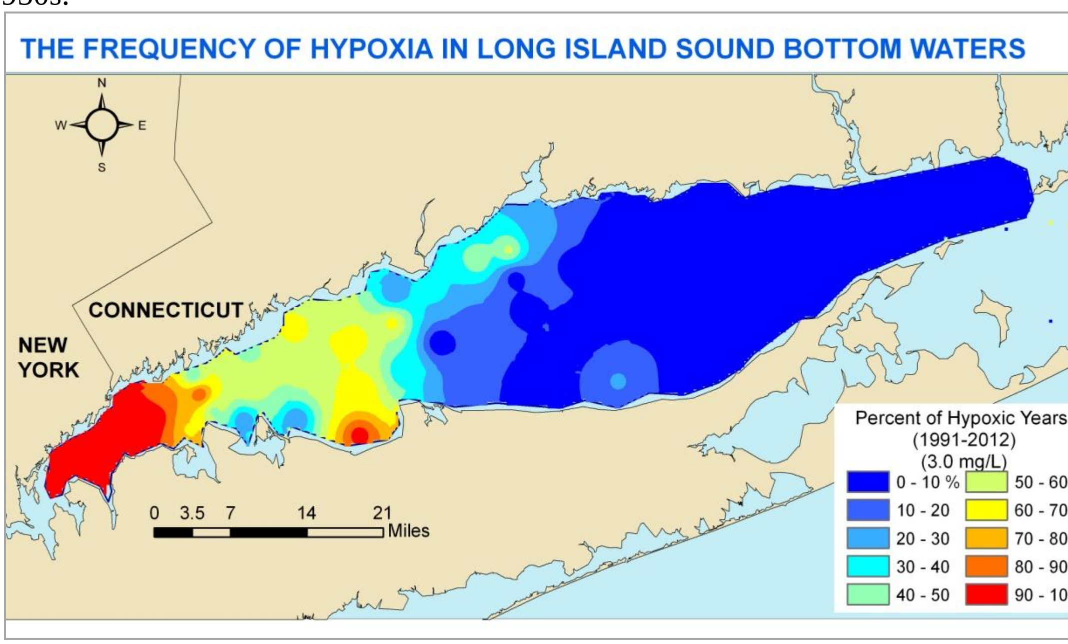


NOAA R/V Thomas Jefferson performing side scan sonar
As seen from the stern of the R/V John Dempsey
Photo Courtesy of Matt Lyman, CT DEEP

What is Hypoxia?



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.

Photo By Lloyd Langevin, June 2007

2012 Important Facts

CT DEEP conducted eight cruises during the summer of 2012 between 29 May and 17 September. Over the course of the season, 23 different stations were documented as hypoxic and of the 259 site visits completed in 2012, hypoxic conditions were found 35 times. Compared to the 22-year averages, 2012 was above average in area and duration (see page 7).

Cruise	Start Date	End Date	Number of stations sampled	Number of hypoxic stations
WQJUN12	5/29/2012	5/31/2012	17	0
HYJUN12	6/12/2012	6/12/2012	20	0
WQJUL12	6/26/2012	6/28/2012	35	0
HYJUL12	7/16/2012	7/18/2012	40	4
WQAUG12	7/30/2012	8/1/2012	43	4
HYAUG12	8/14/2012	8/16/2012	41	22
WQSEP12	8/27/2012	8/30/2012	44	5
HYSEP12	9/17/2012	9/17/2012	19	0

The peak event occurred during the HYAUG12 cruise between 14 and 16 August. The lowest dissolved oxygen concentration (0.90 mg/L) was documented during the HYAUG12 cruise at Station A4. The hypoxia area maps for 2012 appear on pages 10-14.

Based on CT DEEP and IEC data

Estimated Start Date	7/10/2012
Estimated End Date	9/10/2012
Duration (days)	63
Maximum Area (mi^2)	288.5

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.

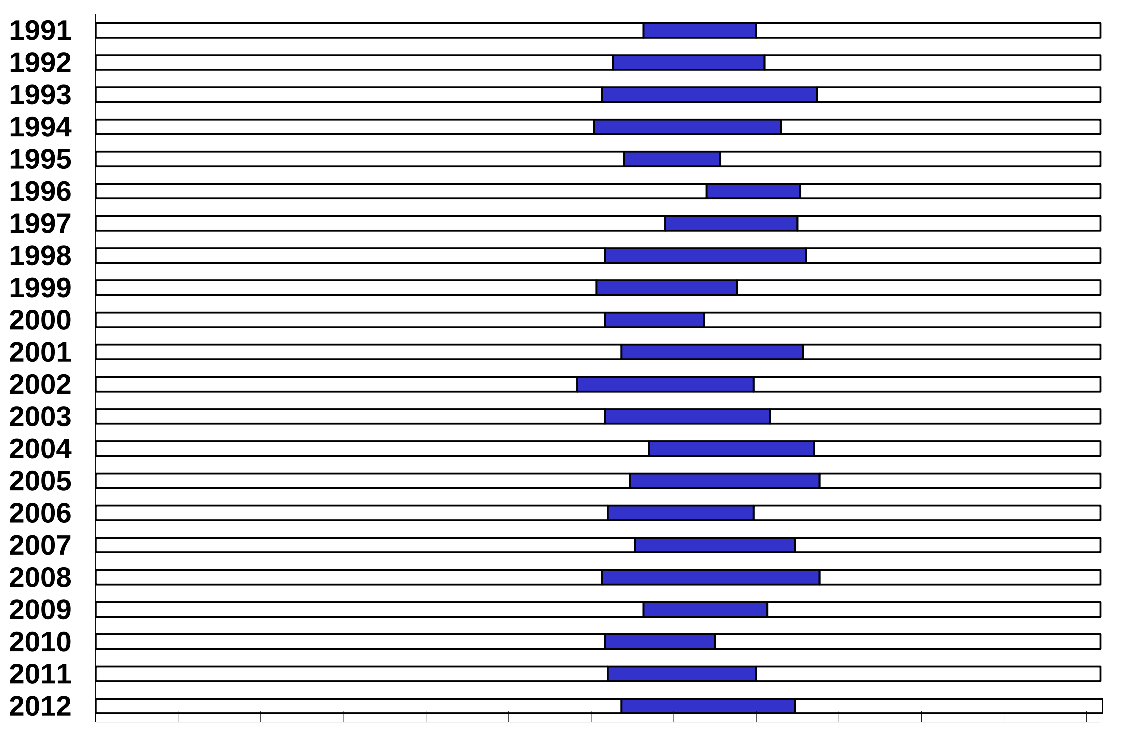
Start date and end date are estimated by plotting DEEP and IEC data from stations A4 and B3 in Excel using a line with markers chart and then interpolating when the DO concentration drops below 3.0 mg/L.

Timing and Duration of Hypoxia, 1991 - 2012

The figure and table below display the onset, duration, and end of the hypoxia events from 1991 through 2012 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
Average	July 10	Sept 3	183	55
Deviation	±10 days	±12 days	± 86 mi^2	± 13 days

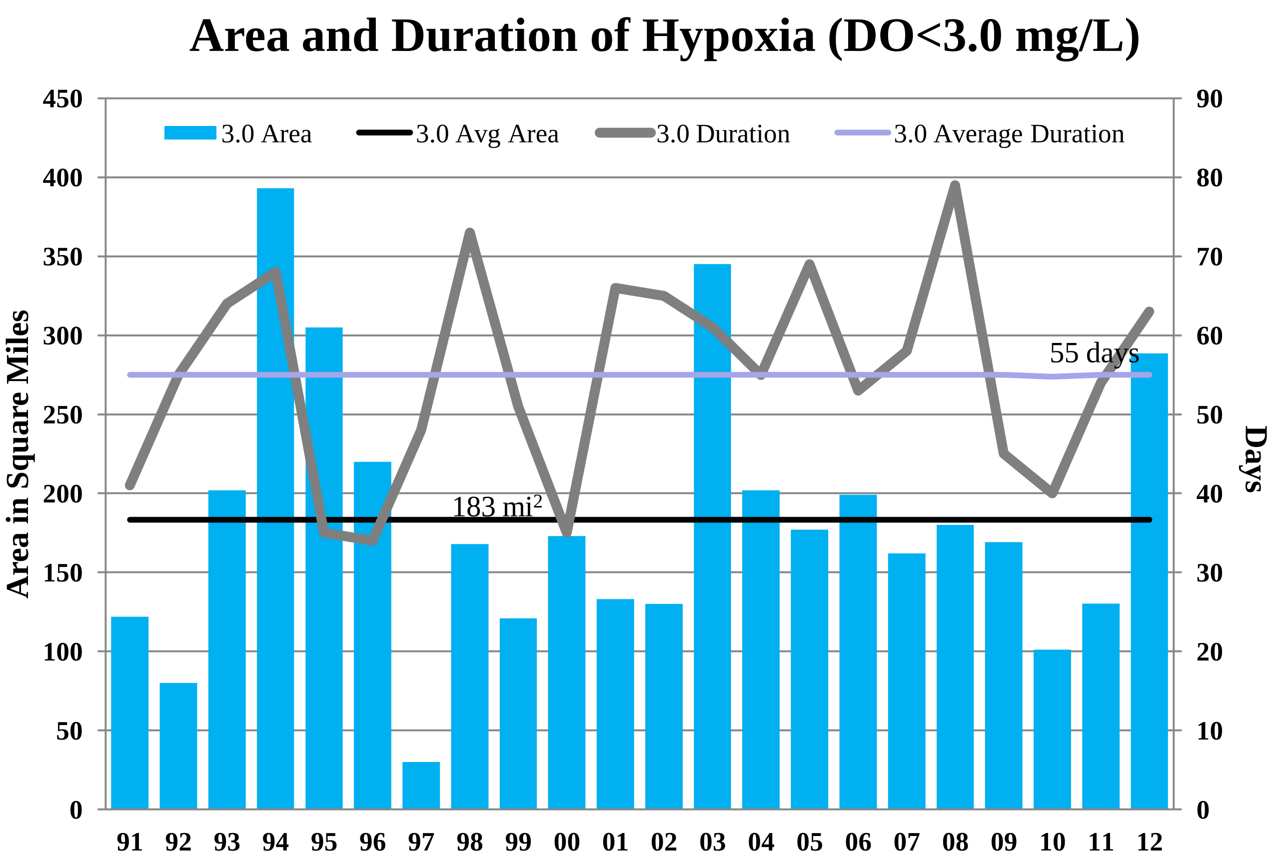
Based on the LISS standard of 3.0 mg/L, the average date of onset was July 10 (± 10 days), the average end date was September 3 (± 13 days), and the average duration was 55 days (± 13 days). The earliest onset of hypoxia (red text) occurred on 25 June 2002 and the latest end date (green text) occurred 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 183 mi^2 and the average duration was 55 days.

