HARBOR HEALTH STUDY

Harbor Watch | 2021

Harbor Health Study: 2021

*The Harbor Health Study is a collaborative effort between **Harbor Watch, Copps Island Oysters, and East Norwalk Blue** to collect data on the ecosystem health of local embayments.*

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This report includes data on:
Demersal fish in Norwalk Harbor and water quality in Stamford Harbor, Five Mile River Harbor, Norwalk Harbor, Saugatuck Harbor, Bridgeport Harbor (Johnsons Creek and Lewis Gut), Housatonic River, and New Haven Harbor (Quinnipiac River)

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About Harbor Watch

The mission of Harbor Watch is to improve water quality and ecosystem health in Connecticut.

Each day we strive to reach this goal through research in the lab and field, collaboration with our municipal partners, and education of students and the public. Harbor Watch addresses pollution threats to Long Island Sound and educates the next generation of scientists through hands-on research and experiential learning. As part of the larger organization of Earthplace, the work performed by Harbor Watch also supports the mission of Earthplace to build a passion in our community for nature and the environment through education, experience, and action.

Since its inception, Harbor Watch has trained over 1,000 high school students, college interns, and adult volunteers in the work of protecting and improving the biological integrity of Long Island Sound and has monitored hundreds of sites for a variety of physical and biological parameters.

Visit www.harborwatch.org for more information!

About East Norwalk Blue

A non-profit focused on pollution prevention in the Western Long Island Sound through on-the-water and land-based programs which serve to protect natural resources in the local coves and bays.

We work to redirect marine based pollution to the proper wastewater treatment facilities through our on-the-water free mobile pumpout service operating along the North Shore of the Western portion of the Long Island Sound. Localized water degradation from vessel waste tank dumping in the Sound creates environmental and health issues to shellfish consumers, swimmers and boaters. We also support monitoring activities to help identify polluters, provide advocacy in teaching the boating community best practices in boating cleanliness, facilitate island cleanups among the many islands in the western portions of the Sound, and assist local not-for-profits in their endeavors to achieve a swimmable and fishable Long Island Sound.

Visit www.eastnorwalkblue.org for more information!

Acknowledgements

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Introduction

Harbor Watch is a water quality research and education program based out of Earthplace in Westport, CT. Our mission is to improve water quality and ecosystem health in Connecticut. In this report, we present data from monitoring conducted in 2021 on the fish community in Norwalk Harbor, Connecticut, led by Harbor Watch, as well as water quality conditions in 7 harbors along the Connecticut coast, led by our partner at Copps Island Oysters and East Norwalk Blue, Richard Harris.

Harbor Watch began conducting a dissolved oxygen profile study in Norwalk Harbor in 1986. A fish study of that harbor was added in 1990 under the guidance of the State of Connecticut's Department of Environmental Protection (now known as the Department of Energy and Environmental Protection) Fisheries Bureau. Since then, the program has grown to include the study of up to 7 harbors annually for dissolved oxygen conditions and Norwalk Harbor for fish.

From April through October 2021, water quality data were collected in 7 harbors (Stamford, Five Mile River, Norwalk, Saugatuck, Bridgeport, Housatonic River, and New Haven Harbor), and the fish study was conducted in one harbor (Norwalk). All 7 harbors were monitored for dissolved oxygen, salinity, water temperature, turbidity, and chlorophyll *a*. Dissolved oxygen is important for the survival of estuarine species; low oxygen or "hypoxic" conditions can impede the use of a harbor as habitat. Water temperature is another critical ecosystem parameter because many species require specific temperature ranges for spawning and survival. Chlorophyll *a* measures the presence of phytoplankton and other photosynthetic organisms in the water, which are important food resources. Finally, fish can be used as an indicator of harbor health and the harbor's functionality as a refuge.

1. Norwalk Harbor Fish Survey

Report written by: Nicole C. Spiller and Sarah C. Crosby
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Norwalk Harbor is an active harbor, used year-round both commercially and recreationally. The harbor is most recognized for its renowned shellfishing industry, which has risen to national prominence since the 1800s. Within the local community, the harbor is also known for its beaches, dining, boating, and other attractions. Positioned just outside the harbor are the Norwalk Islands, which help to protect the inner harbor from the effects of extreme weather events like hurricanes. These islands are part of the Stewart B. McKinney National Wildlife Refuge and serve valuable and important environmental roles to the harbor (Steadman et al., 2016).

