STATE OF CONNECTICUT
DEPARTMENT OF ENERGY AND ENVIRONMENTAL PROTECTION

Daniel C. Esty
Commissioner

Bureau of Natural Resources
Marine Fisheries Division
www.ct.gov/deep/fishing

A STUDY OF MARINE RECREATIONAL FISHERIES IN CONNECTICUT

Federal Aid in Sport Fish Restoration
F-54-R-31 Annual Performance Report
March 1, 2011 – February 29, 2012

Job 5: Cooperative Interagency Resource Monitoring

State of Connecticut
Department of Energy and Environmental Protection
79 Elm Street
Hartford, CT 06106-5127
www.ct.gov/deep

Federal Aid in Sport Fish Restoration
F-54-R-31
Annual Performance Report

Project Title: ***A Study of Marine Recreational Fisheries in Connecticut***

Period Covered: March 1, 2011 - February 29, 2012

Job Title	***Prepared by*:**
Job 1: Marine Angler Survey Part 1: Marine Recreational Fishery Statistics survey Part 2: Volunteer Angler Survey	Roderick E. MacLeod
Job 2: Marine Finfish Survey Part 1: Long Island Sound Trawl Survey	Kurt F. Gottschall Deborah J. Pacileo
Part 2: Estuarine Seine Survey	David R. Molnar
Job 3: Inshore Survey	Jacqueline M. Benway
Job 4: Studies in Conservation Engineering	Inactive
Job 5: Cooperative Interagency Resource Monitoring	Matthew J. Lyman Katie O'Brien-Clayton
Job 6: Public Outreach	David R. Molnar

***Approved by*:**
David G. Simpson, Director
Marine Fisheries Division

Date: August 30, 2012

Cover: A wonderful moment with family enjoying a great catch of summer flounder (fluke).

JOB 5: COOPERATIVE INTERAGENCY RESOURCE MONITORING

LONG ISLAND SOUND AMBIENT WATER QUALITY MONITORING PROGRAM

Inquiries regarding the DEEP's ongoing water quality monitoring efforts in Long Island Sound should be directed to:

Long Island Sound Water Quality Monitoring Program staff (see below)
at
CTDEEP Bureau of Water Management
Planning and Standards Division
79 Elm Street
Hartford, CT 06106-5127

Christine B. Olsen
Phone: (860) 424-3727
E-mail: christine.olsen@ct.gov
program oversight, reporting, data analysis, database management, scheduling and cooperative requests, QA/QC

Matthew J. Lyman
Phone: (860) 424-3158
E-mail: matthew.lyman@ct.gov
database management, data requests, field operations, webpage development, regional monitoring work group contact

Katie O'Brien-Clayton
Phone: (860) 424-3176
E-mail: katie.obrien-clayton@ct.gov
hypoxia area mapping, field operations, survey summaries

Visit the Long Island Sound Water Quality Monitoring Program web page,
with Program information and data at:
http://www.ct.gov/dep/cwp/view.asp?a=2719&q=325534&depNav_GID=1654

JOB 5: COOPERATIVE INTERAGENCY RESOURCE MONITORING

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JOB 5: COOPERATIVE INTERAGENCY RESOURCE MONITORING

GOAL

To provide long-term monitoring of physical, chemical and biological indicators of environmental conditions in order to evaluate the effects of non-fishing activities on the health and abundance of valued recreational species.

OBJECTIVES

1) Provide monthly monitoring of water quality parameters important in the development of summer hypoxia in Long Island Sound including temperature, salinity, and dissolved oxygen, at eighteen fixed axial and lateral stations throughout Long Island Sound.

2) Provide estimates of the area and duration of summer hypoxia (low oxygen) in Long Island Sound based on sampling at an additional 30 fixed sites semi-monthly between June and September.

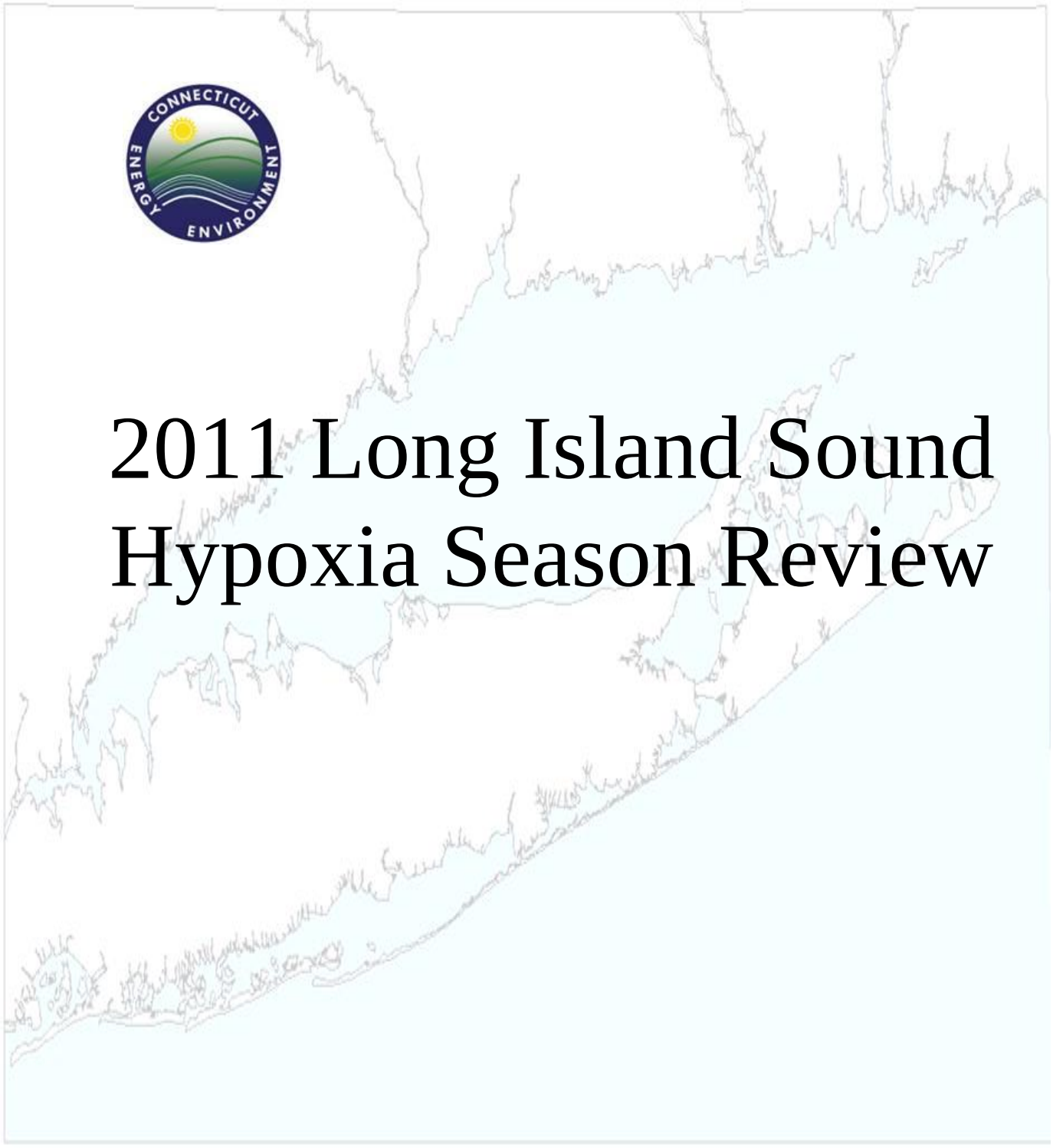
RESULTS AND DISCUSSION

Overview of 2011 Water Quality Monitoring Program

Since 1991, the CT DEP has conducted a water quality monitoring program involving both the Natural Resources Bureau and the Water Management Bureau with support from EPA and Federal Aid to Sportfish Restoration. The 2011 survey was conducted using the same sampling design and methodology as described in previous annual reports. Hypoxic conditions in the Sound usually occur during the summer and are mainly confined to the section of the Sound west of a line from Stratford CT to Port Jefferson NY. The maximum extent of hypoxic conditions in the Sound typically occurs in early August.

During the 2011 survey, seven cruises were conducted between 31 May and 1 September. Onset of hypoxia (< 3 mg/L) in 2011 occurred on or about 6 July and lasted until approximately 28 August. Although this was a typical start date for hypoxia in Long Island Sound, the duration (54 days) was shorter than average (55 days, 1991-2011). The peak hypoxic event occurred during the August 15-17 cruise, when the maximum areal extent of hypoxia was estimated to be 337.5 sq km (130.3 sq mi). The lowest dissolved concentration (1.65 mg/L) recorded at Station A4 in the western Sound. The event did not persist beyond the mid-August cruise, after which the coast was buffeted by two major storms. Hurricane/Tropical Storm Irene impacted the area from 20-28 August, followed by Tropical Storm Lee from 2-5 September. The result was a comparatively mild hypoxia event in Long Island Sound, with average duration but a smaller than average area affected. The index of demersal finfish habitat temporarily affected by hypoxia in 2011 (approximately 4,727 area-days) was also lower than average (approximately 6,900 area-days).

Please see the following ***2011 Long Island Sound Hypoxia Season Review,*** provided by the CT DEEP Water Bureau, for more details and further results of the 2011 hypoxia season.



2011 Long Island Sound Hypoxia Season Review

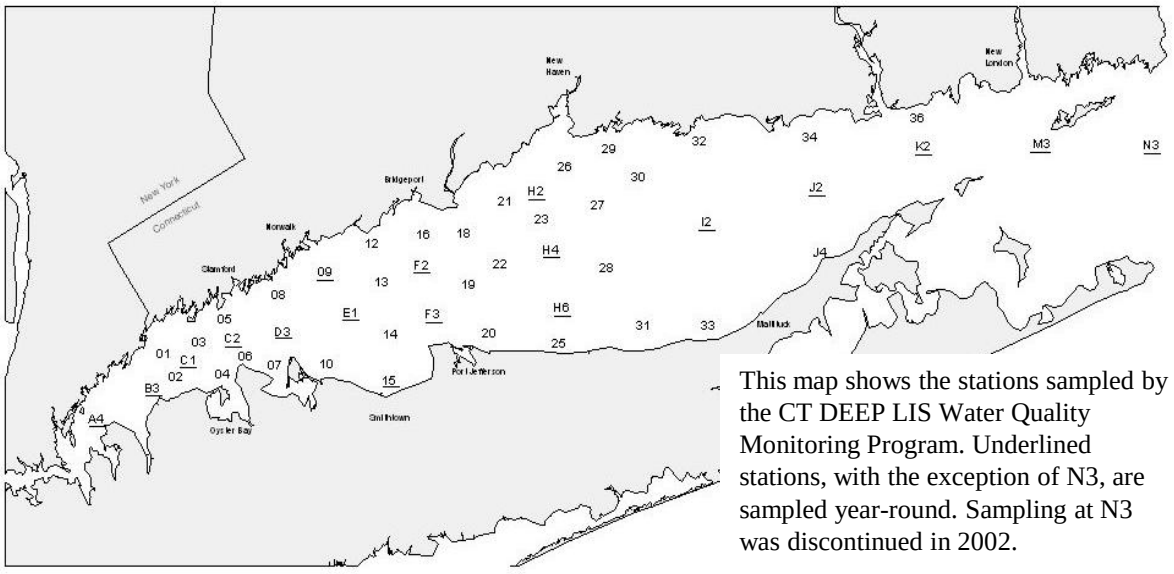
CONNECTICUT DEPARTMENT OF ENERGY & ENVIRONMENTAL PROTECTION
79 ELM STREET, HARTFORD, CT 06106
DANIEL C. ESTY, COMMISSIONER

MONITORING LONG ISLAND SOUND 2011

Program Overview

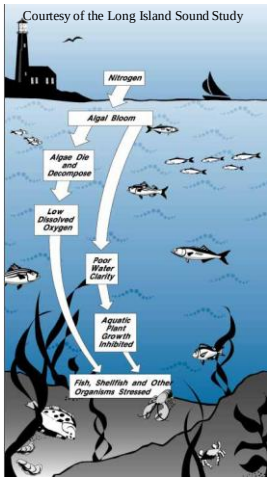
Since 1991, the Connecticut Department of Energy & Environmental Protection (CT DEEP, formerly the Department of Environmental Protection, (CTDEP)) has conducted an intensive year-round water quality monitoring program on Long Island Sound. Water quality is monitored at up to forty-eight (48) sites by 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.