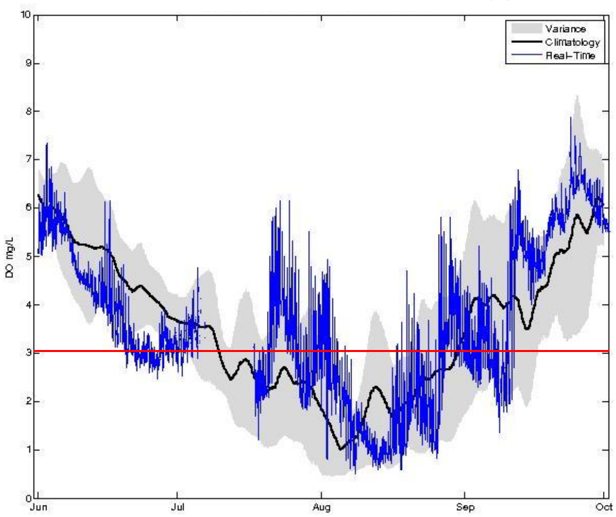


Duration Based on Buoy Data Obtained From the LISICOS Network on 18 October 2012

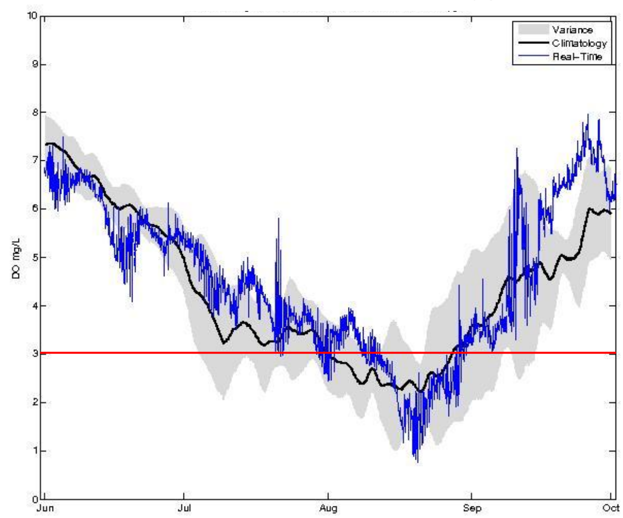
The figures below are from the LISICOS website and depict the 2012 real-time bottom dissolved oxygen data (blue line); the average of the 8 or 11 year dataset, depending on the station (black line); and the variability observed over the historical station record (gray shading).

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).

Execution Rocks Bottom Dissolved Oxygen



Western LIS Bottom Dissolved Oxygen



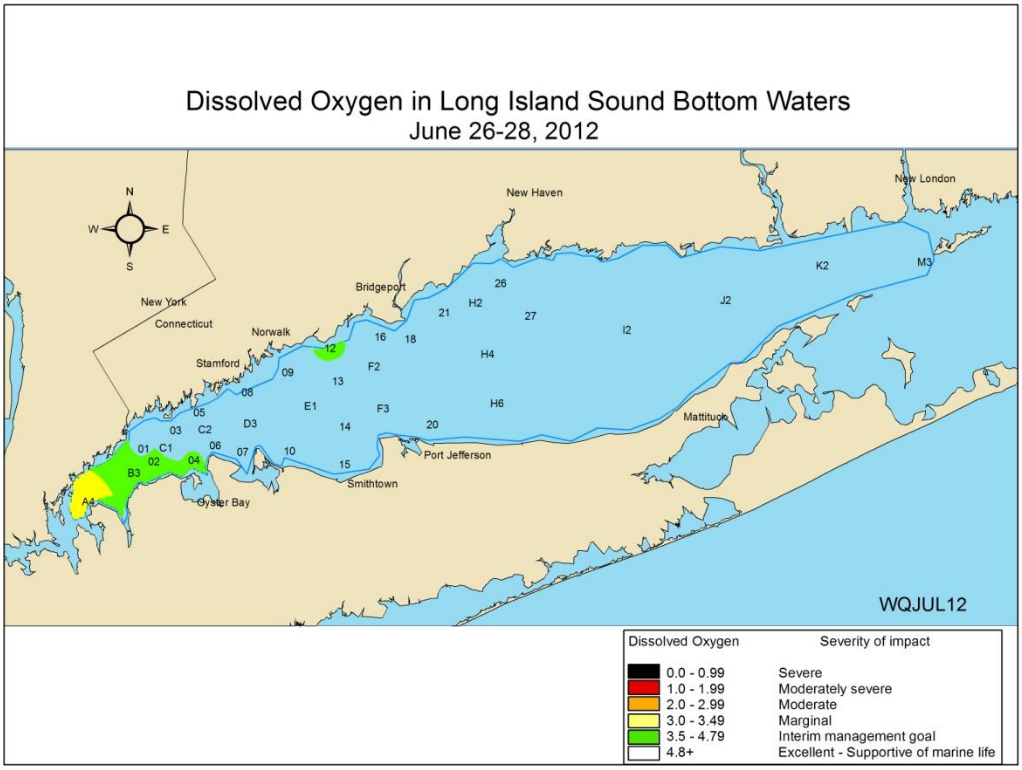
Based on LISICOS Execution Rocks Buoy Data Collected Between 1 June to 18 October

Estimated Start Date	6/20/2012
Estimated End Date	9/11/2012
Duration below 3.0 mg/L (cumulative days)	42.17
Duration below 2.0 mg/L (cumulative days)	18.89
Duration below 1.0 mg/L (cumulative days)	4.04
Minimum DO value (mg/L)	0.52 on 8 August

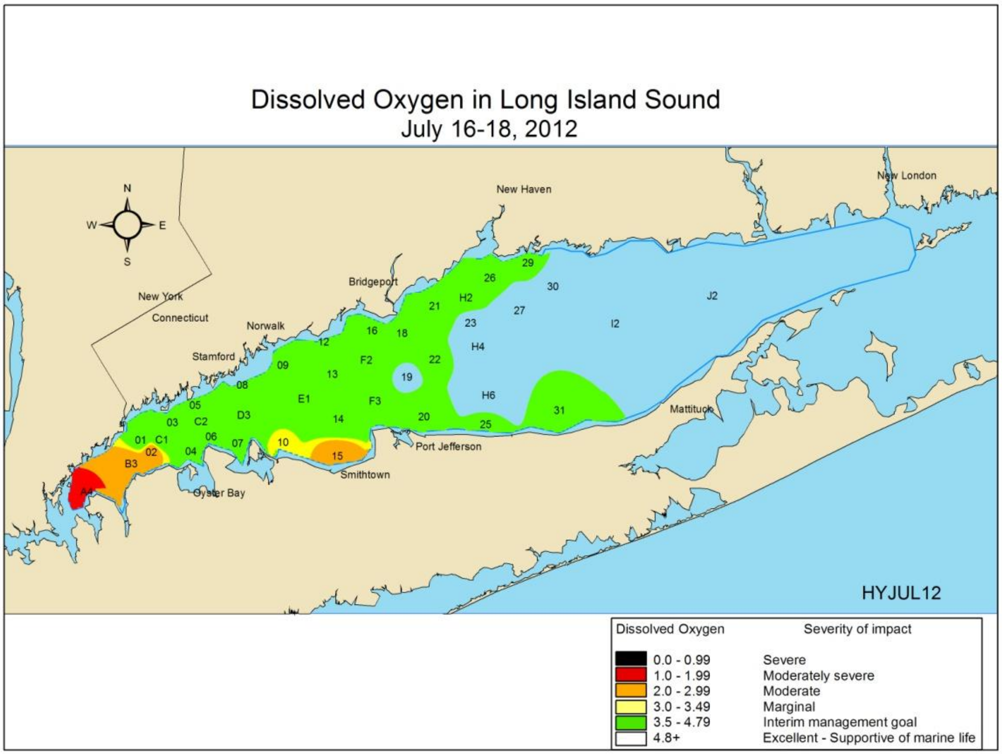
Data obtained from the LISICOS Execution Rocks Bottom Dissolved Oxygen Prediction Tool webpage (http://lisicos.uconn.edu/do_fcst.php?site=exrx). Data are also available for the Western Sound Buoy (http://lisicos.uconn.edu/do_fcst.php?site=wlis) where DO was less than 3.0 mg/L for 20.91 days. Duration 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****.*

Hypoxia Maps

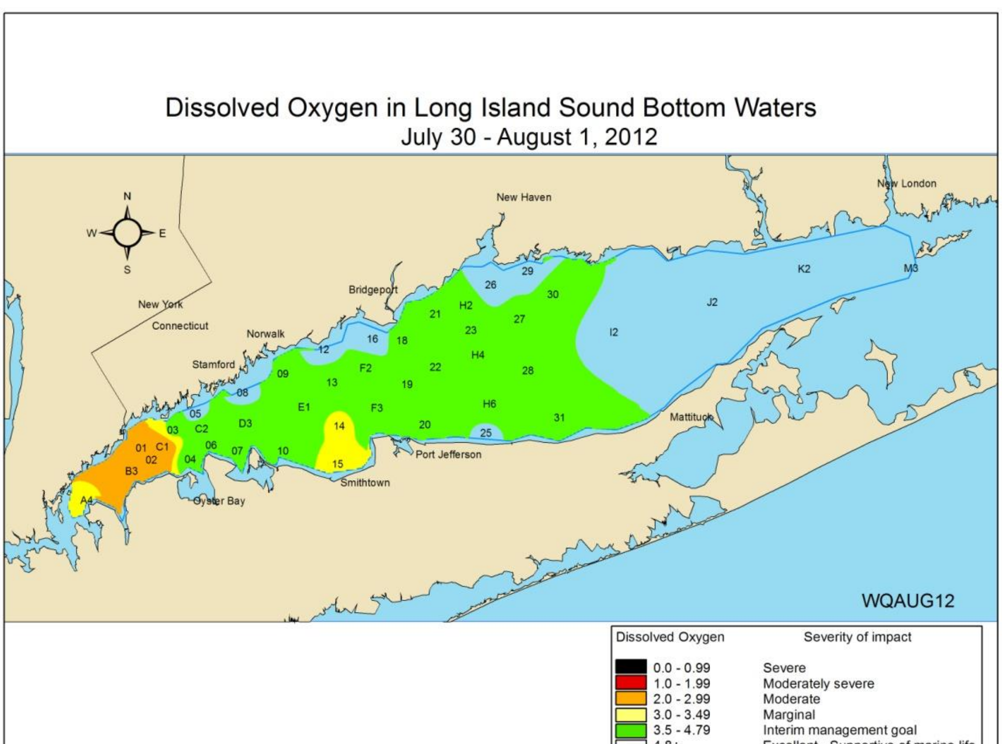
The following maps depict the development of hypoxia based on CT DEEP cruise data through the 2012 season. During the HYJUN12 survey all stations had DO concentrations above 4.8 mg/L. During the WQJUL12 survey DO concentrations were less than 4.8 mg/L at 5 stations and concentrations at A4 had already dropped below 3.5 mg/L. Data for all surveys are available upon request.