During Harbor Watch's 30 years of studying fish in the harbor, there has been a notable increase in development along the harbor banks. As a result of shoreline hardening, there has been a reduction in riparian buffer and loss of salt marshes (personal observations, R. Harris). These factors have potentially contributed to an altered composition of the benthos, from healthy microalgal populations to a silty bottom, particularly in the upper harbor. A shift in animal species found in Norwalk Harbor has also been observed. There appears to have been an increase of Canada geese, osprey, swans, and cormorants (personal observations, R. Harris). Similarly, Harbor Watch has observed changes in fish diversity since 1990 (Figure 1.4).

Estuaries provide refuge, habitat, and other services to many species. Because of their sensitivity to environmental conditions, fish can be used as an indicator to assess the health of an estuary. In Norwalk Harbor, *Pseudopluronectes americanus* (winter flounder) is of particular interest because it is a commercially viable species that uses embayments to spawn. Abundance (catch per trawl) has declined dramatically for this species during recent years (Crosby et al., 2018c).

Harbor Watch and a dedicated network of volunteers, including the Wilton High School Marine Biology Club, have been quantifying the abundance and species composition of fish in Norwalk Harbor, focusing on demersal species. Sampling was conducted from 1990 through 1994. Trawling was not conducted from 1995-2001, but was resumed in 2002 and has continued annually since. It should be noted that the inner harbor was dredged in 2006 and the outer harbor was dredged in 2010 which may have impacted the study (Figure 1.4). In 2020, the monitoring season did not begin until July due to the Covid-19 pandemic which resulted in a shorter season than other years.

Please see our recently published paper in* Estuaries and Coasts *for an in-depth analysis:
Crosby SC, Cantatore NL, Smith LM, Cooper JR, Fraboni PJ, & Harris RB (2018) Three Decades of Change in Demersal Fish and Water Quality in a Long Island Sound Embayment. *Estuaries and Coasts*, 41: 2135–2145.

Norwalk Harbor Fish Survey Methods

Protocols used in trawling events followed those in Quality Assurance Project Plan (QAPP) RFA #20029 for 1m Beam Trawl Harbor Survey approved by the EPA on 5/14/21. Due to the Covid-19 pandemic, the sampling times and days deviated from those listed in the QAPP.

Trawling was conducted from the R.V. Annie, a 26’ converted oyster scow equipped with a pot hauler for trawl retrieval. The crew was comprised of 2 Harbor Watch staff members who served as pilot and deck hand. They were joined by up to 4 additional staff and/or trained volunteers to assist the deck hand. A grid system that divided the harbor into twenty 300m^2 sampling areas (Figure 1.1) was used to identify the location in the harbor where each trawl was conducted. This grid system was established by the CT DEEP in 1990 when the study started. During each trawling session, typically a minimum of 3 of those 20 “boxes” were selected to trawl, one in the upper harbor (box A-F), one in the middle harbor (box G-N), and one in the outer harbor (box O-T). When the research vessel was positioned within the selected box, the 1m beam trawl was launched off the starboard stern. The trawl, which was connected to the boat by approximately 13 meters of line, was equipped with a tapered ¼” mesh net, tickler chain, and rescue buoy. Each box was trawled for 3 minutes at 3 miles per hour. Coordinates were recorded where the trawl was launched and where it was retrieved. At the end of 3 minutes, the trawl was pulled back onto the boat using the pot hauler. The net was removed from the trawl and emptied into a sorting bin. The catch was recorded by species and the number of individuals caught. The total length of each individual fish caught was also recorded to the nearest millimeter using a ruler. Invertebrates were also identified and counted. All organisms present in each trawl net were returned to the harbor following identification and counting.

Over the study’s 30 years, there has been slight variance in data collection due to weather patterns, fish kills, boat repairs, occasional requests from the CT DEEP for Harbor Watch to trawl outside of Norwalk Harbor, and a pandemic which disrupted trawling activity. To standardize the data and enable comparisons from year to year, data are reported as “catch per trawl” or the total number of fish caught in a period of time divided by the total number of trawls conducted during that same time period.