R/V John Dempsey

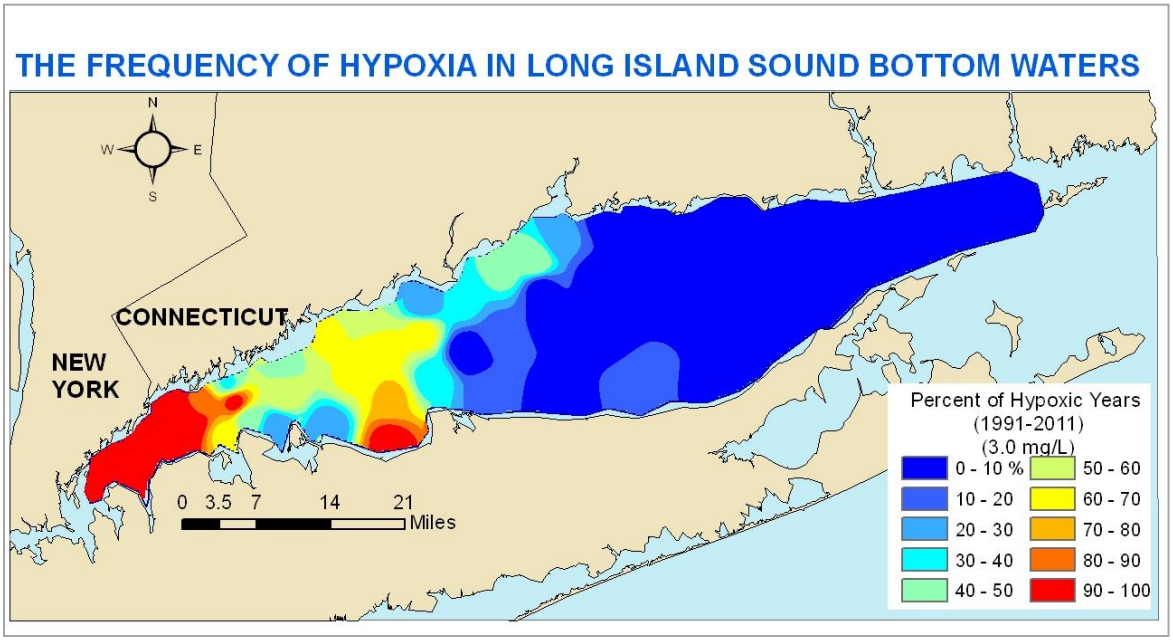


This map shows the stations sampled by the CT DEEP LIS Water Quality Monitoring Program. Underlined stations, with the exception of N3, are sampled year-round. Sampling at N3 was discontinued in 2002.

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

2011 Important Facts

CT DEEP conducted seven cruises during the summer of 2011 between 31 May and 1 September. Over the course of the season, 11 different stations were documented as hypoxic and of the 228 site visits completed in 2011, hypoxic conditions were found 20 times. Compared to the 21-year averages, 2011 was below average in area and slightly below average in duration (see page 4).

Cruise	Start Date	End Date	Number of stations sampled	Number of hypoxic stations
WQJUN11	5/31/2011	6/6/2011	17	0
HYJUN11	6/16/2011	6/16/2011	21	0
WQJUL11	7/5/2011	7/7/2011	39	3
HYJUL11	7/18/2011	7/20/2011	39	1
WQAUG11	8/1/2011	8/3/2011	40	6
HYAUG11	8/15/2011	8/17/2011	35	10
WQSEP11	8/30/2011	9/1/2011	37	0

The peak event occurred during the HYAUG11 cruise between 15 and 17 August. The lowest dissolved oxygen concentration (1.65 mg/L) was documented during the WQAUG11 cruise at Station A4. The hypoxia area maps for 2011 appear on pages 7-11.

Estimated Start Date	7/6/2011
Estimated End Date	8/28/2011
Duration (days)	54
Maximum Area (mi^2)	130.3

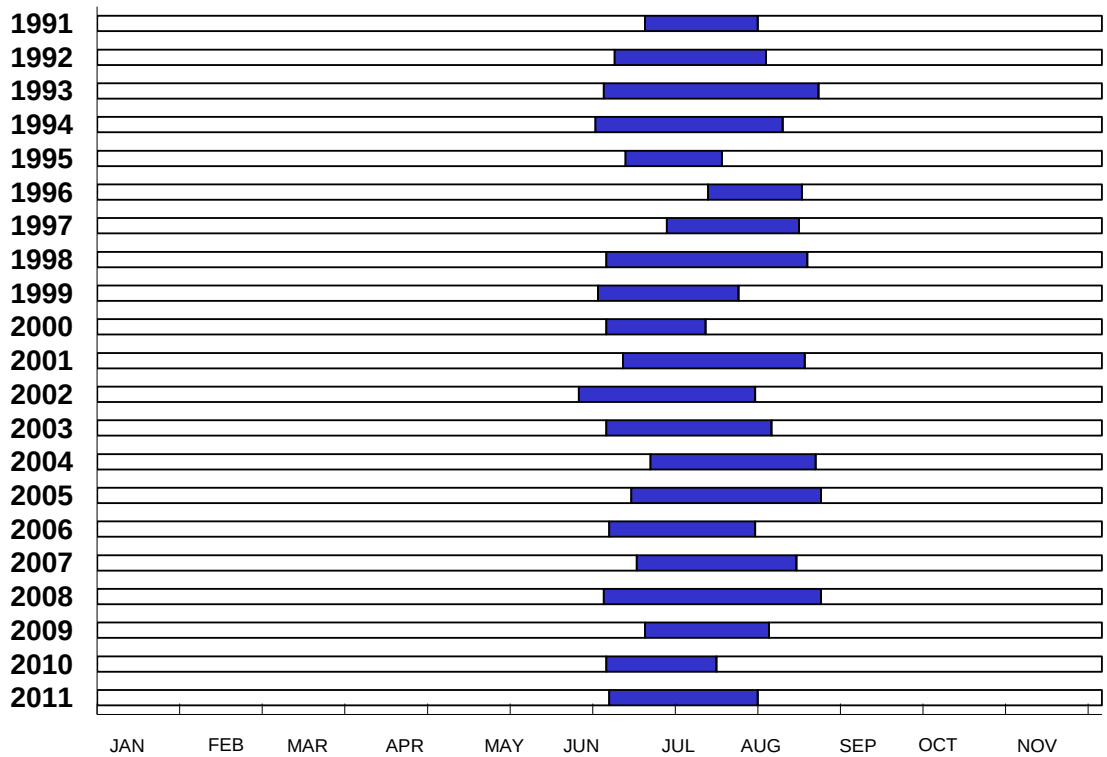
The Long Island Sound Study has defined hypoxia as dissolved oxygen concentrations below 3.0 mg/L. In December 2009, CT DEEP public noticed revisions to the water quality standards that specified dissolved oxygen in Class SA and SB waters shall not be less than 3.0 mg/L at anytime. These revisions were approved and adopted on 25 February 2011.

Timing and Duration of Hypoxia, 1991 - 2011

The figures and tables below displays the onset, duration, and end of the hypoxia events from 1991 through 2011 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
Average	July 10	Sept 3	178	55
Deviation	±10 days	±13 days	± 85 mi^2	± 13 days

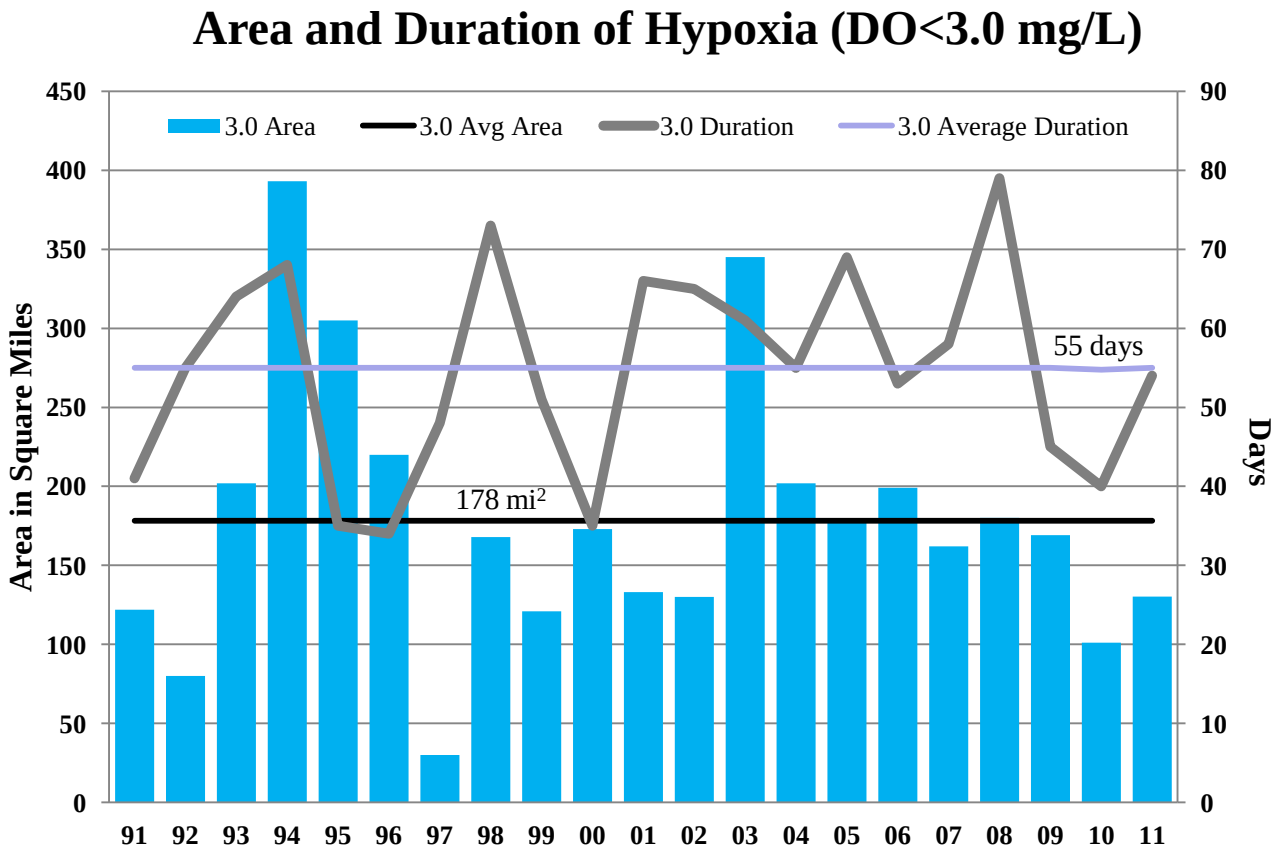
Based on the LISS standard of 3.0 mg/L, the average date of onset was July 10 (± 10 days), the average end date was September 3 (± 13 days), and the average duration was 55 days (± 13 days). The earliest onset of hypoxia (red text) occurred on 25 June 2002 and the latest end date (green text) occurred 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 178 mi^2 and the average duration was 55 days.