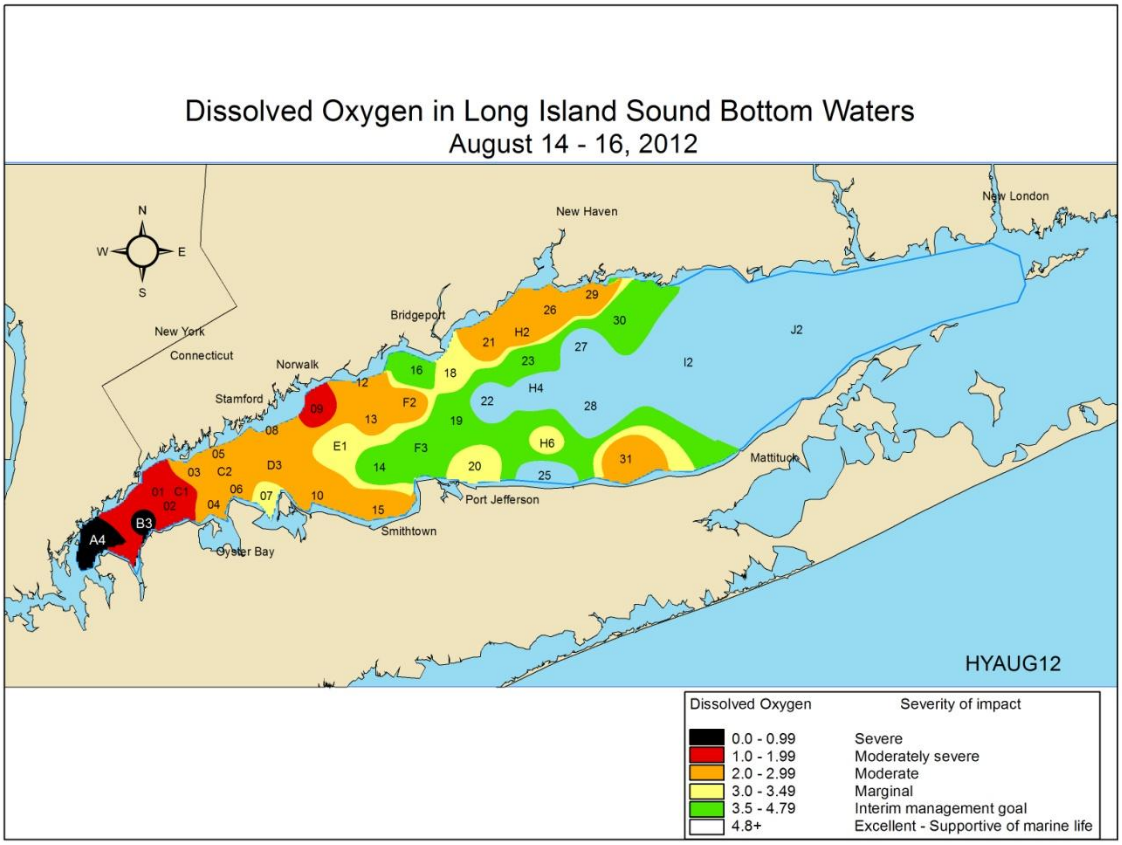
During the HYJUL12 survey, DO concentrations dropped below 4.8 mg/L at 32 stations; four stations were below 3. 0 mg/L, with Station A4 below 2 mg/L. Stations B3 and 02 had mid-water minimum DO concentrations below 3.0 mg/L while the bottom values were 3.79 and 4.12 mg/L, respectively.



During the WQAUG12 survey, DO concentrations were below 3.0 mg/L at 5 stations but all stations were above 2.0 mg/L .



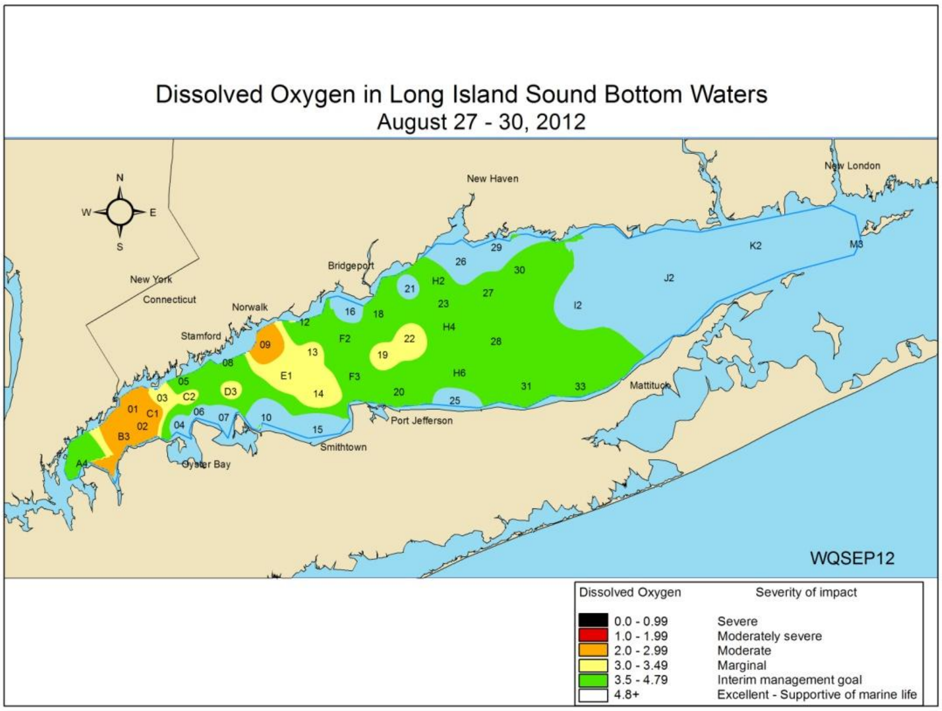
Concentrations continued to decline during the HYAUG12 survey with two stations exhibiting DO concentrations below 1.0 mg/L and four stations below 2.0 mg/L. Additionally, 17 stations had concentrations below the 3.0 mg/L standard and five stations were below 3.5 mg/L.   This survey had the fourth highest areal extent since 1991 and it is the first time since 2008 that CT DEEP recorded DO levels less than 1.0 mg/L.



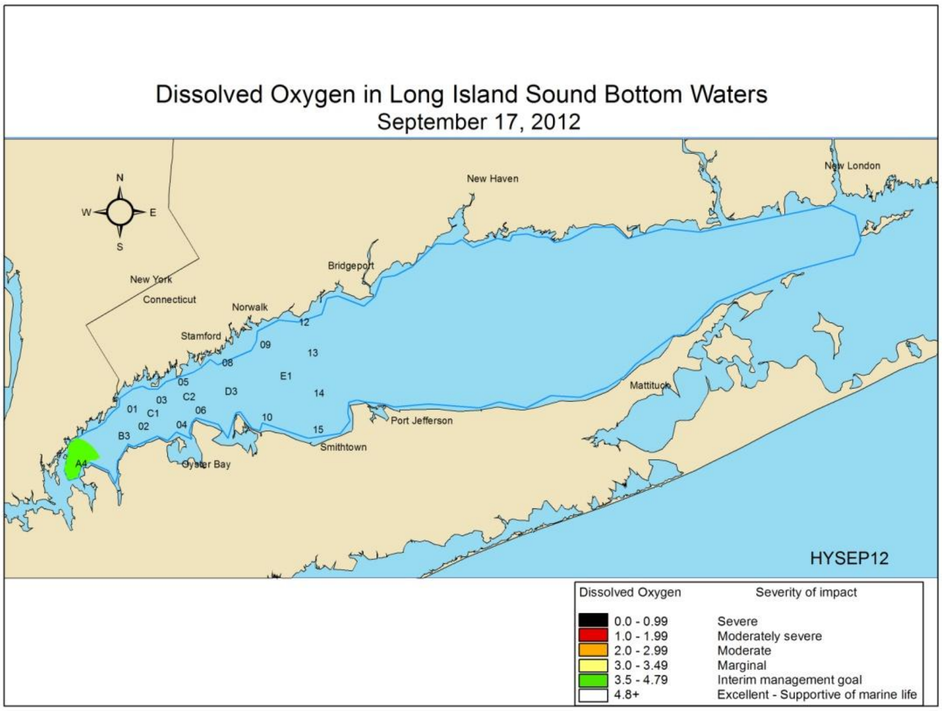
Maximum Areal Extent (288.5 mi^2) of Hypoxia

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

The WQSEP12 survey found conditions improving, with no stations exhibiting DO concentrations below 2.0 mg/L. Five stations still had concentrations less than 3.0 mg/L and eight stations had concentrations less than 3.5 mg/L. This survey was worse than the 2011 survey where no stations were below 3.0. It should be noted that the 2011 survey took place after Tropical Storm Irene which increased mixing and re-oxygenated the bottom waters.



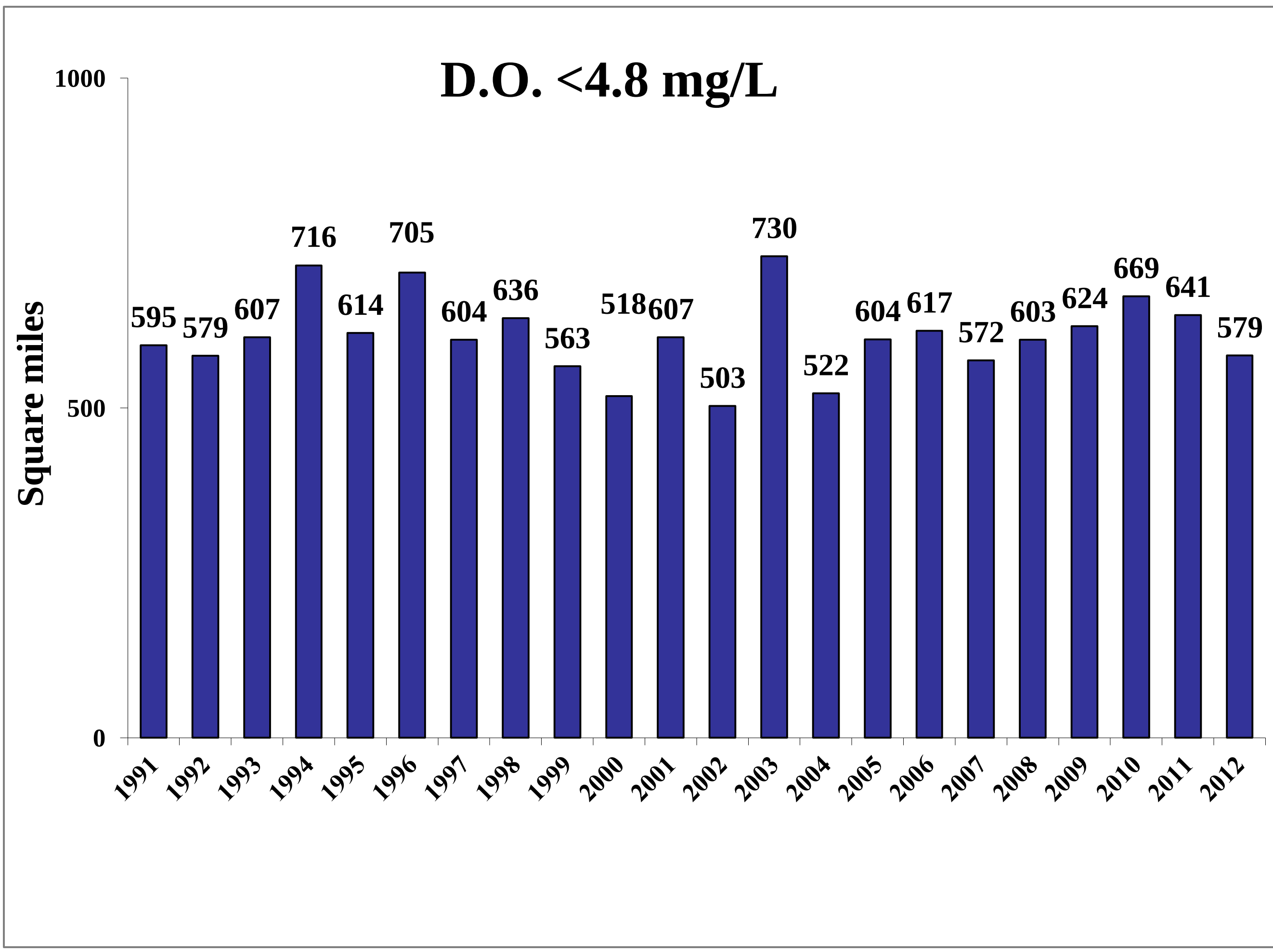
Conditions continued to improve through the HYSEP12 survey with only one station exhibiting DO concentrations below 4.8 mg/L (A4).