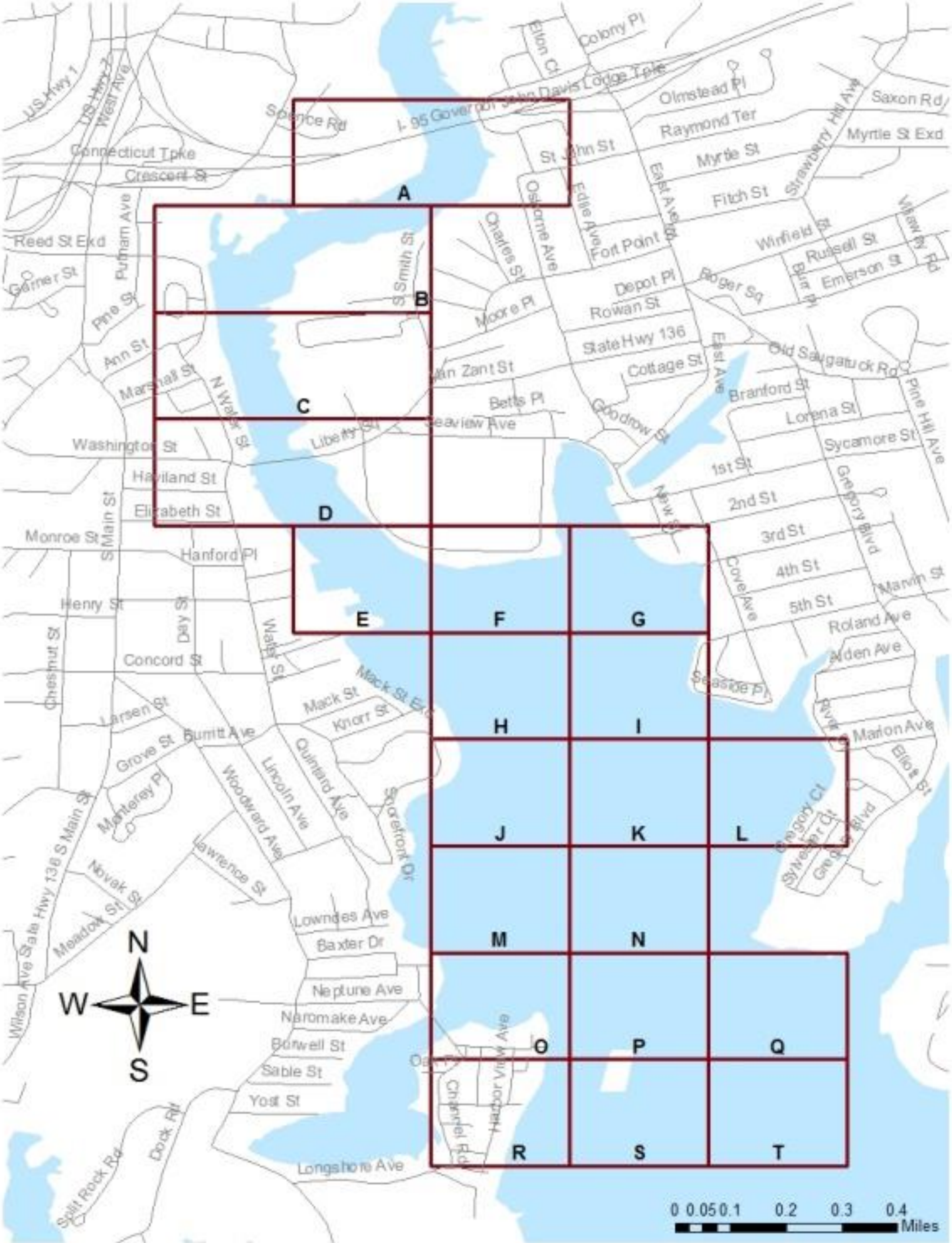

Figure 1.1. Location of trawl sampling areas or “boxes” within Norwalk Harbor.

Norwalk Harbor Fish Survey Results and Discussion

Fish

During the 2021 sampling season, 171 individual fish from 16 different species were caught in Norwalk Harbor. The 3 most abundant species caught in 2021 were porgy (*Stenotomus chrysops*), sea robin (*Prionotus spp.*), and winter flounder (*Pseudopleuronectes americanus*), which accounted for 66% of the total number of individuals (Figure 1.2). Fish were observed in all 19 boxes sampled. Trawling was not conducted in box "D" due to underground cable which is present in the box. Box "I" had the greatest number of fish per trawl during 2021 with 24 individuals caught in four trawls. While sampling was typically conducted in the upper, middle, and outer harbor during each trawling trip, tidal cycles impeded access to some of the boxes during some sampling sessions as they were inaccessible during low tide (Table 1.1).

Table 1.1. Total number of trawls per box, May through October 2021. No trawling was conducted in box D due to a cable crossing

Box	# of Trawls
A	3
B	4
C	4
D	0
E	5
F	4
G	4
H	4
I	4
J	4
K	4
L	3
M	2
N	3
O	3
P	4
Q	3
R	3
S	3
T	4