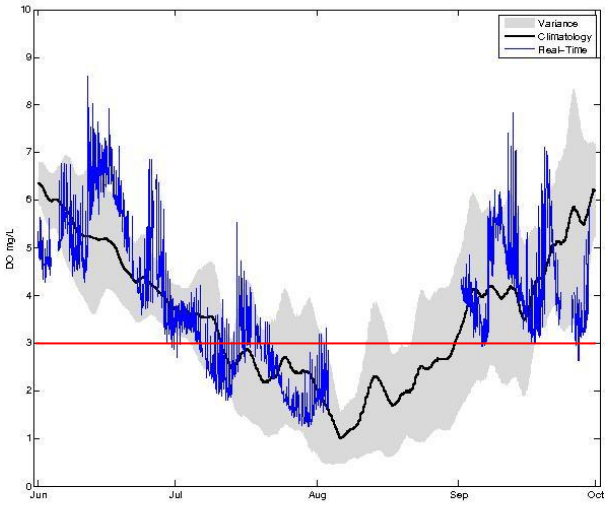


Duration Based on Buoy Data Obtained From the LISICOS Network on 28 September 2011

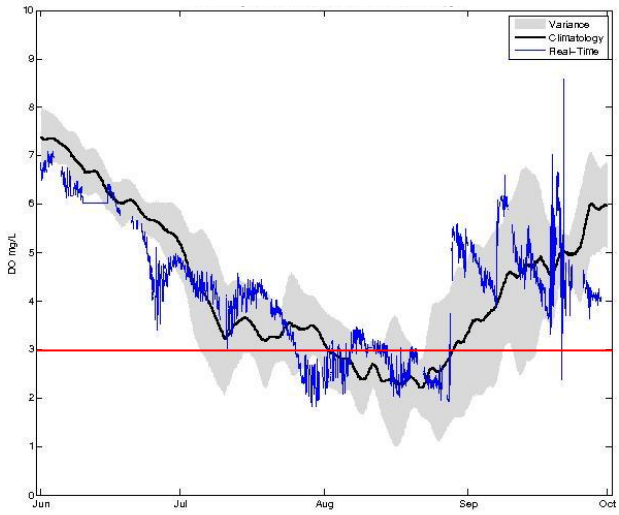
"LISICOS, or the Long Island Sound Integrated Coastal Observing System, was established in 2003 as a component of a regional/national ocean observing system, with the initial goal of developing a capability to observe and understand the LIS ecosystem and predict its response to natural and anthropogenic changes." LISICOS monitors water quality parameters (salinity, temperature, dissolved oxygen, photosynthetically available radiation and chlorophyll) as well as meteorological parameters (wind direction, speed, surface wave height) throughout the sound using a series of buoys and sensors. Data are sent 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.

Duration and maximum /minimum concentration statistics are available on the LISICOS website for the Execution Rocks and Western Long Island Sound stations. Please note however that these statistics are based upon telemetered data and due to various events (Tropical Storm Irene, Tropical Storm Lee) data were not available real-time during August and early September. After data processing from the sondes, these statistics will likely be revised. UConn is expecting to fill in the data gaps by the end of November/early December.

Execution Rocks Bottom Dissolved Oxygen



Western LIS Bottom Dissolved Oxygen



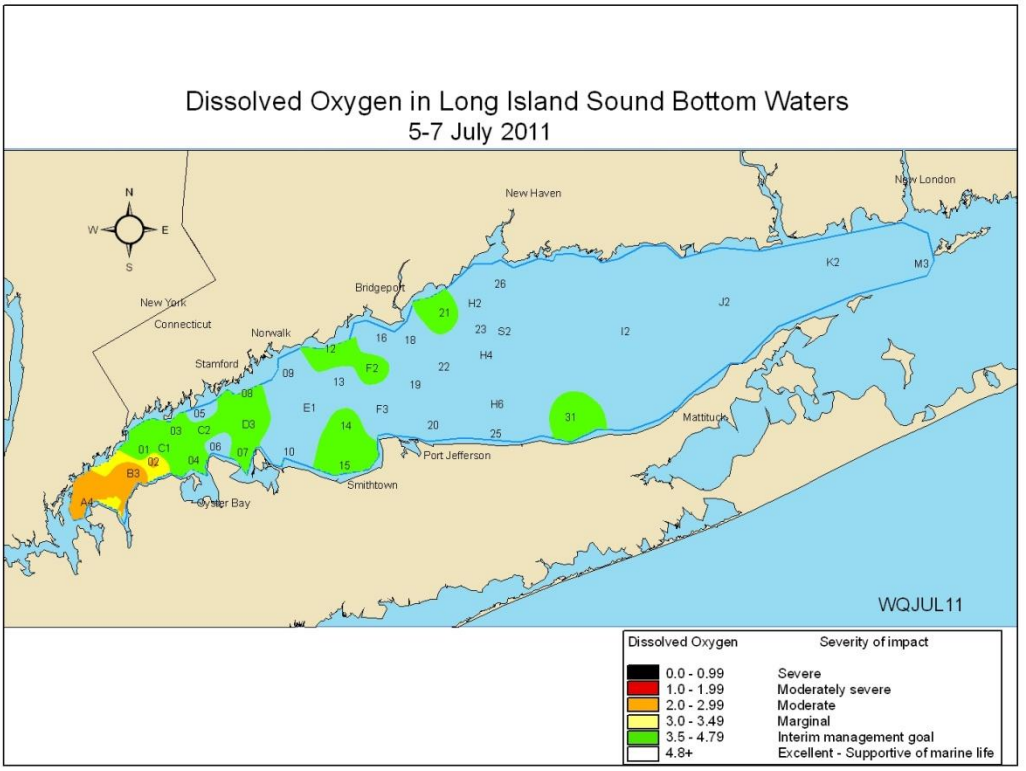
Blue line is the 2011 real-time data, black line is the average of the entire dataset (7 or 10 years, depending on the station) and the gray shading is the variability.

Based upon data obtained from the LISICOS Execution Rocks Bottom Dissolved Oxygen Prediction Tool webpage (http://lisicos.uconn.edu/do_fcst.php?site=exrx), between 1 June and 29 September, there were **21.18** days when the DO concentration was below or equal to 3.0 mg/L. The minimum DO concentration recorded was 1.25 mg/L on 30 July.

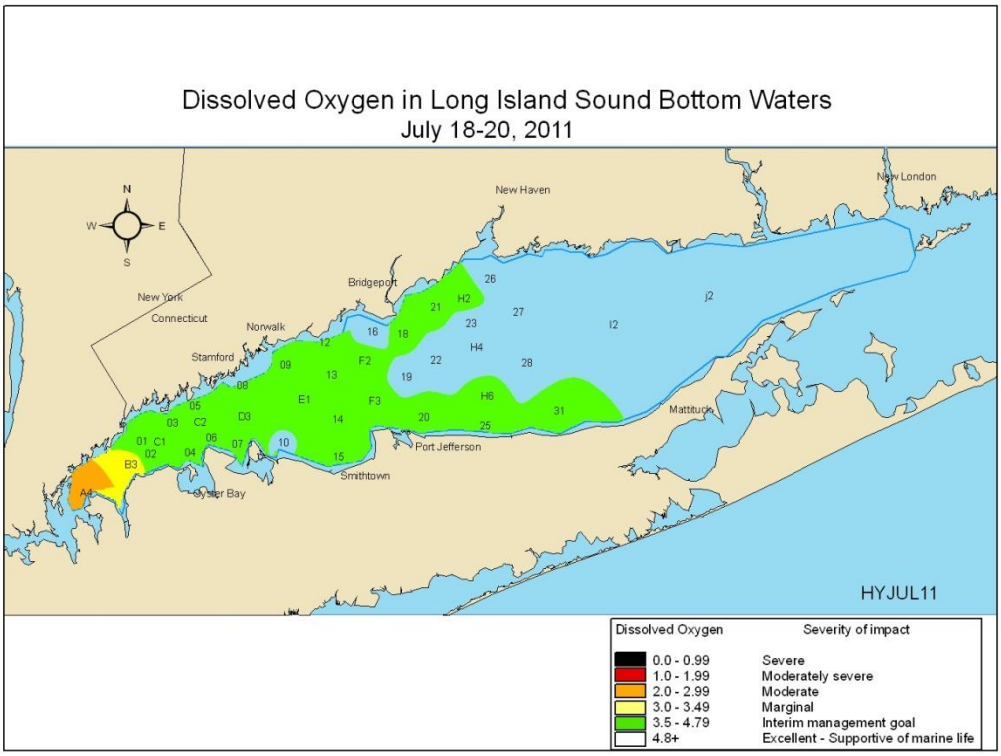
Based upon data obtained from the LISICOS Western LIS Bottom Dissolved Oxygen Prediction Tool website (http://lisicos.uconn.edu/do_fcst.php?site=wlis), there were **22.51** days of DO concentration below or equal to 3.0 mg/L between 1 June and 29 September. The minimum DO concentration recorded was 1.84 mg/L on 29 July.

Hypoxia Maps

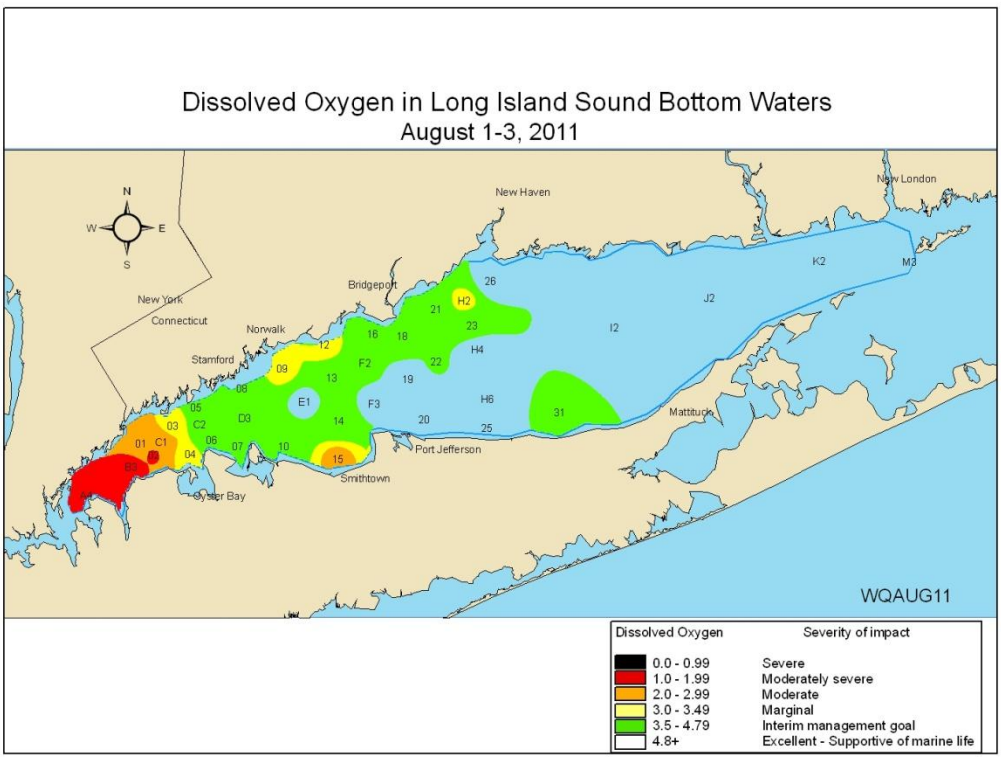
The following maps depict the development of hypoxia based on CT DEEP cruise data through the 2011 season. During the HYJUN11 survey all stations had DO concentrations above 4.8 mg/L. During the WQJUL11 survey DO concentrations were less than 4.8 mg/L at 14 stations and concentrations at B3 and A4 had already dropped below 3 mg/L. Data for all surveys are available upon request.