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.

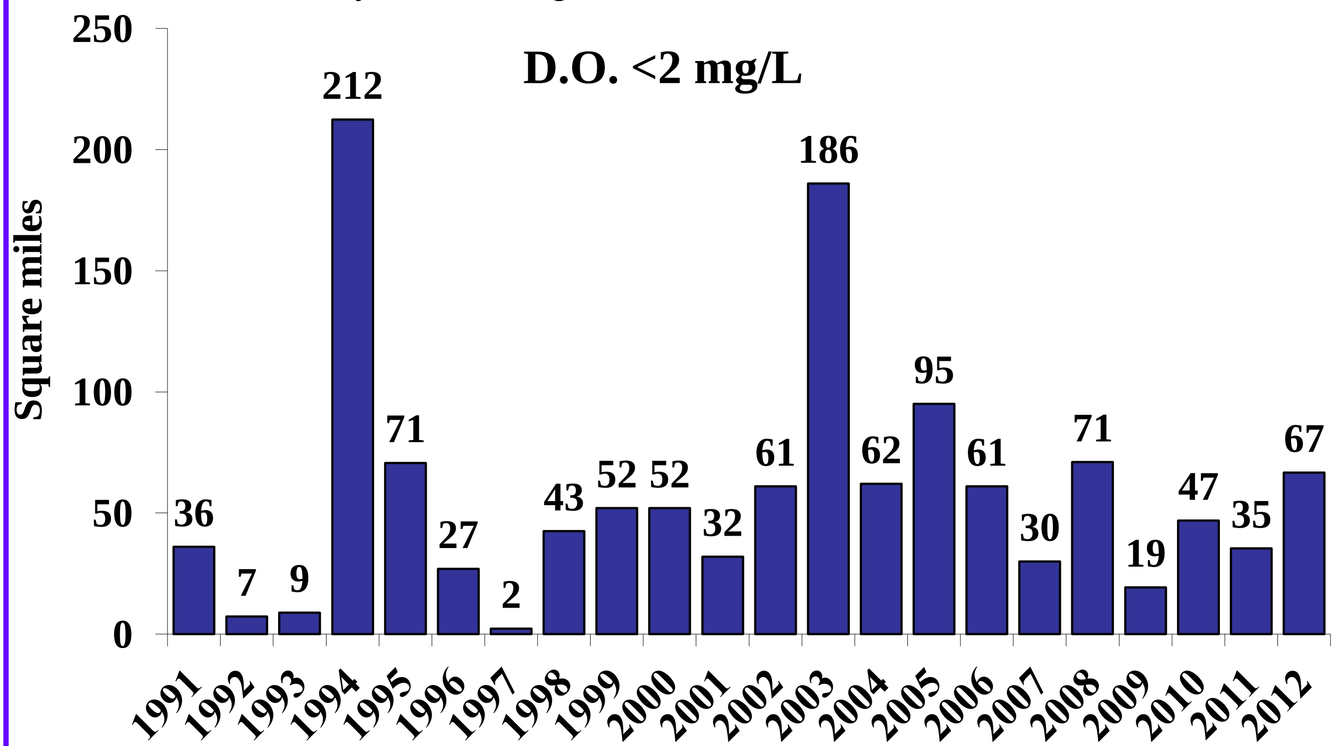
This chart illustrates the maximum area of bottom waters within Long Island Sound with DO concentrations less than 4.8 mg/L. In 2012, the maximum area occurred during the HYAUG12 survey and was estimated at 579 square miles which was lower than in 2011. From 1991-2012, the area affected by concentrations less than 4.8 mg/L averages 609.4 square miles and varies slightly from 503 to 730 square miles.



Severe Hypoxia

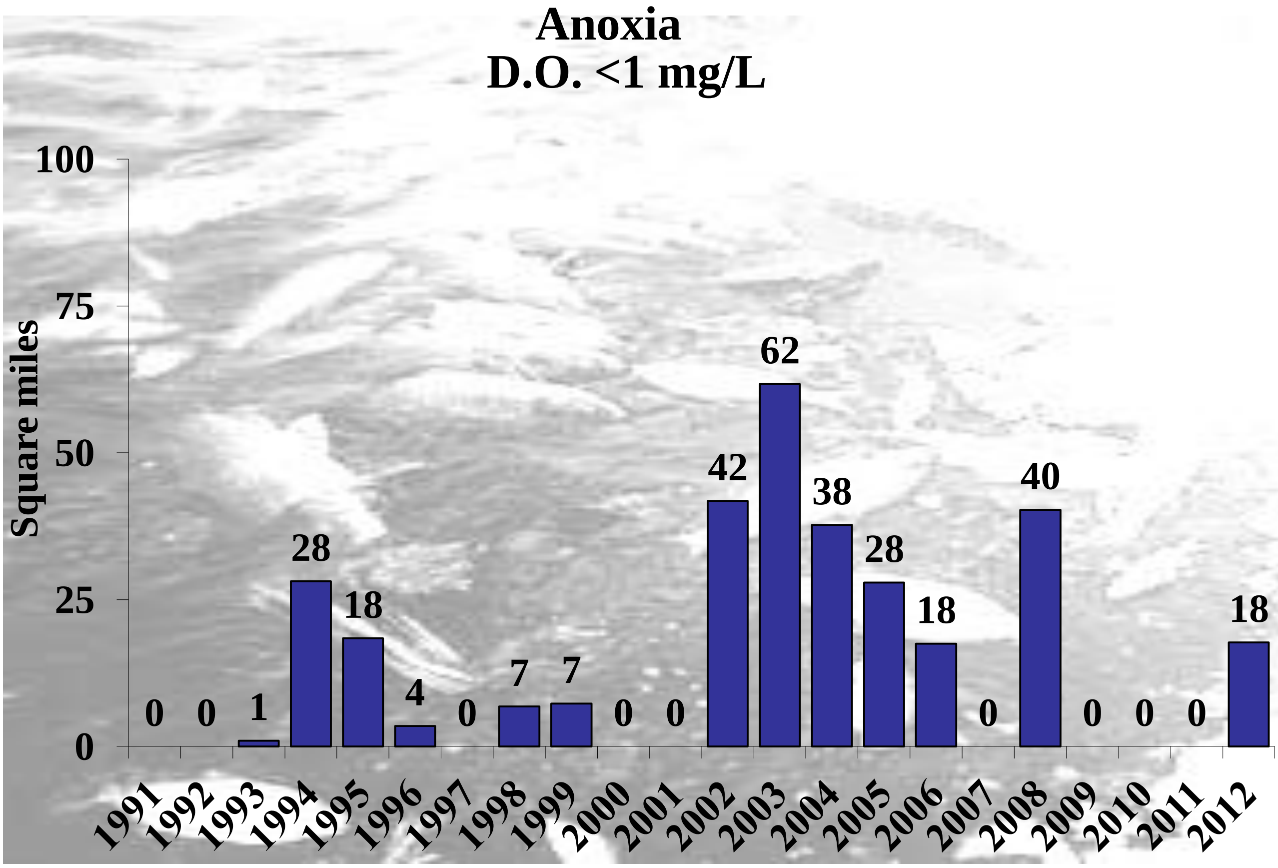
The Gulf of Mexico is another water body that exhibits severe hypoxia, although the standard is determined at the 2.0 mg/L level. The average size of the hypoxic zone in the northern Gulf of Mexico from 1985-2010 is roughly 5330 mi^2. The maximum area of the Gulf of Mexico hypoxic zone occurred in 2002 and was estimated at 8,841 mi^2. The 2012 hypoxic zone was forecasted to cover 6,213 km^2 (slightly larger than Connecticut).
http://www.gulfhypoxia.net/Research/Shelfwide%20Cruises/ /

This chart illustrates the maximum area of bottom waters of Long Island Sound with concentrations less than 2 mg/L. In 2012, the maximum area of LIS affected by severe hypoxia was 66.7 mi^2, an increase from 2011. The average area, calculated from 1991-2012, is 58.1 mi^2. Based on CT DEEP data there were 23 days when DO was less than 2.0 mg/L. Based on the LISICOS Execution Rocks data there were 18.89 days below 2.0 mg/L.



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) the summer (June-August) of 2012 was the 12th warmest in 118 years. August 2012 was the 20th warmest on record in New York State and warmest since 2005. Connecticut was also above normal; the average August temperature was 2.1° F warmer than usual, 10th warmest since 1895.

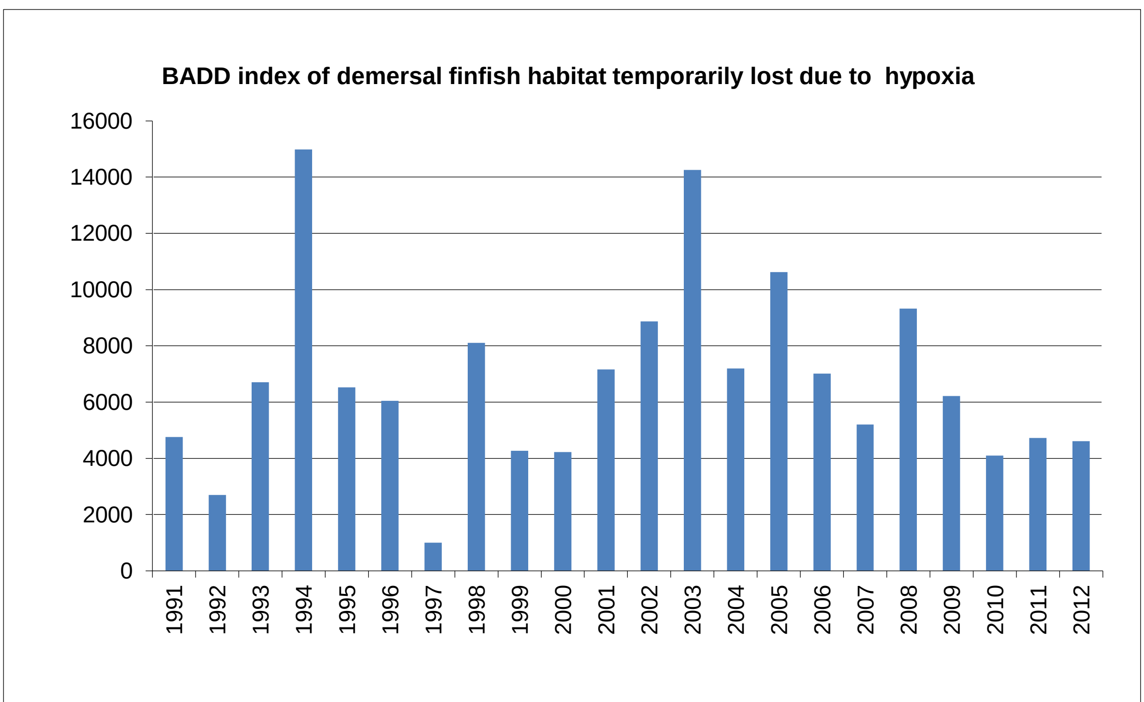


For management purposes the Long Island Sound Study defines anoxia as DO concentrations less than 1 mg/L. In nine of the twenty-two years there was no anoxia reported by CT DEEP. The greatest area with D.O. below 1 mg/L observed in LIS, based on ~biweekly sampling by CT DEEP, was during the summer of 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 1991-2012 is 14.1 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 0.52mg/L).

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 over 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 10 July – 10 September (63 d). The index is then expressed as a percentage of the available area-days (sample area 2,723 km^2 x 63 d, or 171,549 area-days).