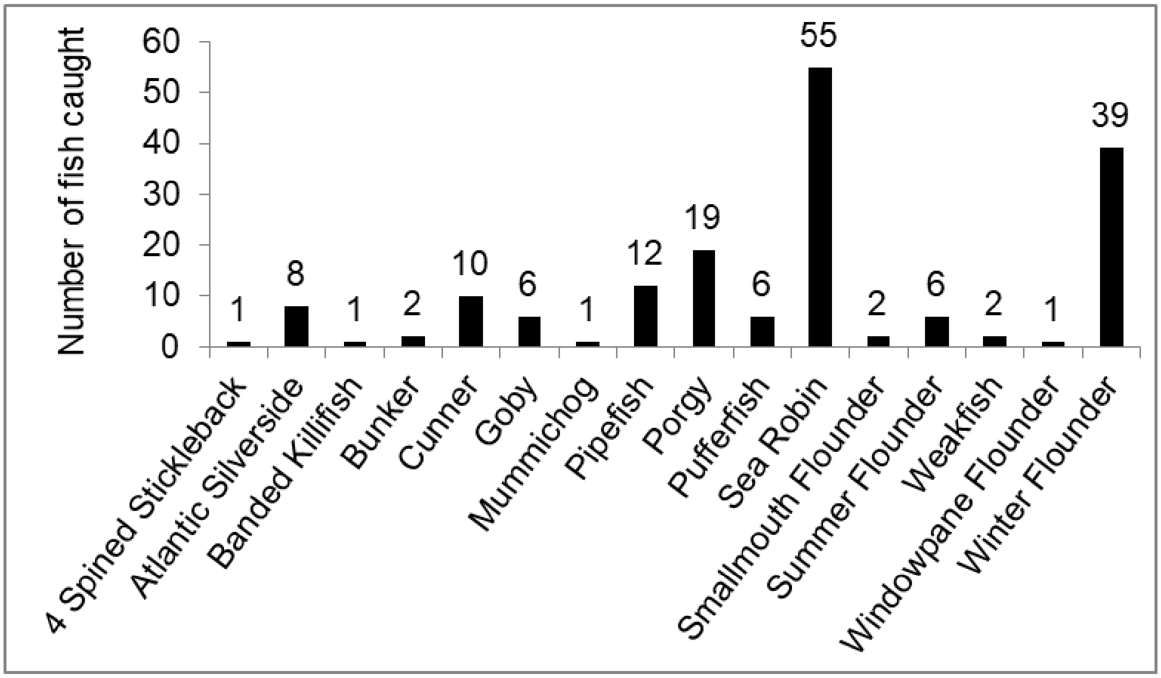

Figure 1.2. Total number of individuals caught for each species in Norwalk Harbor, May through October 2021.

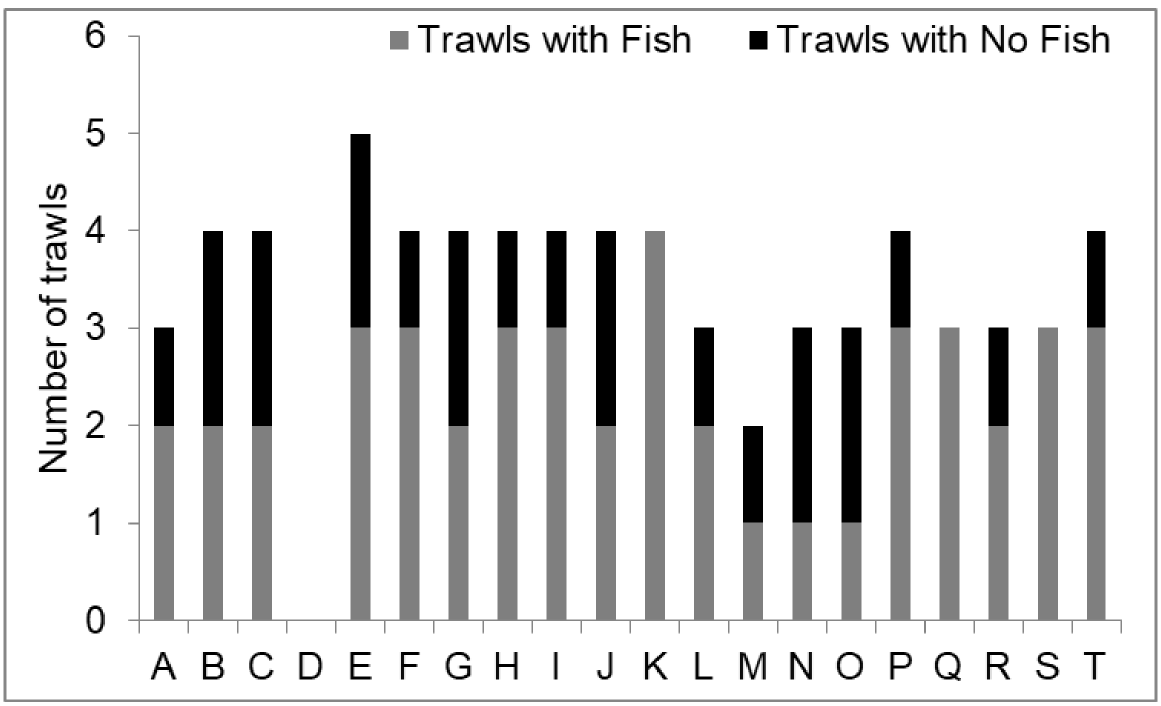

Figure 1.3. Number of trawls with fish or without fish in each "box" in Norwalk Harbor, May through October 2021. No trawling was conducted in box D due to a cable crossing.