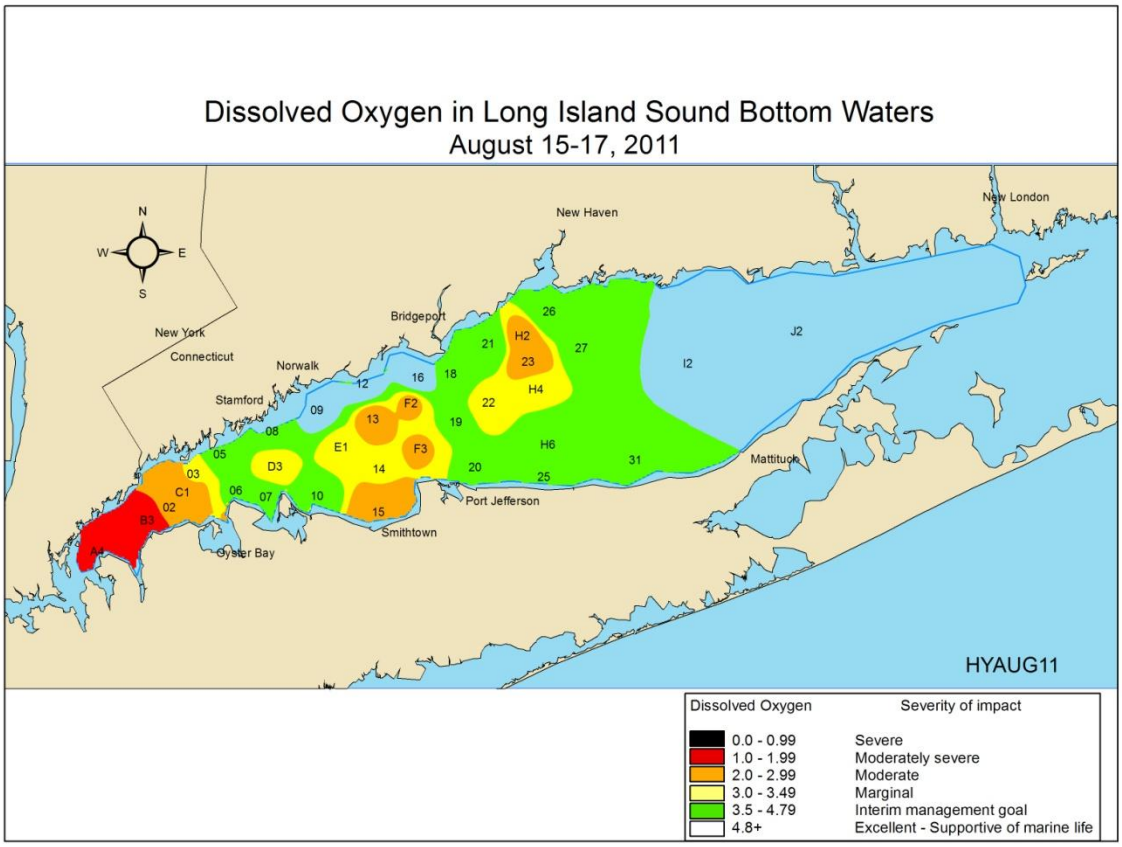
During the HYJUL11 survey, DO concentrations dropped below 4.8 mg/L at 26 stations; Station A4 remained below 3 mg/L, but concentrations at B3 improved slightly.



During the WQAUG11 survey, DO concentrations dropped below 3.5 mg/L at 5 stations, 3 stations fell below 3 mg/L, and three stations were below 2 mg/L.



Concentrations continued to decline during the HYAUG11 survey with two stations exhibiting DO concentrations below 2 mg/L. Eight stations had concentrations below the 3.0 mg/L standard and six stations were below 3.5 mg/L.



Maximum Areal Extent (130.3 mi^2) of Hypoxia

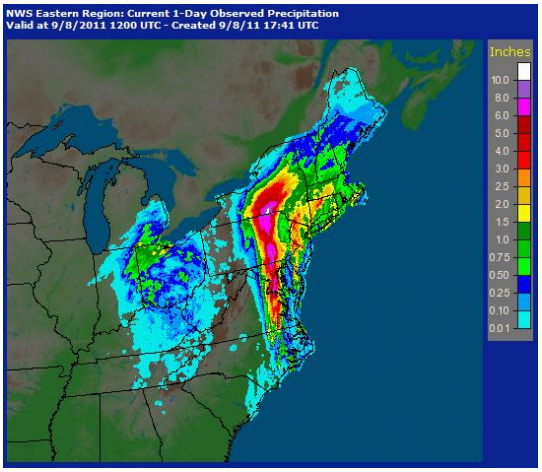
The map illustrates the dissolved oxygen concentrations in the bottom waters of Long Island Sound during the height of the hypoxic event.

Hurricane/Tropical Storm Irene and Tropical Storm Lee

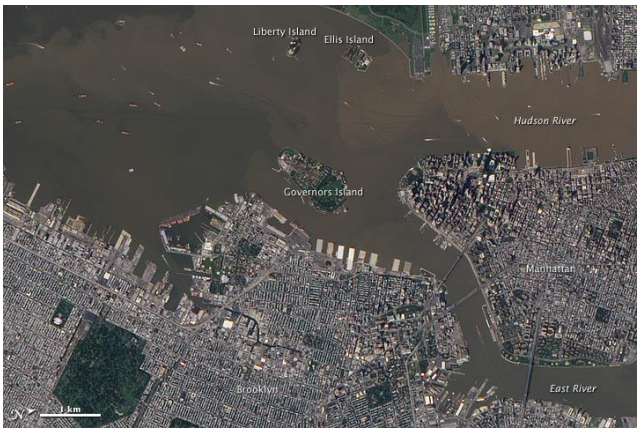
Hurricane/Tropical Storm Irene buffeted the east coast of the US from 20-28 August and impacted the northeast two days before the scheduled September survey. USGS provisional storm surge data associated with the storm are available at the following link http://water.usgs.gov/osw/floods/2011_HIrene/. Select meteorological data (http://www.erh.noaa.gov/box/dailystns.shtml) for 8/28 around the region are tabulated below. Data from the LISICOS buoys are also included.

Location	Rainfall (inches)	Avg wind speed (mph)	Max gust (mph)
Bridgeport	3.35	24.9	63
Central Park	6.87	14	60
LaGuardia	5.69	27.7	67
JFK	5.03	28.8	59
Bennington, VT	4.23	10.1	30
North Adams, MA	5.11	9.7	47
ESTRN	N/A	25.8	51
CLIS	N/A	27.9	64
WLIS	N/A	26.9	48
EXRX	N/A	25.4	49

Following Irene, Tropical Storm Lee pummeled the area from 2-5 September. Maximum sustained winds reported by the National Hurricane Center were 60 mph.

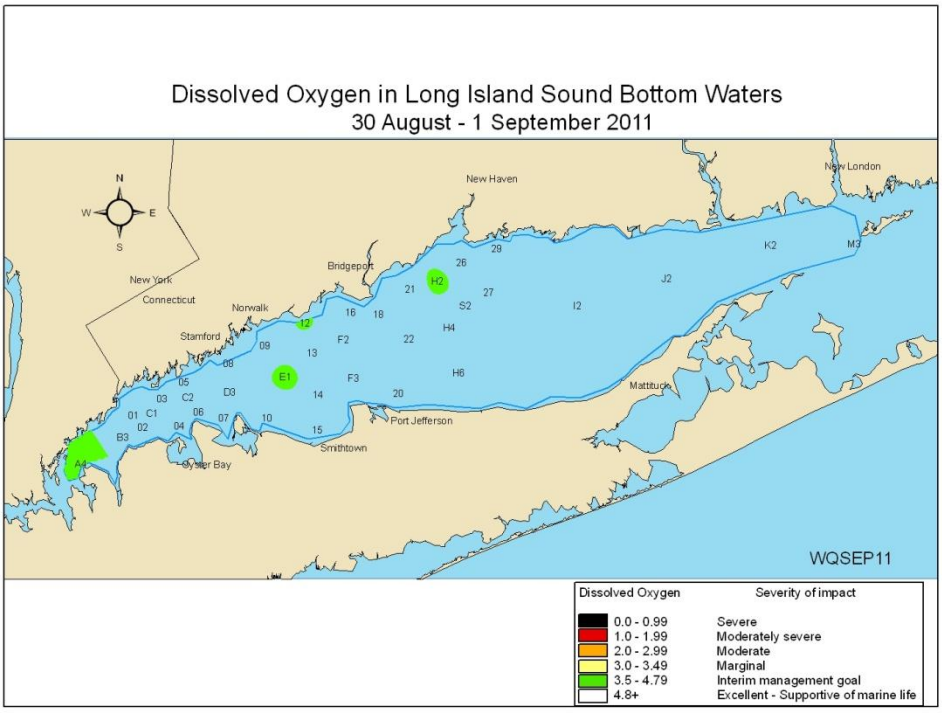


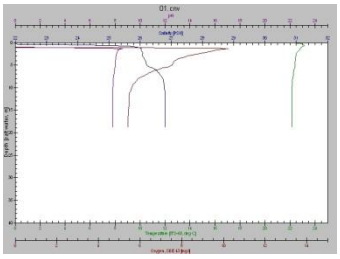
Northeast 24-hour Observed Precipitation. Image from NWS found on USGS Tropical Storm Lee Activities website http://water.usgs.gov/osw/floods/2011_TSLee/index.html



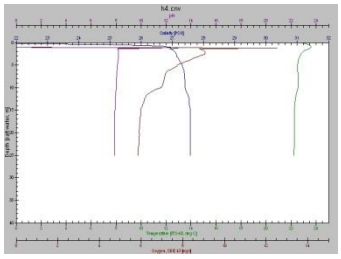
Sediment plumes in Hudson River acquired 9/12/11 http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=52125

The WQSEP11 survey was postponed one day due to Tropical Storm Irene. The wind and rain helped to mix the water column, easing thermal stratification, and all but eliminating hypoxic conditions. Only three stations had concentrations below 4.8 mg/L. Conditions continued to improve and the HYSEP11survey was cancelled.

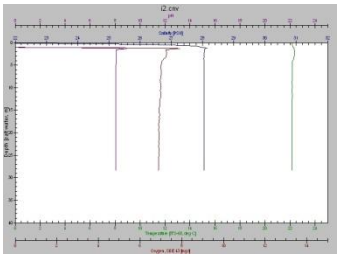




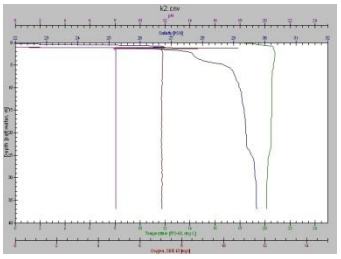
Station 01



Station H4



Station I2



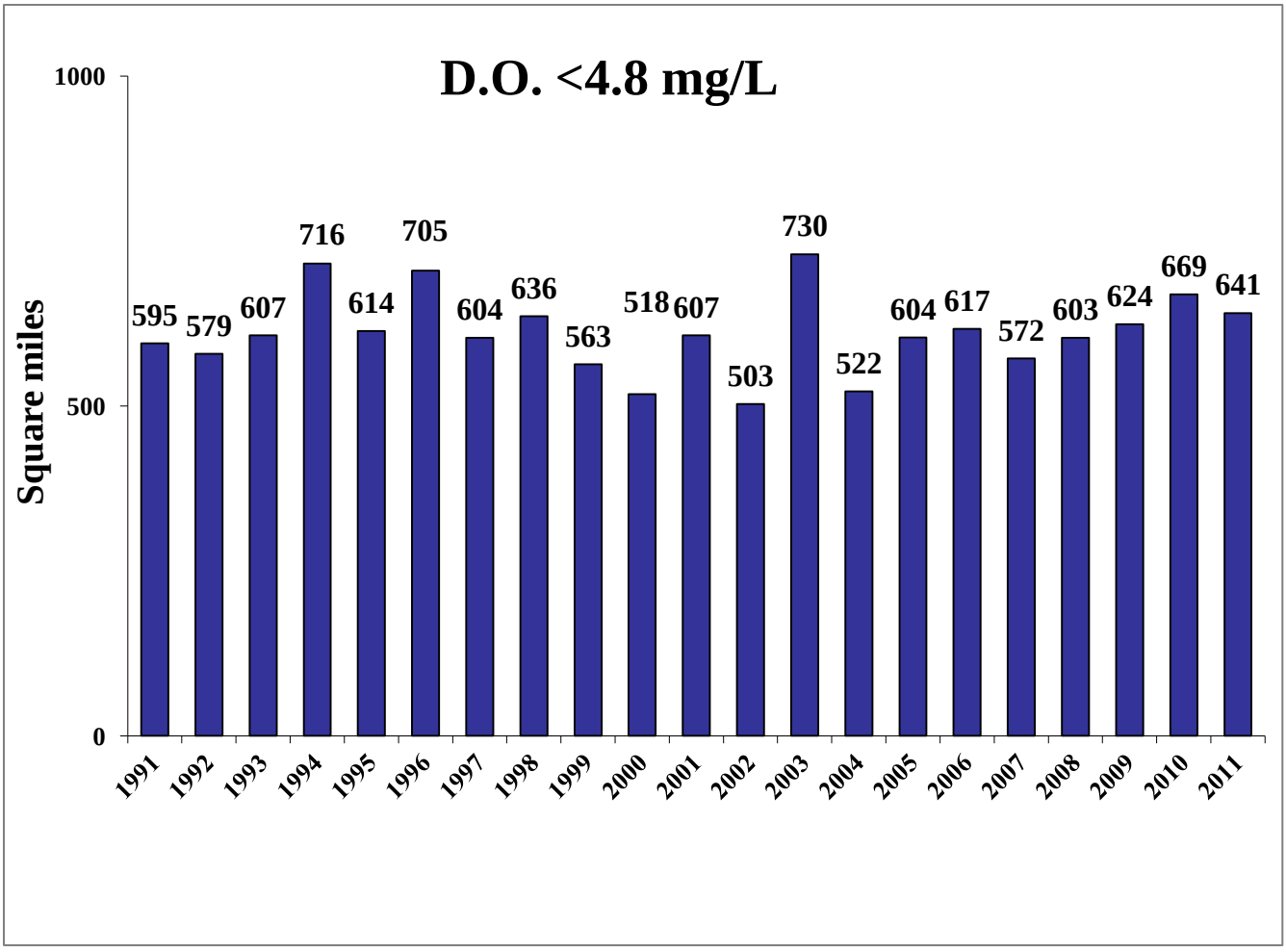
Station K2

CTD profiles obtained during the WQSEP11 survey. The blue line is salinity, green is temperature, darker red is oxygen, and magenta is pH.