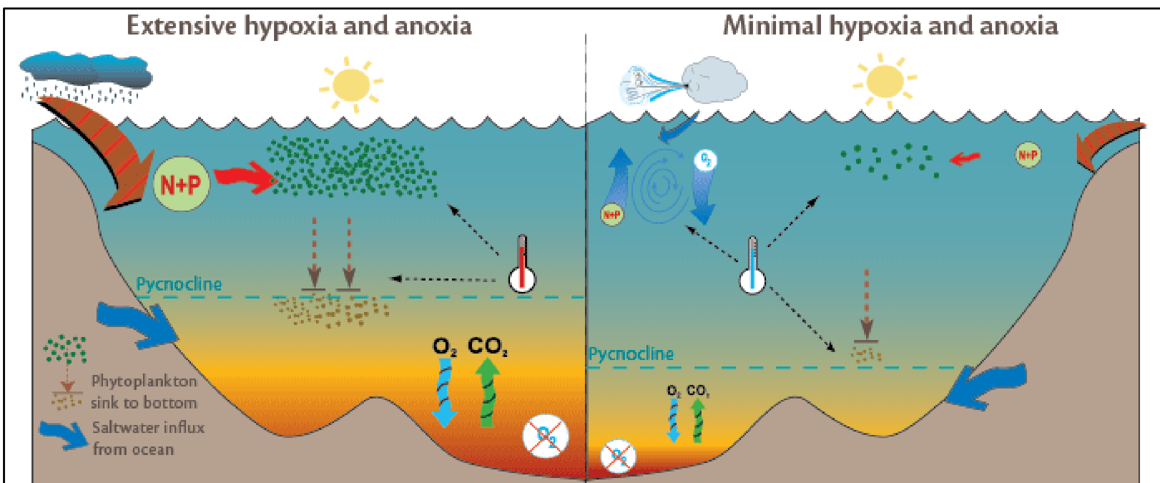


Simpson, David G., Kurt Gottschall, and Mark Johnson. 1995. Cooperative interagency resource assessment (Job 5). In : A study of marine recreational fisheries in Connecticut, CT DEP Marine Fisheries Office, PO Box 719, Old Lyme, CT 06371, p 87-135.

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.



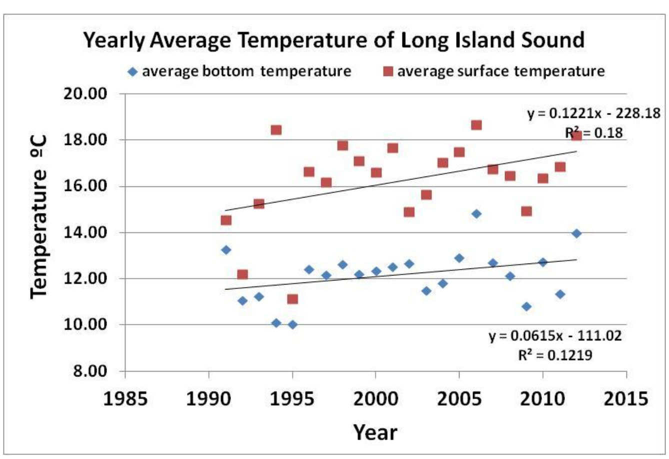
	Loads	Phytoplankton	Decomposition	Temperature	Wind event
Large amount of low dissolved oxygen	Large nitrogen and phosphorus loads	Elevated nutrients cause large phytoplankton blooms	High oxygen consumption by decaying phytoplankton	Warm water a) Stimulates decomposition b) Stratifies water column c)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

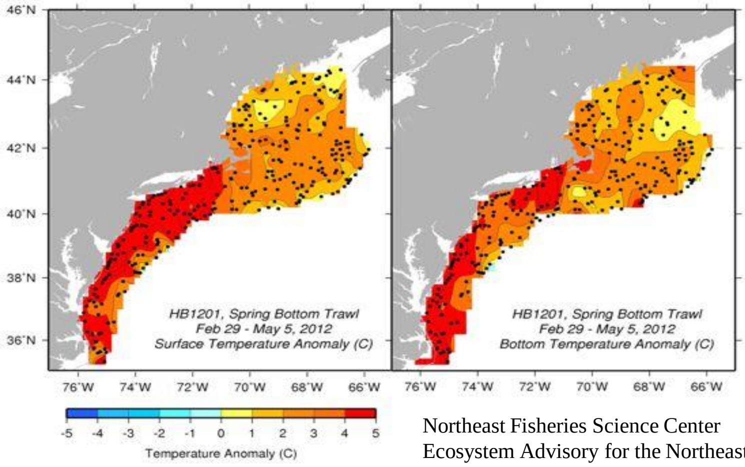
2012 Water Temperature Data

2012 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	2012 Max	1991-2011 Max	2012 Min	1991-2011 Min	2012 Average	1991-2011 Average
WQJAN	9.311	8.101	5.606	0.500	7.087	4.286
WQFEB	6.748	5.869	4.122	-1.223	5.058	1.835
CHFEB	4.464	4.328	3.716	0.846	4.179	2.264
WQMAR	6.611	5.385	3.984	-0.431	4.977	2.393
CHMAR	6.575	5.721	5.146	0.917	5.67	3.635
WQAPR	9.069	10.069	6.477	2.456	7.626	5.415
WQMAY	11.751	14.117	9.79	6.777	10.493	10.187
WQJUN	21.066	21.299	12.055	10.215	14.459	15.200
HYJUN	19.877	21.842	13.728	13.553	16.75	18.443
WQJUL	21.124	25.336	14.589	15.899	17.883	20.301
HYJUL	25.829	25.762	18.525	16.093	20.456	21.591
WQAUG	24.584	27.017	19.177	17.341	21.669	22.657
HYAUG	25.517	25.189	21.328	19.986	22.875	22.721
WQSEP	24.925	24.749	20.578	18.719	23.258	22.336
HYSEP	23.484	23.153	22.315	20.490	22.827	22.007
WQOCT	21.181	21.551	17.875	16.190	20.272	19.176
WQNOV		16.072		10.478		13.755
WQDEC		12.526		4.891		8.840



The Sound is coldest during February and March and warmest during August and September. The yearly average surface and bottom temperature of the Sound appear to be increasing.



Northeast Fisheries Science Center Ecosystem Advisory for the Northeast Shelf Large Marine Ecosystem. Contact Kevin Friedland @noaa.gov.

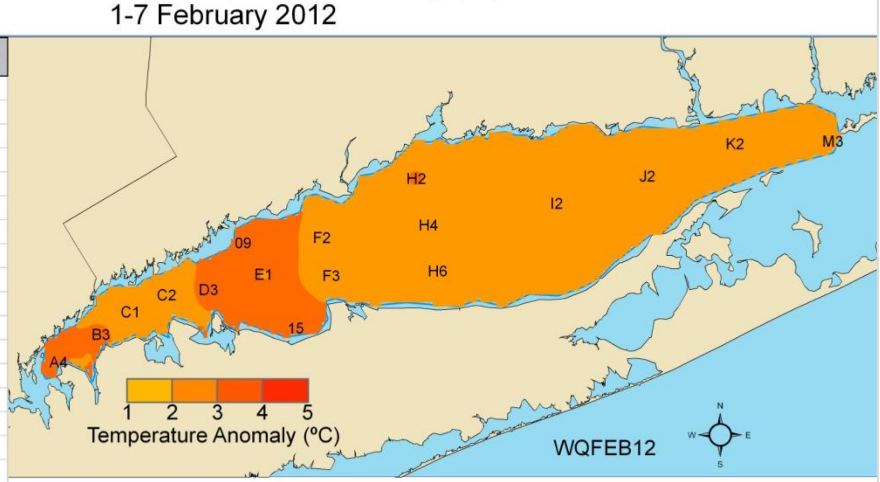
The Northeast Fisheries Science Center stated that sea surface temperatures in the Northeast Shelf Large Marine Ecosystem during the first six months of 2012 were the highest ever recorded. See the Ecosystem Advisory for additional details http://www.nefsc.noaa.gov/ecosys/advisory/current/advisory.html.

CT DEEP data show 2012 average surface water temperatures were generally above the long-term averages (1991-2011) ranging from 0.41ºC above average in August to 3.01ºC above average in February. Only WQJUL water temperatures were below the long-term average. Bottom water temperatures in 2012, while not shown, were also above the long-term averages. The figure below illustrates the surface water temperature anomaly during the WQFEB12 survey.

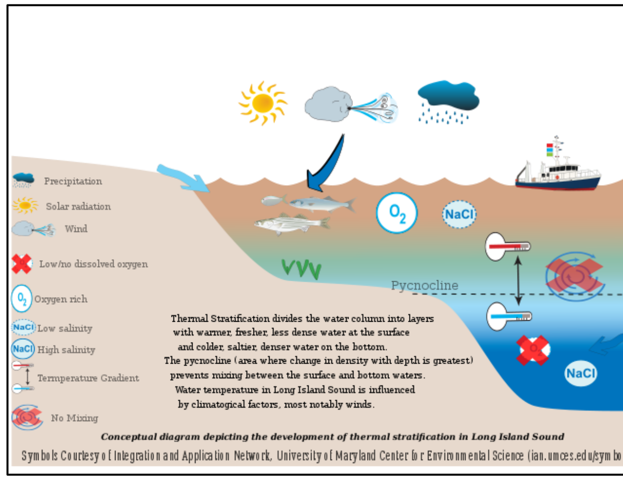
	2012			1991-2011	
Cruise	Max	Min	Avg	Avg	# of surveys
WQJAN	8.30	5.62	6.56	4.22	n=19
WQFEB	6.48	4.12	4.78	1.77	n=19
CHFEB	4.10	3.74	3.90	2.35	n=7
WQMAR	6.46	3.98	4.82	2.43	n=19
CHMAR	6.57	6.09	6.32	3.66	n=8
WQAPR	9.05	7.25	8.08	5.39	n=19
WQMAY	11.75	10.46	10.92	10.08	n=21
WQJUN	21.04	14.05	18.12	15.16	n=21
HYJUN	19.86	17.43	18.78	18.30	n=18
WQJUL	21.11	17.80	19.34	20.29	n=21
HYJUL	25.77	20.04	23.03	21.61	n=18
WQAUG	24.57	19.69	22.92	22.51	n=20
HYAUG	25.48	22.88	24.33	22.76	n=17
WQSEP	24.92	20.90	23.93	22.29	n=20
HYSEP	23.46	22.43	23.01	21.68	n=7
WQOCT	21.18	18.15	20.17	19.07	n=21