The overall number of fish per trawl in 2021 was 2.51 fish which was higher than 2020, but still relatively low compared to prior years in the early 2000s and 2010s. Potential drivers of the apparent decline in catch over time may include increasing water temperature, low dissolved oxygen values, or predation from other species inhabiting the estuary (with an observed increase in the number of cormorants; personal observation R.B. Harris). Additional research is needed to evaluate the contribution of these and other factors, and this study is expected to continue in 2022.

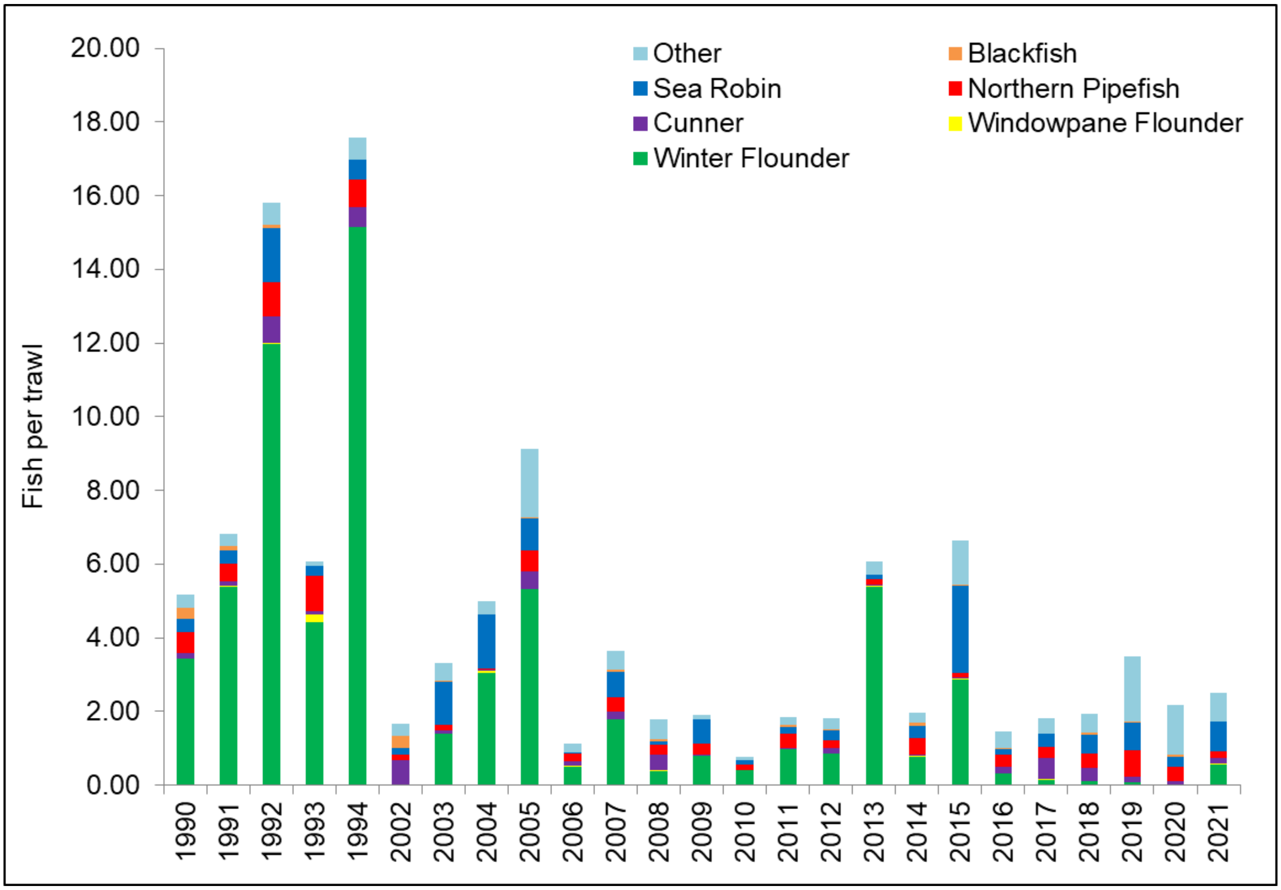

Figure 1.4. Number of fish caught per trawl (total number of individuals divided by total number of trawls) of select species of interest from 1990 to 2021 in Norwalk Harbor.