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 2011, the maximum area occurred during the HYAUG11 survey. This area was lower than 2010 but higher than 2009. The area affected by concentrations less than 4.8 mg/L averages 610.9 square miles and varies slightly from 503 to 730 square miles.

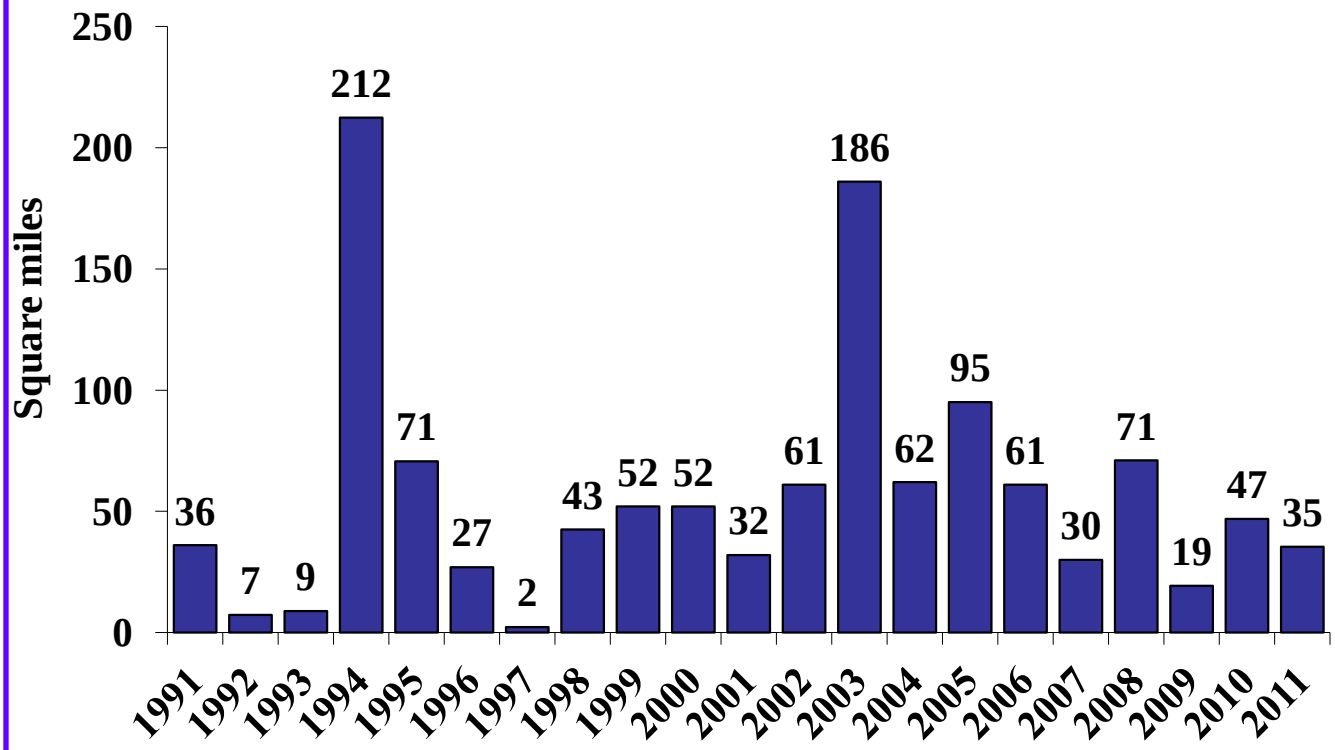


Severe Hypoxia

D.O. <2 mg/L

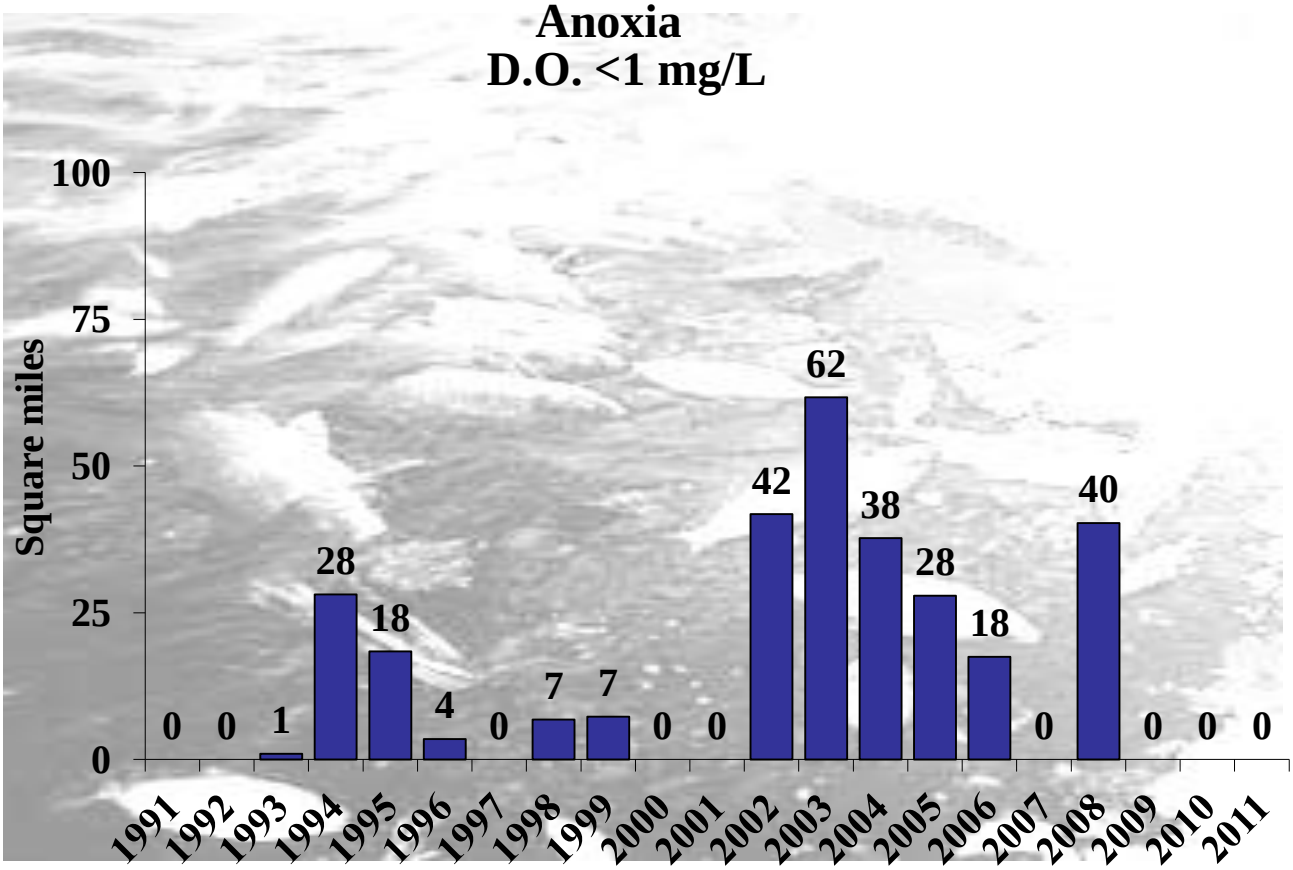
The Gulf of Mexico is another water body that exhibits severe hypoxia, although the standard is determined at the 2.0 mg/L level. The average size of the hypoxic zone in the northern Gulf of Mexico from 1985-2010 is roughly 5330 mi^2. The maximum area of the Gulf of Mexico hypoxic zone occurred in 2002 and was estimated at 8,841 mi^2. (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 2011, the maximum area of LIS affected by severe hypoxia was 35 mi^2, a decrease from 2010. The average area, calculated from 1991-2011, is 57.7 mi^2.

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

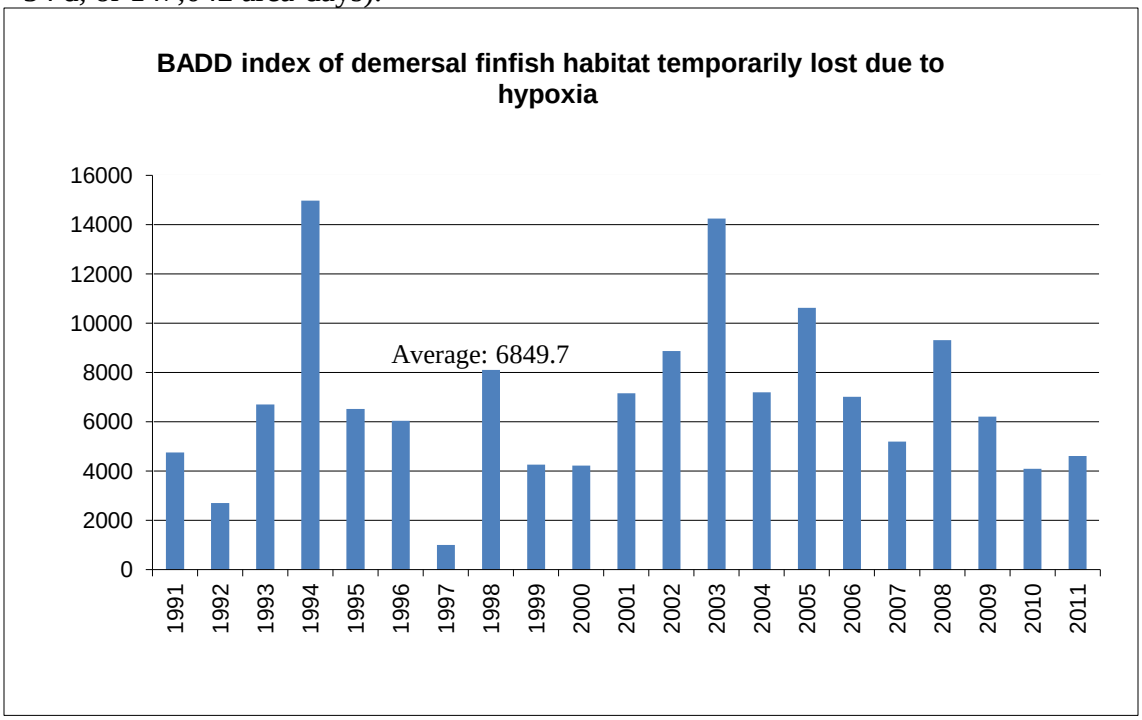


For management purposes the Long Island Sound Study defines anoxia as DO concentrations less than 1 mg/L. In eight of the twenty-one years there was no anoxia reported by CT DEEP. The greatest area with D.O. below 1 mg/L observed in LIS, based on ~biweekly sampling by CT DEEP, was during the summer of 2003. Prior to 2002, the average area of bottom waters affected by anoxia was 5.92 mi^2. From 2002-2011 the average area affected was 22.69 mi^2. The overall average area affected from 1991-2011 is 13.9 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, on 31 August2009 the Interstate Environmental Commission documented two stations that were anoxic, Stations B3 (same as CT DEEP) and B2 (northwest of B3). In 2010 IEC also documented two stations that were anoxic- Station B3 on 2 August and Station H-D (Hempstead Harbor) on 9 September. In 2011, no stations were documented to have gone anoxic by either the IEC or CT DEEP; the lowest concentration documented by IEC was 1.53 mg/L at Station B3 and the lowest concentration documented by CT DEEP was 1.65 mg/L at Station A4. Additionally the lowest concentration reported at the LISICOS Execution Rocks buoy (Station A4) for 2011 was 1.25 mg/L . The buoy is operated by the University of Connecticut, Department of Marine Sciences.