LIS Surface Water Temperature Anomaly (ºC)
1-7 February 2012

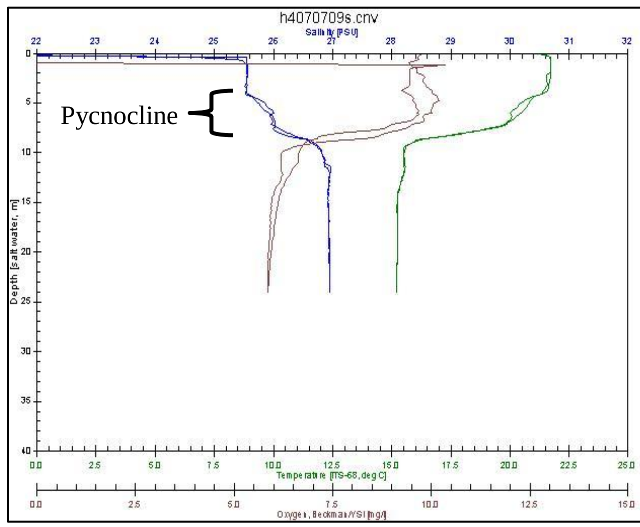
station name	2012 temperature	Avg 1991-2011 temp	Anomaly
9	4.65	1.15	3.51
15	4.37	1.13	3.24
A4	4.49	1.37	3.12
B3	4.19	1.15	3.03
C1	4.35	1.62	2.73
C2	4.12	1.71	2.42
D3	4.60	1.47	3.13
E1	4.46	1.47	2.99
F2	4.29	1.34	2.95
F3	4.63	1.76	2.87
H2	4.96	1.95	3.01
H4	4.60	1.88	2.71
H6	4.62	1.80	2.82
I2	4.92	2.23	2.69
J2	5.51	2.86	2.65
K2	5.90	3.63	2.27
M3	6.48	3.92	2.56



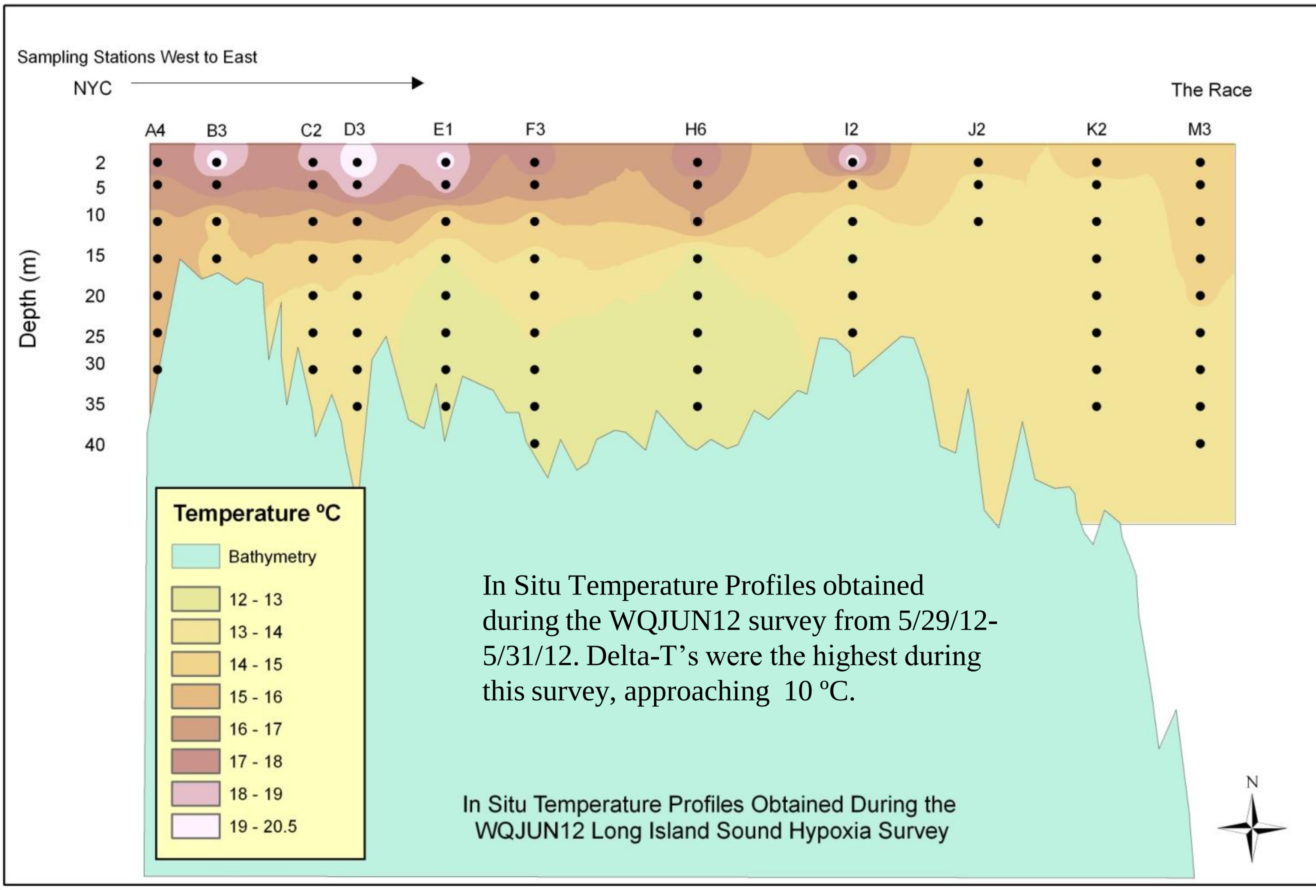
Delta T and Stratification



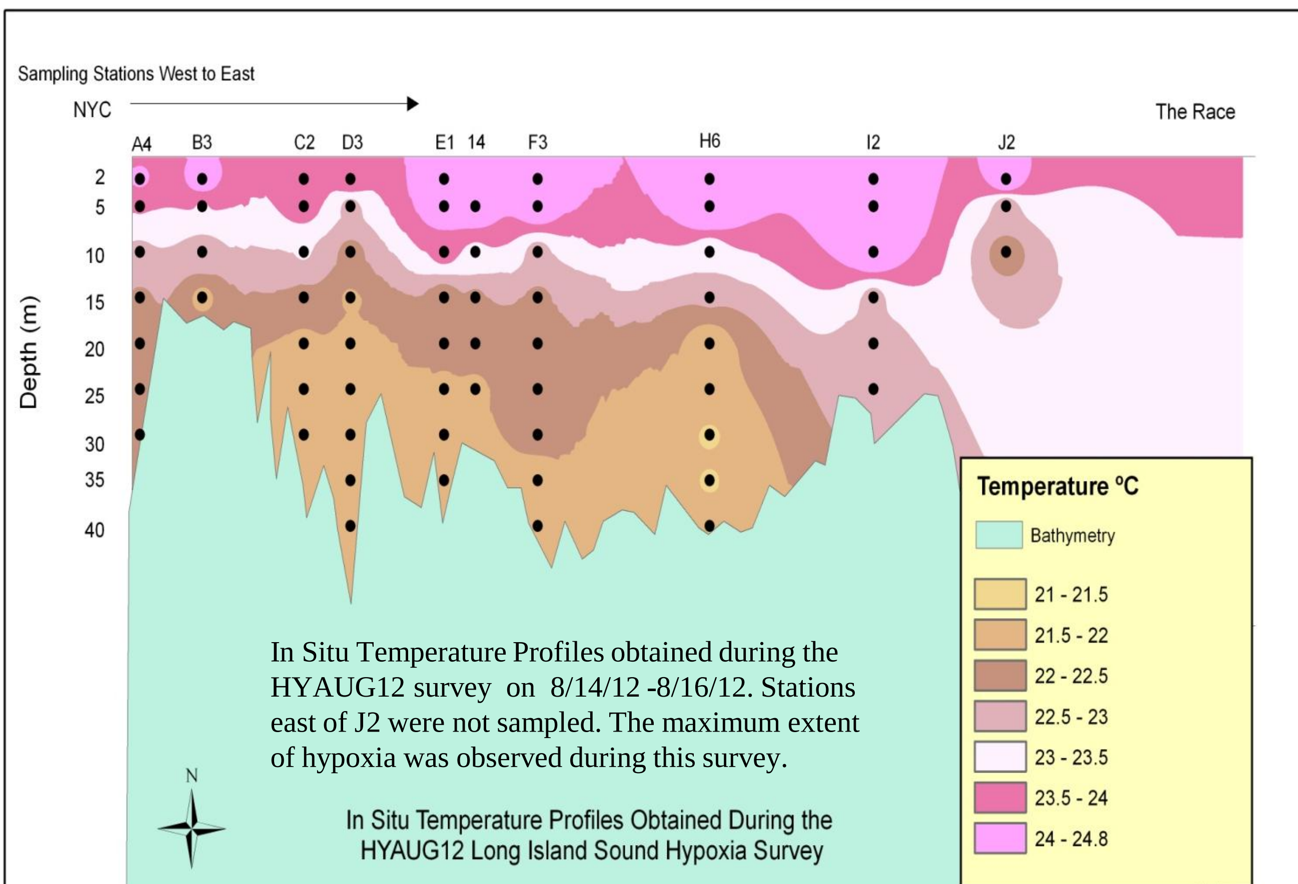
The temperature difference between the bottom waters and the surface waters is known as "Delta T". This Delta T, along with salinity differences, creates a density difference, or "density gradient" resulting in a separation or "stratification" of water layers that hinders the oxygenated surface waters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



The temperature graphs on page 23 show computer interpolations along the west-east axis of LIS generated from profile data collected during two CT DEEP surveys. During the WQJUN12 survey, surface water temperatures had warmed to an average of 17.6 ºC while the bottom water remained cooler around an average of 14ºC. 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 HYAUG12 survey when hypoxic conditions were at their worst. The graphs on page 17 show how the Delta T's varied over the course of the summer sampling season. Delta T's increased from the WQAPR12 survey through the WQAUG12 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 HYSEP12 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.

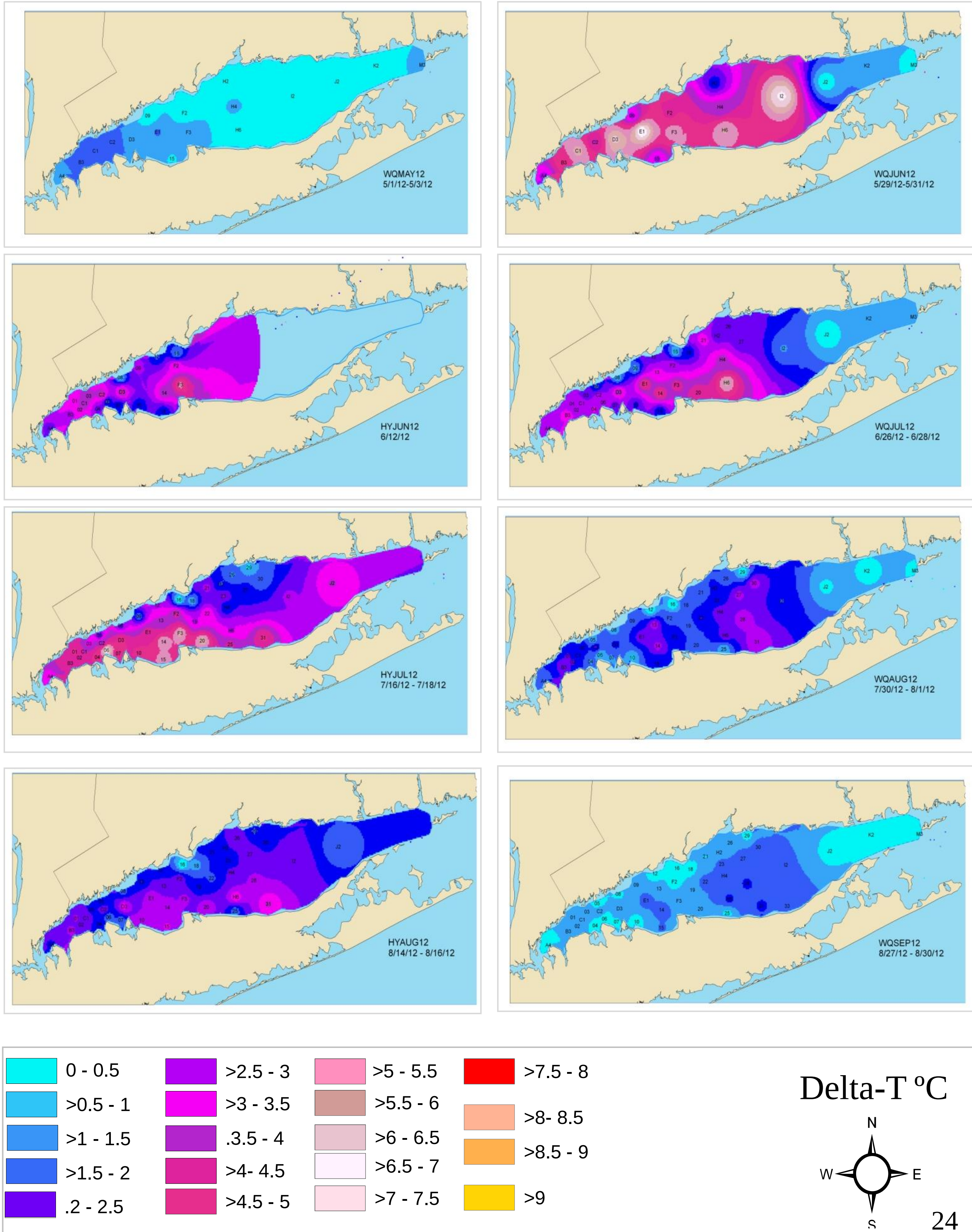


In Situ Temperature Profiles obtained during the WQJUN12 survey from 5/29/12-5/31/12. Delta-T's were the highest during this survey, approaching 10 ºC.