Table 1.2 Catch per trawl for select species of interest from 1990 to 2021 in Norwalk Harbor

	Winter Flounder	Windowpane Flounder	Cunner	Pipefish	Sea Robin	Blackfish	Other	Total
1990	3.44	0.00	0.14	0.58	0.35	0.30	0.37	5.19
1991	5.38	0.03	0.12	0.48	0.36	0.12	0.33	6.83
1992	11.97	0.05	0.70	0.93	1.47	0.10	0.58	15.80
1993	4.42	0.23	0.07	0.96	0.26	0.01	0.12	6.07
1994	15.14	0.00	0.55	0.76	0.52	0.00	0.62	17.59
2002	0.00	0.00	0.67	0.17	0.17	0.33	0.33	1.67
2003	1.39	0.00	0.09	0.17	1.15	0.02	0.50	3.33
2004	3.05	0.05	0.03	0.03	1.48	0.00	0.34	4.98
2005	5.33	0.00	0.48	0.56	0.85	0.04	1.85	9.13
2006	0.51	0.03	0.12	0.20	0.03	0.00	0.25	1.13
2007	1.78	0.00	0.22	0.39	0.70	0.04	0.52	3.65
2008	0.38	0.02	0.44	0.26	0.10	0.06	0.54	1.80
2009	0.79	0.00	0.03	0.29	0.66	0.00	0.12	1.90
2010	0.41	0.00	0.00	0.16	0.12	0.00	0.07	0.75
2011	0.97	0.00	0.05	0.38	0.18	0.05	0.20	1.84
2012	0.87	0.00	0.13	0.22	0.28	0.03	0.29	1.82
2013	5.37	0.03	0.02	0.16	0.12	0.00	0.35	6.06
2014	0.76	0.05	0.01	0.47	0.32	0.10	0.27	1.97
2015	2.88	0.01	0.03	0.13	2.36	0.03	1.21	6.65
2016	0.32	0.00	0.20	0.33	0.15	0.02	0.44	1.45
2017	0.14	0.01	0.58	0.32	0.34	0.01	0.41	1.82
2018	0.12	0.00	0.36	0.39	0.51	0.04	0.52	1.97
2019	0.08	0.00	0.14	0.73	0.75	0.01	1.79	3.51
2020	0.03	0.00	0.07	0.41	0.25	0.05	1.37	2.19
2021	0.57	0.01	0.15	0.18	0.81	0.00	0.79	2.51

Crustaceans

2,505 individual crustaceans representing 13 species were observed in 2021. The catch was dominated by mud crabs, sand shrimp, and shore shrimp, with those three species accounting for approximately 84% of the total (Figure 1.5). Individual speciation for mud crabs and spider crabs was not conducted. "Mud crab" identification represents potentially four species (*Panopeus herbsti, Hexapanopeus angustifrons, Neopanopeus sayi, and Eurypanopeus depresssus)* but was likely dominated by black fingered mud crab (*Panopeus herbsti*). "Spider crab" identification represents potentially two species (*Libinia emarginata* and *Libinia dubia*) but was likely dominated by the nine-spined spider crab (*Libinia emarginata*). Additional notable catches include the 163 blue crabs (*Callinectes sapidus*), which is more individuals caught than the previous 4 years combined (2017-2020 caught a total of 121 blue crabs), and the white shrimp (*Penaeus setiferus*), which has not been previously caught in Harbor Watch's trawls, but has been seen by local oystermen recently in Norwalk Harbor (personal observation, Jimmy Bloom).