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 July 5- August 28 (54 d). The index is then expressed as a percentage of the available area-days (sample area 2,723 km^2 x 54 d, or 147,042 area-days).

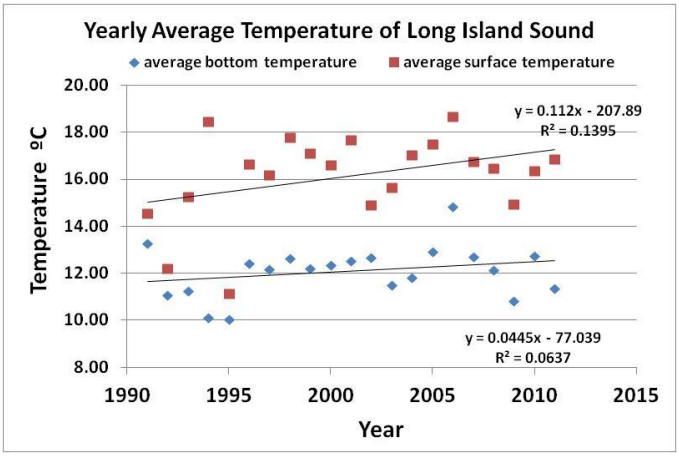


Simpson, David G., Kurt Gottschall, and Mark Johnson. 1995. Cooperative interagency resource assessment (Job 5). In : A study of marine recreational fisheries in Connecticut, CT DEP Marine Fisheries Office, PO Box 719, Old Lyme, CT 06371, p 87-135.

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

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. In LIS, there are two key contributors to hypoxia: nutrient enrichment and stratification. 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. 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.



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.

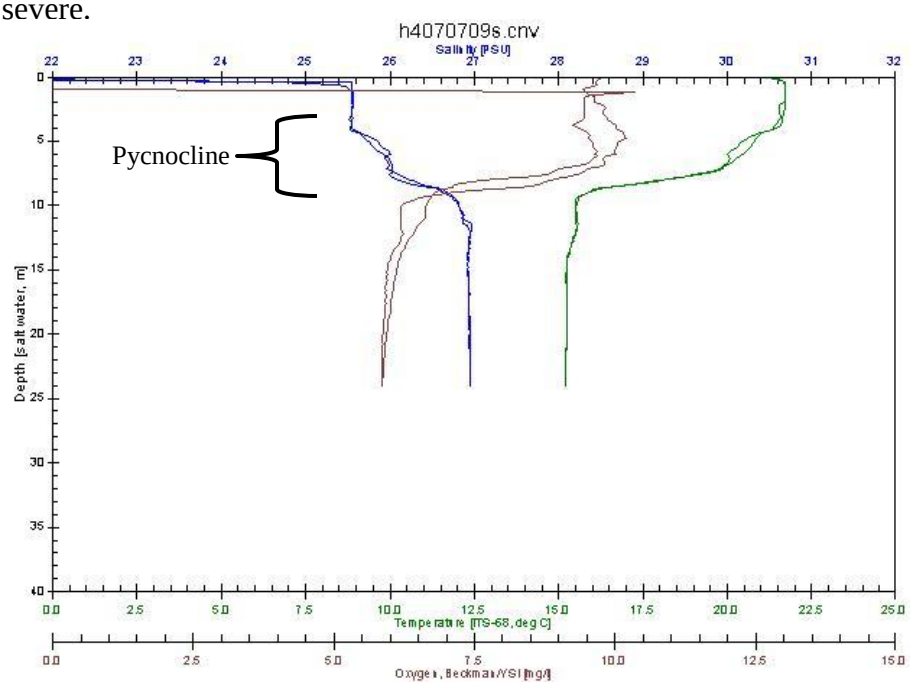
2011 maximum, minimum, and average temperatures (ºC) across Long Island Sound by cruise based upon CT DEEP Conductivity, Temperature, Depth (CTD) profile data

Cruise	Max	Min	Average
WQJAN11	4.601	0.595	2.923
WQFEB11	2.334	0.232	0.871
CHFEB11	1.302	0.678	0.791
WQMAR11	4.121	1.809	2.564
WQAPR11	7.060	3.732	5.147
WQMAY11	11.736	6.584	8.238
WQJUN11	21.436	9.778	12.927
HYJUN11	18.571	12.532	15.837
WQJUL11	23.774	15.197	17.734
HYJUL11	23.789	16.924	19.432
WQAUG11	24.791	18.366	20.818
HYAUG11	23.737	20.420	21.644
WQSEP11	23.876	19.711	21.952

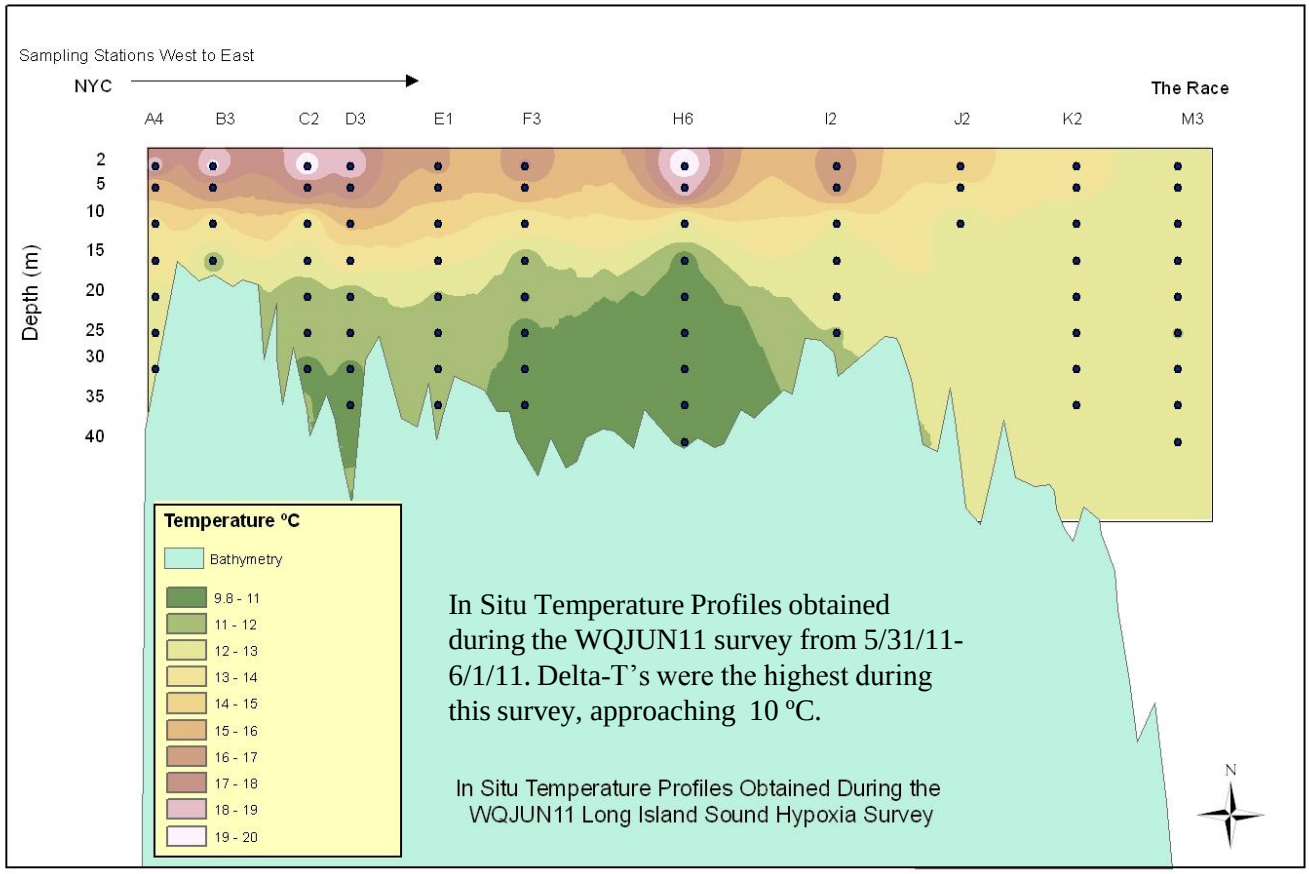
Delta T

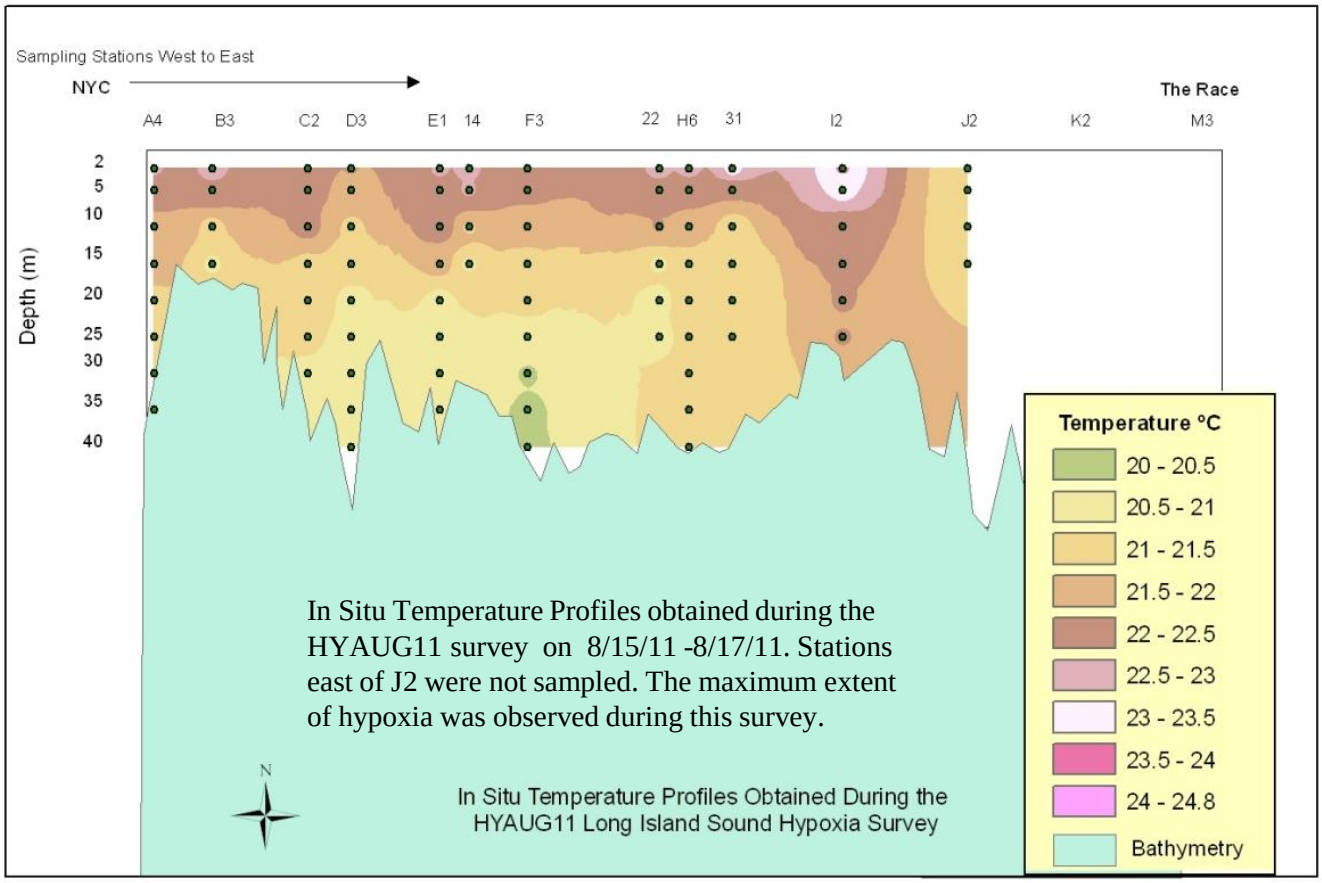
The temperature difference between the bottom waters and the surface waters is known as "delta T". This delta T, along with salinity differences, creates a density difference, or "density gradient" resulting in a separation or "stratification" of water layers that hinders the oxygenated surface waters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