In Situ Temperature Profiles obtained during the HYAUG12 survey on 8/14/12 -8/16/12. Stations east of J2 were not sampled. The maximum extent of hypoxia was observed during this survey.

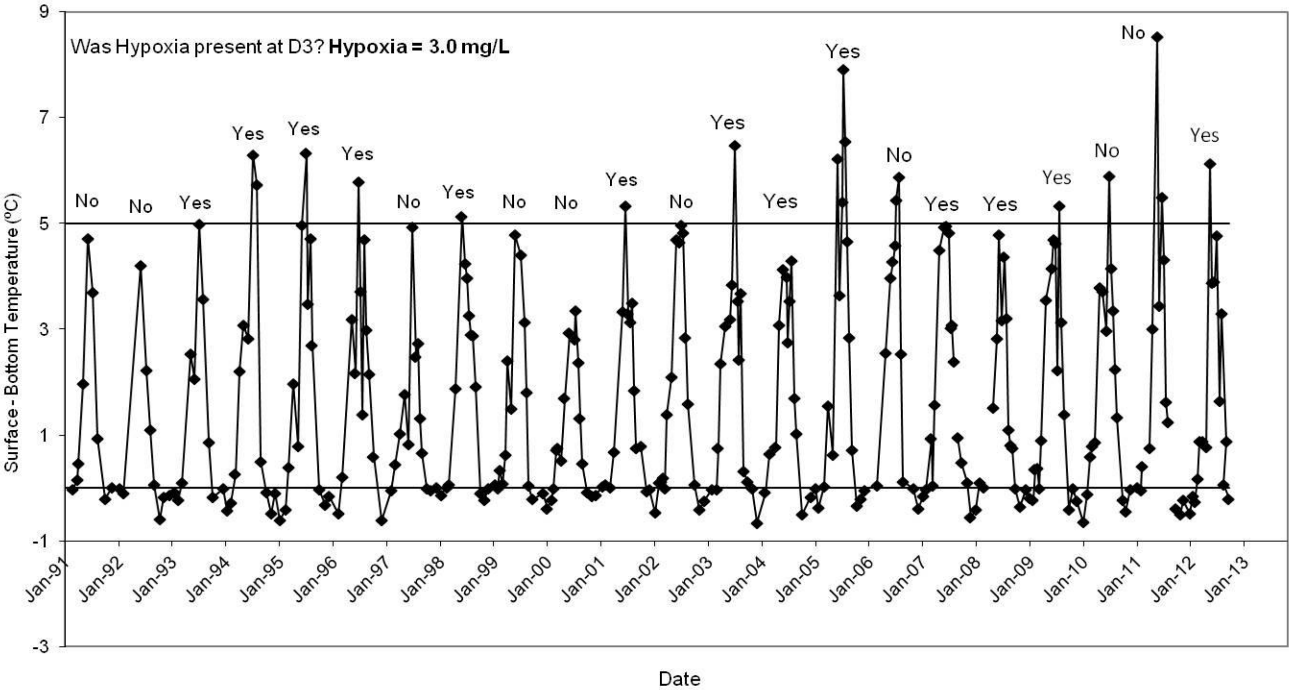
2012 Delta-T Maps



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

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 ∆T (surface water temperature - bottom water temperature) at station D3, 1991 through 2012.

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).

Salinity

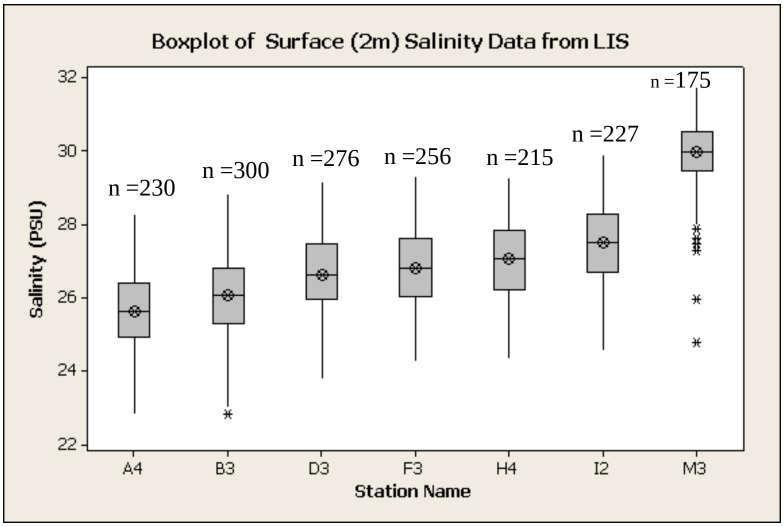
Salinity is a measure of the dissolved salts content of seawater. It is usually expressed in practical salinity units (PSU). Salinity levels across Long Island Sound vary from 23 PSU in the Western Sound at Station A4 to 33 PSU in the eastern Sound at Station M3. The Thames, Connecticut, and Housatonic 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	269	23.823	28.727	26.305	26.305	0.057	0.934	0.873
B3	317	24.259	28.926	26.588	26.546	0.0521	0.928	0.861
D3	294	24.912	29.215	27.224	27.266	0.0521	0.893	0.797
F3	274	25.153	29.432	27.587	27.611	0.0523	0.865	0.748
H4	234	25.508	29.7	27.732	27.738	0.0557	0.851	0.725
I2	258	25.762	29.985	28.054	28.12	0.0526	0.845	0.714
M3	215	28.608	32.622	30.571	30.565	0.0486	0.712	0.507

		2012 Bottom Water Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	16	25.288	27.651	26.381	26.255	0.19	0.761	0.579
B3	16	25.485	27.96	26.694	26.516	0.202	0.809	0.655
D3	16	25.936	28.55	27.246	27.083	0.218	0.873	0.762
F3	13	26.602	28.824	27.768	27.539	0.212	0.765	0.585
H4	12	26.235	28.931	27.879	27.513	0.268	0.929	0.863
I2	11	27.312	29.469	28.296	28.162	0.227	0.754	0.569
M3	9	30.082	31.61	30.943	31.09	0.196	0.587	0.345

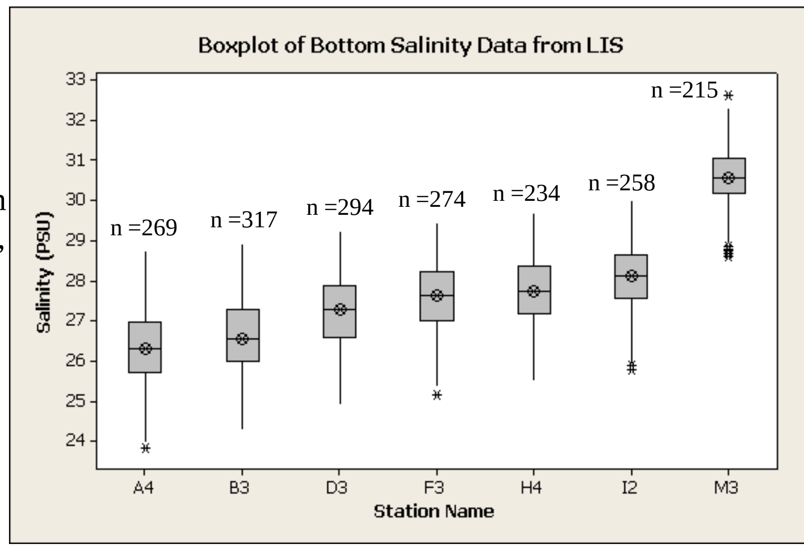
		1991-2012 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	260	22.833	28.278	25.614	25.605	0.0643	1.036	1.074
B3	300	22.8	28.84	26.018	26.05	0.0618	1.07	1.145
D3	276	23.772	29.146	26.645	26.611	0.0635	1.054	1.111
F3	256	24.246	29.307	26.816	26.809	0.0672	1.076	1.157
H4	215	24.315	29.262	27.039	27.059	0.0733	1.075	1.155
I2	227	24.56	29.909	27.467	27.518	0.0691	1.041	1.084
M3	175	24.789	31.758	29.92	29.98	0.0764	1.011	1.022

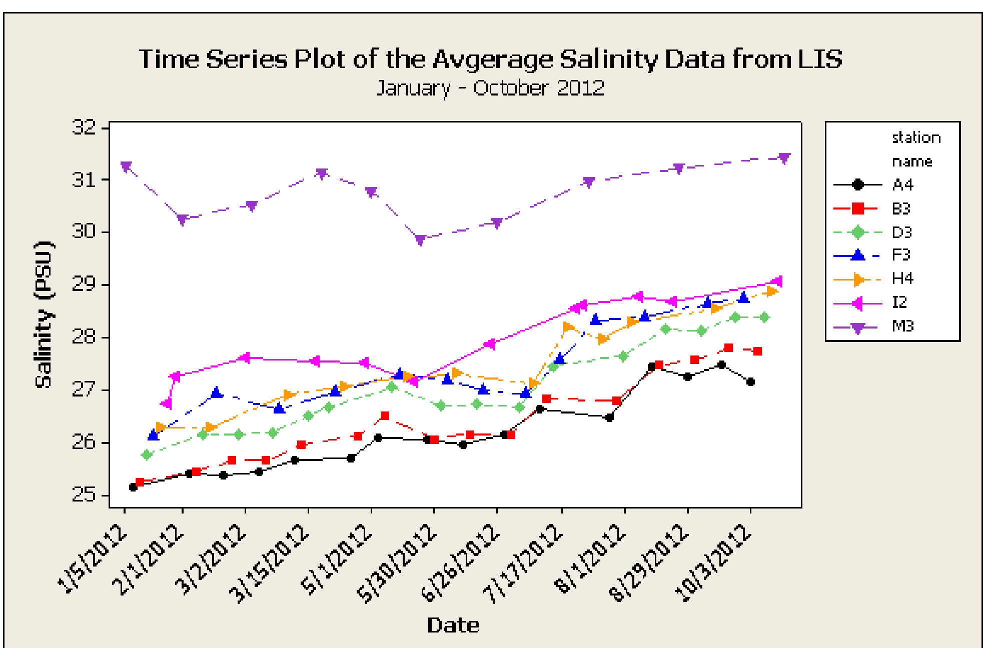
		2012 Surface Statistics						
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	14	24	27.208	25.633	25.397	0.244	0.914	0.836
B3	16	24.539	27.596	25.96	25.75	0.247	0.989	0.978
D3	15	25.451	28.328	26.641	26.135	0.236	0.913	0.833
F3	13	25.701	28.683	26.853	26.582	0.233	0.841	0.708
H4	12	25.798	28.839	27.115	27.011	0.245	0.849	0.72
I2	12	26.333	28.764	27.336	27.455	0.213	0.737	0.544
M3	10	29.461	31.195	30.317	30.258	0.186	0.588	0.345



This box plot, based upon data collected during CT DEEP surveys from January - October 2012 (n=431, 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- October 2012 (n=431, 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.