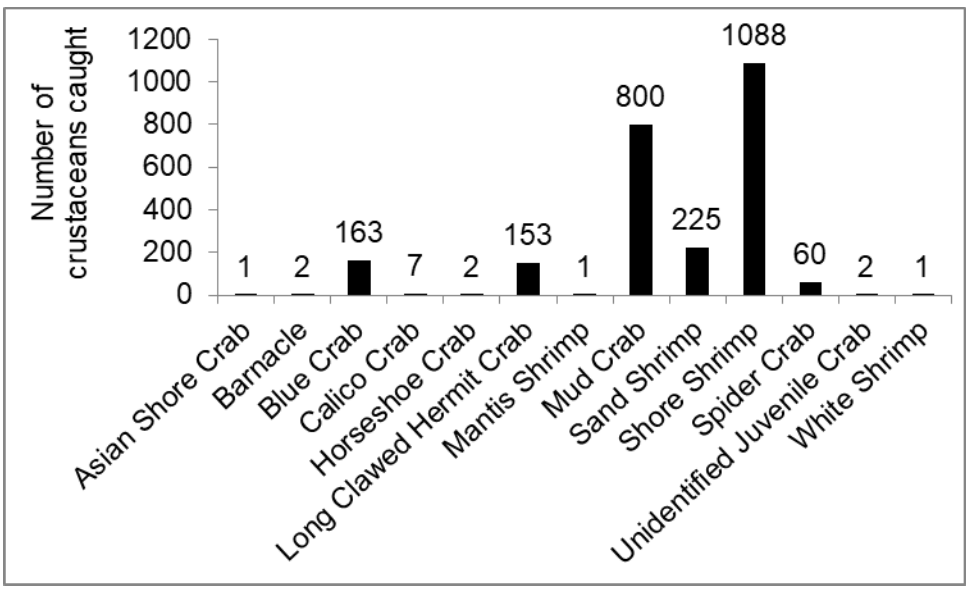

Figure 1.5. Crustaceans caught in Norwalk Harbor from May through October 2021.

2. Water Quality Surveys

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Norwalk Harbor, Saugatuck Harbor, Five Mile River Harbor, Stamford Harbor, Bridgeport Harbor (Johnsons Creek and Lewis Gut sections), Housatonic River, and New Haven Harbor (Quinnipiac River section) were studied in 2021. These harbors are used year-round for recreational activities such as boating, swimming, and fishing as well as for commercial activities and play an important role in the Long Island Sound shellfish industry. In 2021, monitoring of these 7 harbors was led by Richard Harris (formerly of Harbor Watch, now on staff at Copps Island Oysters), with assistance from Harbor Watch staff and volunteers.

Water quality surveys were conducted to evaluate harbor health and assess their ability to support marine life and in particular shellfish beds. The parameters measured in this study included dissolved oxygen, salinity, water temperature, water clarity, and chlorophyll *a*. In 2021, Norwalk Harbor had the greatest percentage of dissolved oxygen observations below 3 mg/L (7%) of the 7 harbors studied (Figure 2.3), indicative of hypoxic conditions that may be harmful to marine life. Norwalk Harbor has a history of extended periods of hypoxia in the upper reaches of the harbor. Hypoxia (defined as values < 3 mg/L) was not observed in Stamford Harbor, Five Mile River Harbor, Bridgeport Harbor, Housatonic River, or New Haven Harbor during this year's sampling. Saugatuck Harbor only had one reading less than 3 mg/L during the monitoring season.

The harbors monitored in this study are estuaries, which are marine embayments with a freshwater source (resulting in brackish water). The mixing of these freshwater and saltwater sources in many harbors consists of a "tidal wedge" (Figure 2.1), which is comprised of salt water underlying a freshwater surface layer, which is usually incoming water from a river. The more dense salt water layer oscillates laterally within the harbor in response to the semidiurnal tides. Because of this density-driven stratification within estuaries, the bottom water often becomes depleted of dissolved oxygen when exposed to oxygen demanding (reducing) bottom sediments and poor flushing. As fresh water moves seaward above the tidal wedge, salt water is entrained in the freshwater layer, reducing the stratification. This mixing of fresh and salt water occurs along the length of a harbor, with the salinity of the surface layer increasing as the distance from the freshwater source increases. Mixing of the salt water from the tidal wedge (Figure 2.1) causes a flow of marine water to enter the estuary, bringing nutrients and oxygen with it.

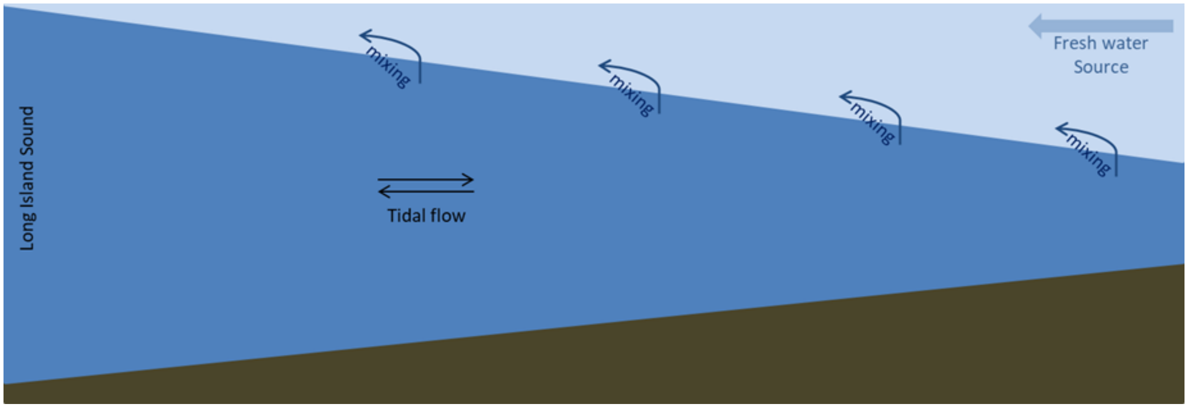


Figure 2.1. Sketch of estuary tidal wedge, water flow, and water column mixing.