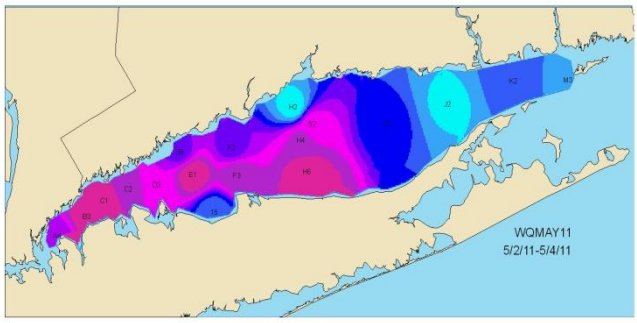


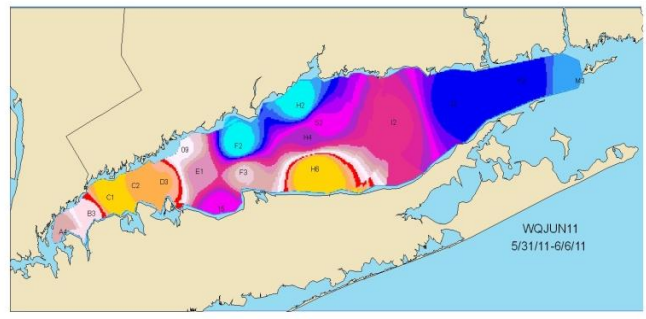
The temperature graphs on page 16 show computer interpolations along the west-east axis of LIS generated from profile data collected during two CT DEEP surveys. During the WQJUN11 survey, surface water temperatures had warmed to 21ºC while the bottom water remained cooler around 12ºC. This set up the largest differences in temperatures between the surface and bottom waters. The second graph shows how the water column was thermally stratified during the HYAUG11 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 WQAPR11 survey, decreased during the HYJUN11 survey, then increased again through the WQAUG11 survey, setting up the stratification and leading to the maximum extent of hypoxia in late August. By the September survey with the help of remnants of two tropical storms, Delta T's decreased to around 1 ºC over much of the Sound 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.

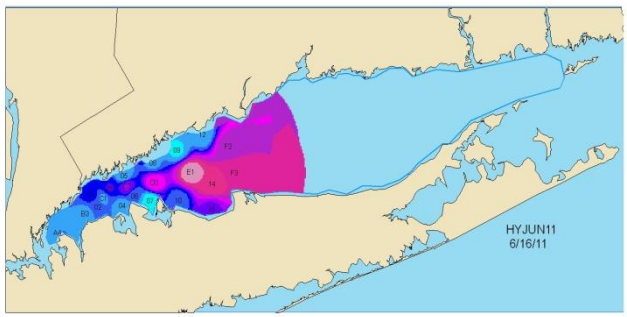

Sampling Stations West to East
NYC
The Race
A4
B3
C2
D3
E1
F3
H6
I2
J2
K2
M3
Depth (m)
2
5
10
15
20
25
30
35
40
Temperature °C
Bathymetry
9.8 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
In Situ Temperature Profiles obtained during the WQJUN11 survey from 5/31/11-6/1/11. Delta-T's were the highest during this survey, approaching 10 ºC.
In Situ Temperature Profiles Obtained During the WQJUN11 Long Island Sound Hypoxia Survey
N

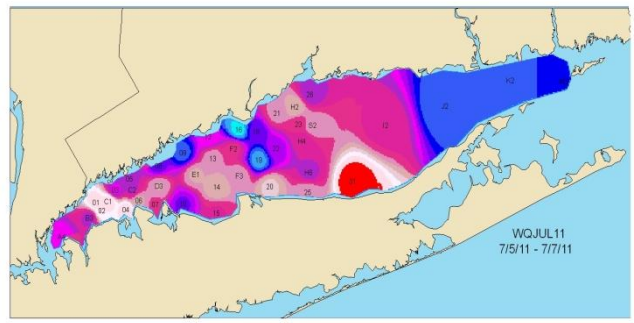

Sampling Stations West to East
NYC
The Race
A4
B3
C2
D3
E1
14
F3
22
H6
31
I2
J2
K2
M3
Depth (m)
2
5
10
15
20
25
30
35
40
Temperature °C
20 - 20.5
20.5 - 21
21 - 21.5
21.5 - 22
22 - 22.5
22.5 - 23
23 - 23.5
23.5 - 24
24 - 24.8
Bathymetry
In Situ Temperature Profiles obtained during the HYAUG11 survey on 8/15/11 -8/17/11. Stations east of J2 were not sampled. The maximum extent of hypoxia was observed during this survey.
In Situ Temperature Profiles Obtained During the HYAUG11 Long Island Sound Hypoxia Survey
N

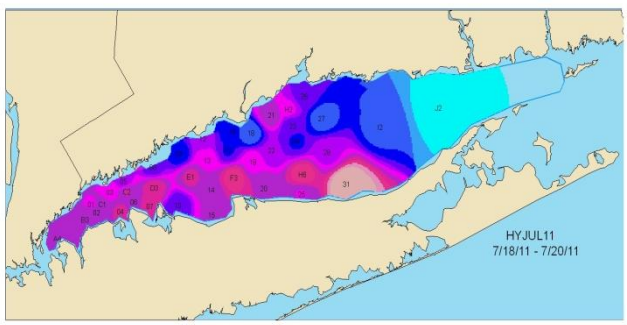
2011 Delta-T Maps

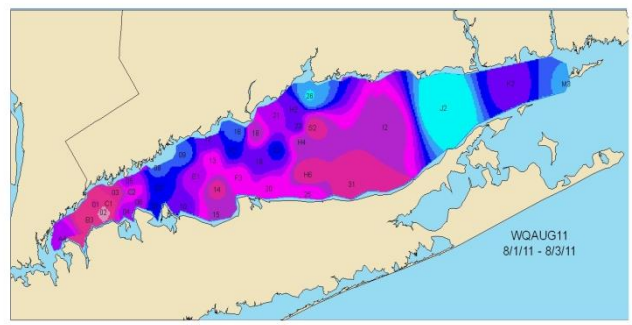


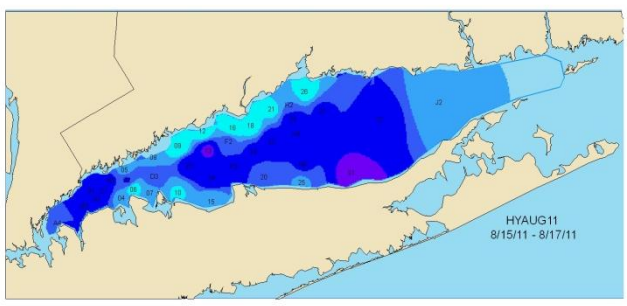


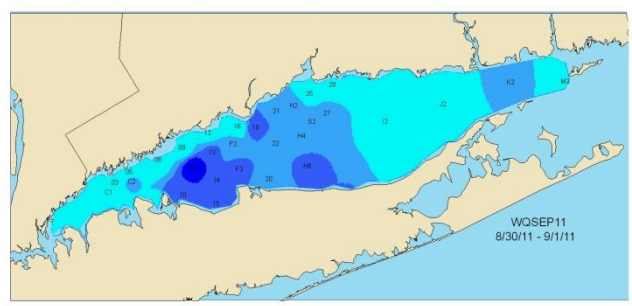












0 - 0.5
>0.5 - 1
>1 - 1.5
>1.5 - 2
.2 - 2.5
>2.5 - 3
>3 - 3.5
.3.5 - 4
>4- 4.5
>4.5 - 5
>5 - 5.5
>5.5 - 6
>6 - 6.5
>6.5 - 7
>7 - 7.5
>7.5 - 8
>8- 8.5
>8.5 - 9
>9

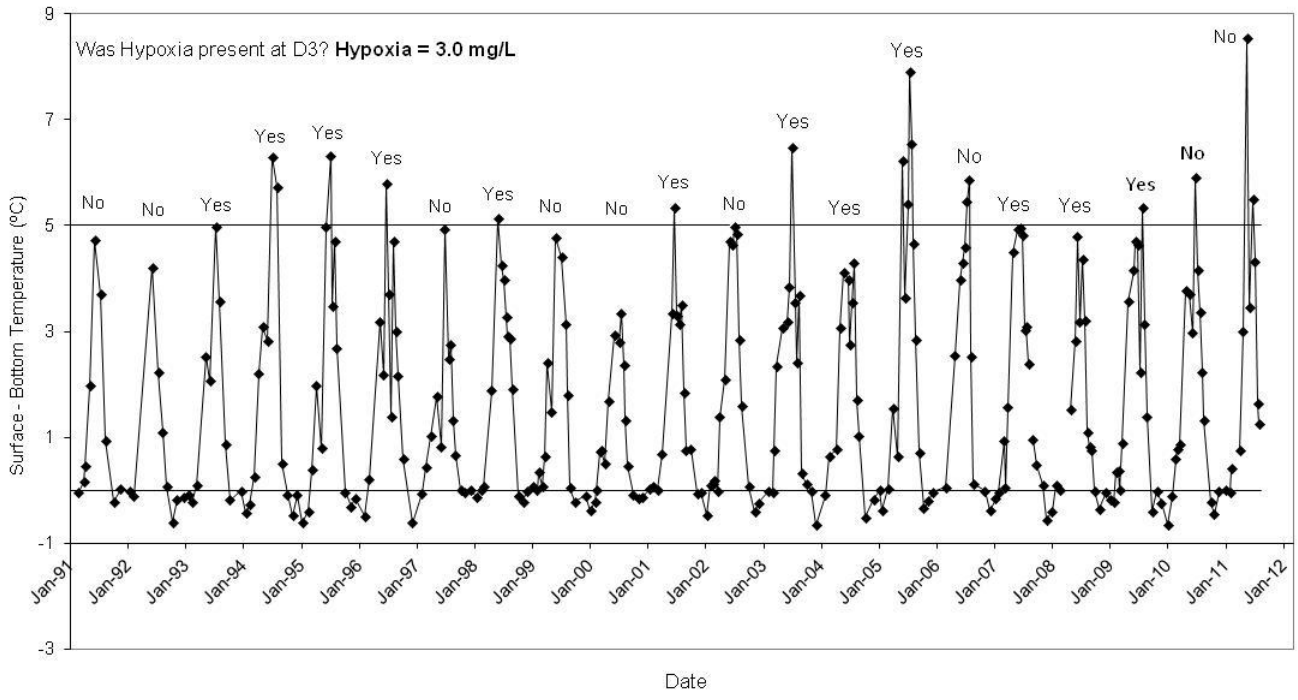
Delta-T ºC

N
W
E
S

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. 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

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 2011.

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. In fact, over the period of record this year (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.