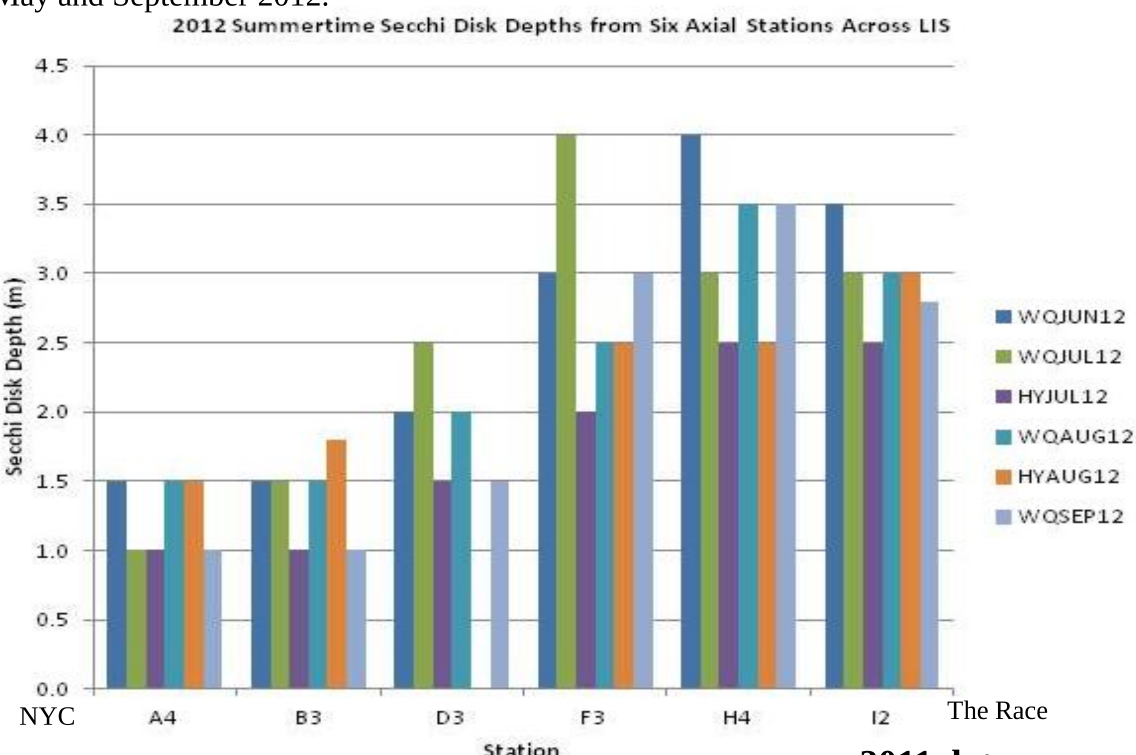




This time series plot illustrates the temporal variability of the mean salinity values by station from January- October 2012.

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, 2466 measurements have been entered into our database; of those 1370 are from the 17 stations sampled annually. The 2000-2012 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 2012.



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**

2011 data

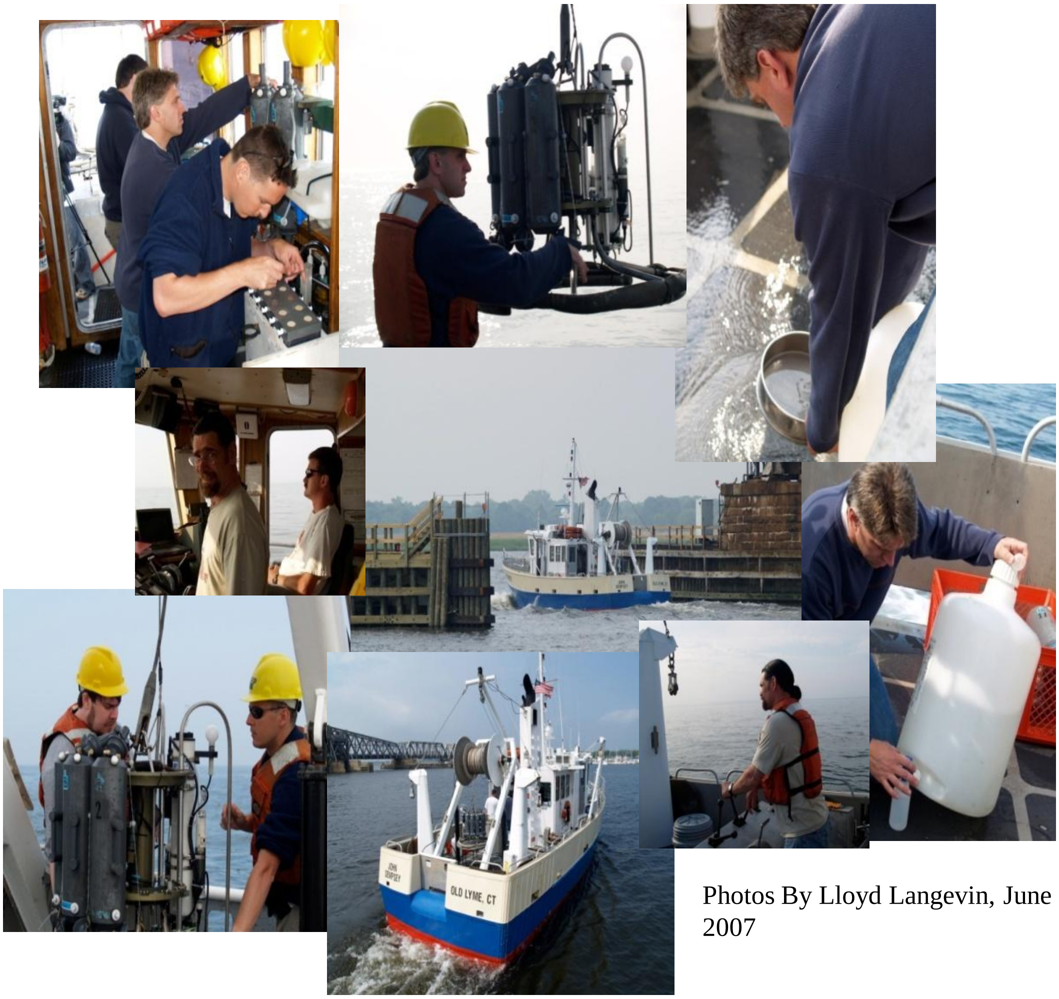
- **Average Secchi Disk Depth: 2.25 m (n=194)**
- **Minimum Secchi Disk Depth: 1.0 m at Station 02 & 07 during the WQJUL11 cruise and Station 29 during the WQSEP11 cruise**
- **Maximum Secchi Disk Depth: 3.6 m at Stations K2 and J2 during the WQAUG11 cruise**

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 to date are summarized below.

	Surface					Bottom			
Cruise	Max	Min	Avg	Count	Cruise	Max	Min	Avg	Count
HYAUG10	8.22	7.50	8.00	34	HYAUG10	7.98	7.51	7.74	34
WQSEP10	8.34	7.67	8.15	28	WQSEP10	8.18	7.52	7.79	28
WQOCT10	8.13	7.84	8.03	16	WQOCT10	8.07	7.89	8.01	16
WQNOV10	8.24	8.02	8.16	15	WQNOV10	8.25	8.04	8.15	16
WQDEC10	8.23	8.06	8.16	14	WQDEC10	8.21	8.07	8.15	16
WQJAN11	8.32	8.06	8.23	14	WQJAN11	8.34	8.18	8.25	16
WQFEB11	8.61	7.96	8.27	15	WQFEB11	8.76	8.12	8.43	16
WQMAY11	8.81	7.58	8.52	18	WQMAY11	8.64	8.22	8.52	18
WQJUN11	8.04	7.06	7.66	16	WQJUN11	7.80	7.26	7.59	16
HYJUN11	7.89	7.34	7.72	21	HYJUN11	7.62	7.44	7.56	21
WQJUL11	8.36	7.61	7.95	32	WQJUL11	7.76	7.31	7.57	28
HYJUL11	7.98	7.38	7.83	39	HYJUL11	7.82	7.32	7.61	39
WQAUG11	8.28	7.72	8.01	40	WQAUG11	8.05	7.38	7.74	39
HYAUG11	7.96	7.40	7.71	37	HYAUG11	7.79	7.45	7.60	38
WQSEP11	8.19	7.37	7.95	30	WQSEP11	8.07	7.64	7.86	14
WQOCT11	8.08	7.73	7.89	14	WQOCT11	8.00	7.73	7.87	13
WQNOV11	8.14	7.94	8.04	12	WQNOV11	8.07	7.02	7.94	16
WQDEC11	8.01	7.29	7.86	9	WQDEC11	8.01	7.85	7.95	16
WQJAN12	8.15	7.62	7.77	16	WQJAN12	8.17	7.65	7.82	17
WQFEB12	8.21	7.89	8.06	16	WQFEB12	8.19	7.99	8.11	17
CHFEB12	7.52	7.44	7.47	6	CHFEB12	7.41	7.35	7.37	6
WQMAR12	8.29	8.02	8.14	17	WQMAR12	8.22	7.99	8.08	17
CHMAR12	8.21	8.13	8.17	5	CHMAR12	8.15	8.06	8.10	6
WQAPR12	8.35	7.95	8.20	16	WQAPR12	8.30	8.12	8.20	17
WQMAY12	8.19	6.78	7.95	17	WQMAY12	8.17	6.70	8.01	17
WQJUN12	8.41	6.43	8.04	17	WQJUN12	8.21	6.42	7.97	17
HYJUN12	8.31	8.01	8.16	19	HYJUN12	8.19	7.90	8.04	9
WQJUL12	8.23	7.77	8.05	35	WQJUL12	8.18	7.75	8.00	17
HYJUL12	8.27	7.07	8.00	40	HYJUL12	8.23	7.46	7.86	15
WQAUG12	8.33	7.86	8.14	43	WQAUG12	8.16	7.67	7.93	17
HYAUG12	8.28	7.86	8.10	41	HYAUG12	8.12	7.62	7.91	15
WQSEP12	7.87	7.24	7.62	44	WQSEP12	7.78	7.38	7.54	16
HYSEP12	8.06	7.55	7.82	18	HYSEP12	7.90	7.47	7.70	8
WQOCT12	7.87	7.24	7.52	17	WQOCT12	7.88	7.32	7.64	16



Photos By Lloyd Langevin, June 2007

Acknowledgements

Funding for the CT DEEP Long Island Sound Water Quality Monitoring Program is provided through a grant from the EPA through the Long Island Sound Study.