Salinity

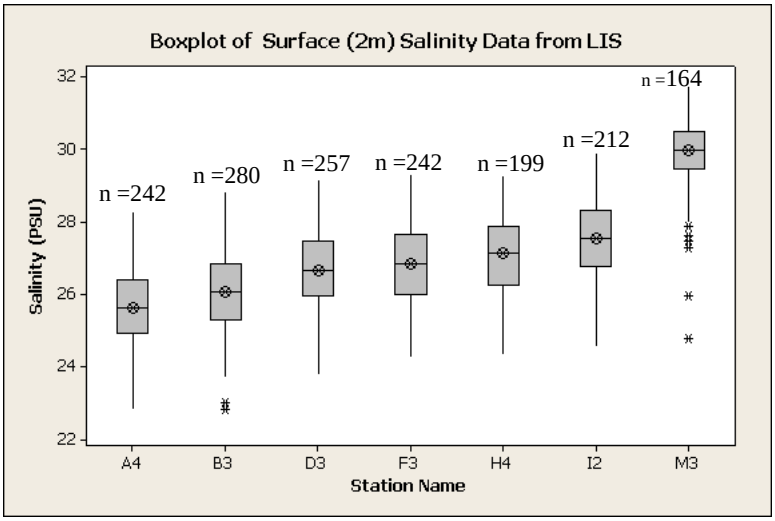
Salinity is a measure of the dissolved salts content of seawater. It is usually expressed in practical salinity units (PSU). Salinity levels across Long Island Sound vary from 23 PSU in the Western Sound at Station A4 to 33 PSU in the eastern Sound at Station M3. The Thames, Connecticut, and Housatonic rivers are the major sources of freshwater entering the Sound. Summary statistics for salinity data collected from seven stations across the Sound from1991-20101are presented in the tables below. Data collected this year are also presented separately.

	1991-2011 Bottom Water Statistics							
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	249	23.823	28.727	26.324	26.31	0.0591	0.933	0.87
B3	297	24.259	28.926	26.6	26.557	0.0538	0.928	0.861
D3	274	24.912	29.215	27.243	27.359	0.0535	0.886	0.784
F3	258	25.153	29.432	27.592	27.636	0.0538	0.864	0.746
H4	217	25.508	29.7	27.743	27.765	0.0574	0.845	0.714
I2	242	25.762	29.985	28.063	28.153	0.0542	0.844	0.712
M3	203	28.608	32.622	30.559	30.556	0.0503	0.717	0.514

	2011 Bottom Water Statistics							
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	11	24.413	27.579	25.832	25.736	0.313	1.037	1.075
B3	11	24.681	27.773	26.101	26.008	0.302	1.001	1.003
D3	11	25.376	27.908	26.811	27.36	0.29	0.963	0.928
F3	10	25.852	28.204	27.145	27.428	0.281	0.89	0.792
H4	9	26.235	28.215	27.437	27.681	0.238	0.715	0.511
I2	9	26.511	28.323	27.553	27.865	0.232	0.696	0.484
M3	4	29.379	30.182	29.89	30	0.183	0.366	0.134

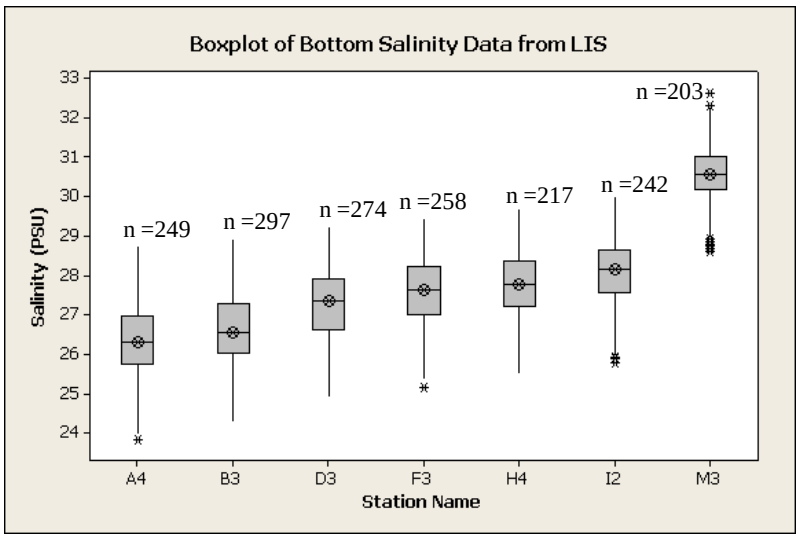
	1991-2011 Surface Statistics							
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	242	22.833	28.278	25.636	25.623	0.0664	1.033	1.068
B3	280	22.8	28.84	26.041	26.073	0.0639	1.07	1.145
D3	257	23.772	29.146	26.663	26.645	0.0662	1.061	1.126
F3	242	24.246	29.307	26.819	26.826	0.0699	1.087	1.182
H4	199	24.315	29.262	27.056	27.145	0.0771	1.088	1.183
I2	212	24.56	29.909	27.489	27.552	0.0725	1.056	1.115
M3	164	24.789	31.758	29.899	29.979	0.0804	1.029	1.06

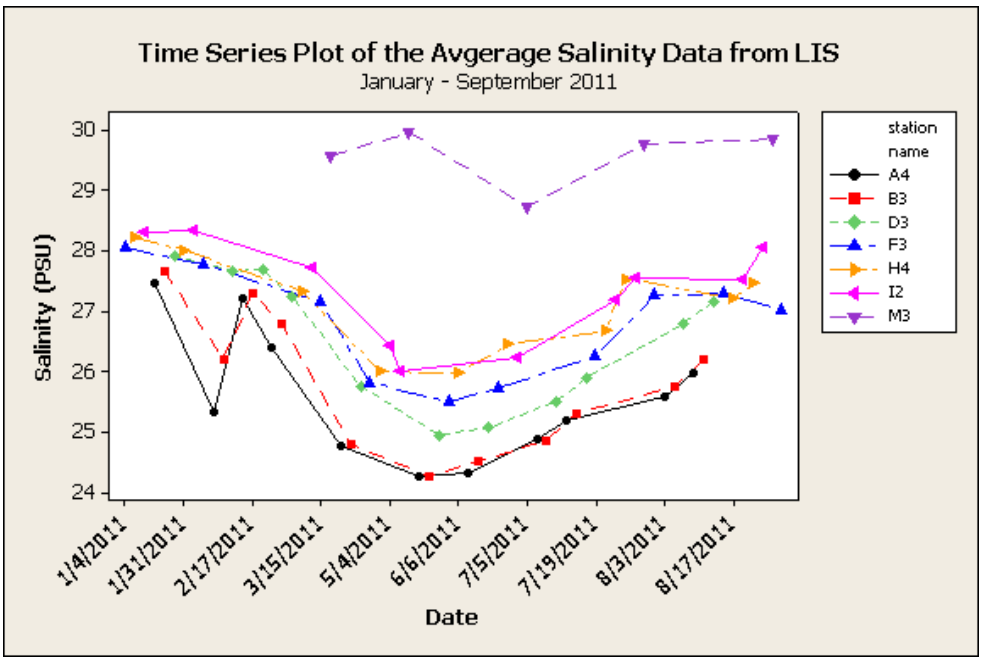
	2011 Surface Statistics							
Station Name	Count	Minimum	Maximum	Mean	Median	SE Mean	Standard Deviation	Variance
A4	11	22.865	27.099	24.912	24.824	0.453	1.433	2.054
B3	11	22.8	27.073	24.731	24.708	0.448	1.416	2.004
D3	11	23.772	27.907	25.92	25.668	0.445	1.407	1.979
F3	10	24.416	27.94	25.889	25.591	0.363	1.148	1.318
H4	10	24.922	28.216	26.303	26.238	0.362	1.143	1.307
I2	10	24.56	28.317	26.576	26.431	0.43	1.361	1.851
M3	5	27.623	29.281	28.64	28.829	0.366	0.732	0.535



This box plot, based upon data collected during CT DEEP surveys from January 1991-September 2011 (n=317, 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 1991-September 2011 (n=317, 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.

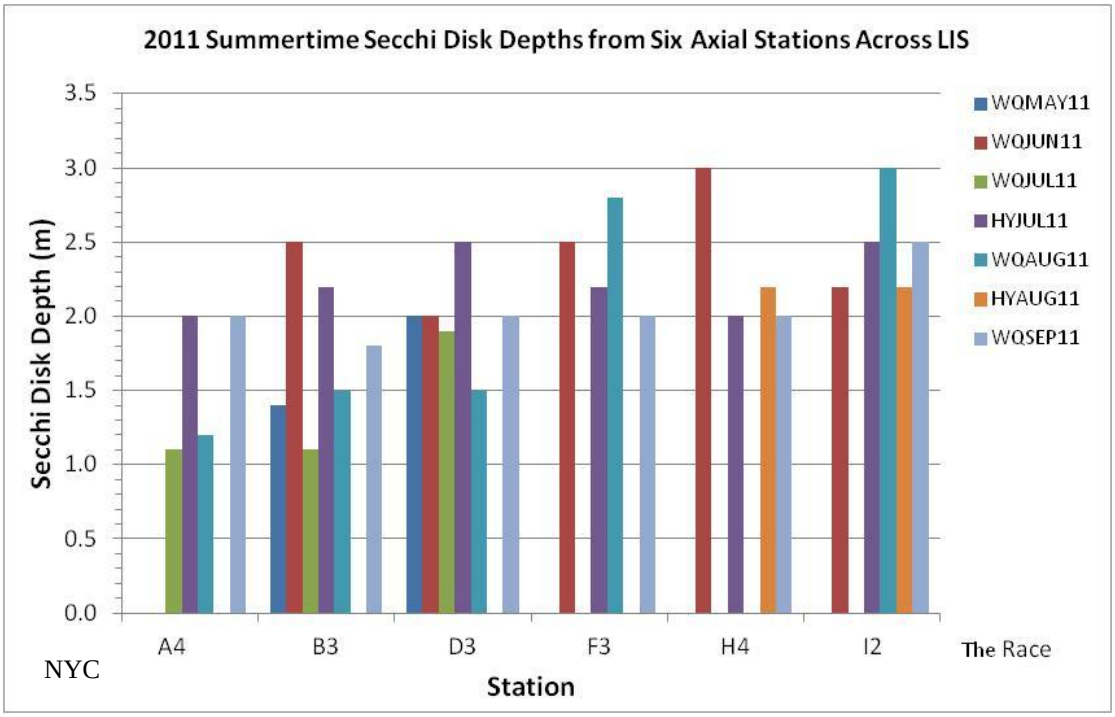




This time series plot illustrates the temporal variability of the mean salinity values by station from January-September 2011.

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, 2,163 measurements have been entered into our database; of those 1256 are from the 17 stations sampled annually. The 2000-2011 average Secchi depth is 2.44 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 2011.



2010 data

- **Average Secchi Disk Depth: 2.68 m (n=174)**
- **Minimum Secchi Disk Depth: 0.9 m at Station B3 during the WQSEP10 cruise**
- **Maximum Secchi Disk Depth: 6.1 m at Station F3 during the HYAUG10 cruise**

2011 data

- **Average Secchi Disk Depth: 2.16 m (n=157)**
- **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 DEP upgraded its SeaCat Profilers and began collecting and reporting pH data in August 2010. Data are summarized below.

	Surface			
Cruise	Max	Min	Avg	Count
HYAUG10	8.22	7.50	8.00	34
WQSEP10	8.34	7.67	8.15	28
WQOCT10	8.13	7.84	8.03	16
WQNOV10	8.24	8.02	8.16	15
WQDEC10	8.23	8.06	8.16	14
WQJAN11	8.32	8.06	8.23	14
WQFEB11	8.61	7.96	8.27	15
WQMAY11	8.81	7.58	8.52	18
WQJUN11	8.04	7.06	7.66	16
HYJUN11	7.89	7.34	7.72	21
WQJUL11	8.36	7.61	7.95	32
HYJUL11	7.98	7.38	7.83	39
WQAUG11	8.28	7.72	8.01	40
HYAUG11	7.96	7.40	7.71	37
WQSEP11	8.19	7.37	7.95	31

	Bottom			
Cruise	Max	Min	Avg	Count
HYAUG10	7.98	7.51	7.74	34
WQSEP10	8.18	7.52	7.79	28
WQOCT10	8.07	7.89	8.01	16
WQNOV10	8.25	8.04	8.15	16
WQDEC10	8.21	8.07	8.15	16
WQJAN11	8.34	8.18	8.25	16
WQFEB11	8.76	8.12	8.43	16
WQMAY11	8.64	8.22	8.52	18
WQJUN11	7.80	7.26	7.59	16
HYJUN11	7.62	7.44	7.56	21
WQJUL11	7.76	7.31	7.57	28
HYJUL11	7.82	7.32	7.61	39
WQAUG11	8.05	7.38	7.74	39
HYAUG11	7.79	7.45	7.60	38
WQSEP11	8.07	7.39	7.78	32

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