Another factor assisting with the flushing of an estuary is the presence of salt marshes. Marshes provide large expanses of low-lying land that serve as a biological filter for the water flowing over and through them during flood tides. Ebb tides return this large volume of marine water to the main harbor channel, where it is then flushed out of the estuary. Unfortunately, all too often these valuable natural resources are filled in for shoreline development and are replaced with man-made bulk-heading. Three harbors monitored in this study, where large marshes are present and contribute to the improvement of local water quality, are New Haven Harbor (Quinnipiac River section), Bridgeport Harbor (Lewis Gut section), and the Housatonic River. In many harbors throughout New England, the majority of historic salt marshes have been reduced or lost (Bromberg and Bertness 2005).

Two natural forces that can affect flushing in a harbor are winds and air temperature. Strong winds, especially from the north, facilitate the movement of the surface layer of water seaward, and decreases in air temperature can drive vertical mixing by increasing the density of the surface waters causing them to sink. As the surface water sinks, it causes the (often oxygen-depleted) bottom waters to be forced upward (upwelling and downwelling). This vertical movement of water can help to increase oxygen concentrations at the bottom of the harbor.

Rainfall can have negative or positive effects on hypoxia in the harbors. Rain adds water to the system, which increases the flow and turbulence of the water on the surface which is one way for rivers and harbors to renew dissolved oxygen in the water column. Rain also increases flow within a river system which can increase vertical mixing and promote cycling within the tidal wedge, in turn increasing dissolved oxygen levels. Conversely, rain can be a conduit to flush nutrients and other pollutants into a waterway via runoff which negatively impacts dissolved oxygen levels. Excess nutrients (eutrophication) can cause plant growth which will initially add oxygen to the system, but as the plants begin to die and decompose the available dissolved oxygen is consumed, causing stressful conditions for many marine species.

Rainfall per month varied widely along the coast during 2021. The largest amount of rainfall fell during July (8.99 inches) with the smallest accumulation in June (1.93 inches), based on the mean of data from three rain gauges across the coast (Figure 2.2, Greenwich Town Hall Rain

Gauge, Norwalk Health Department Rain Gauge, Sikorsky Memorial Airport Rain Gauge). Rainfall totals were highest in the Norwalk area, totaling 32.59 inches from May through September (Greenwich Town Hall Rain Gauge, Norwalk Health Department Rain Gauge, Sikorsky Memorial Airport Rain Gauge).

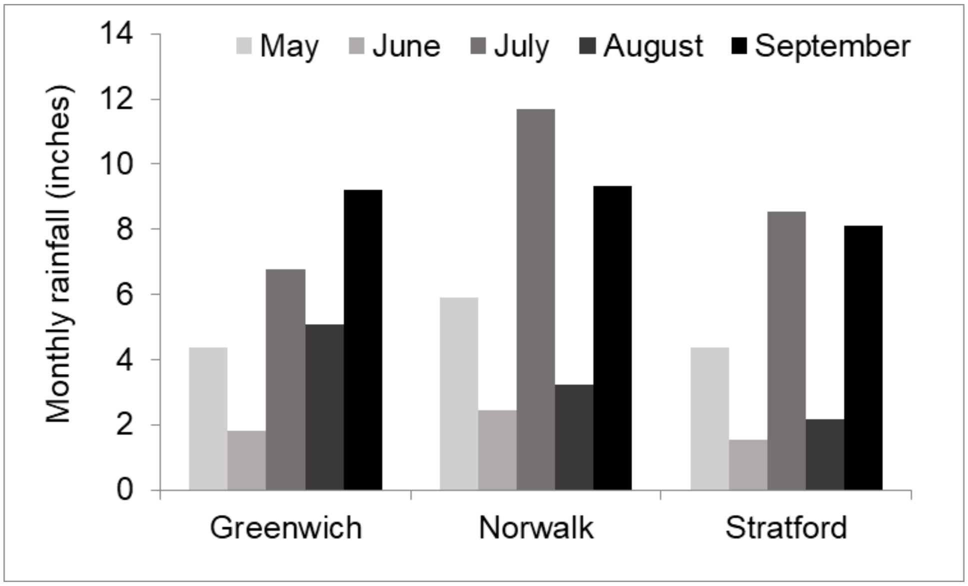
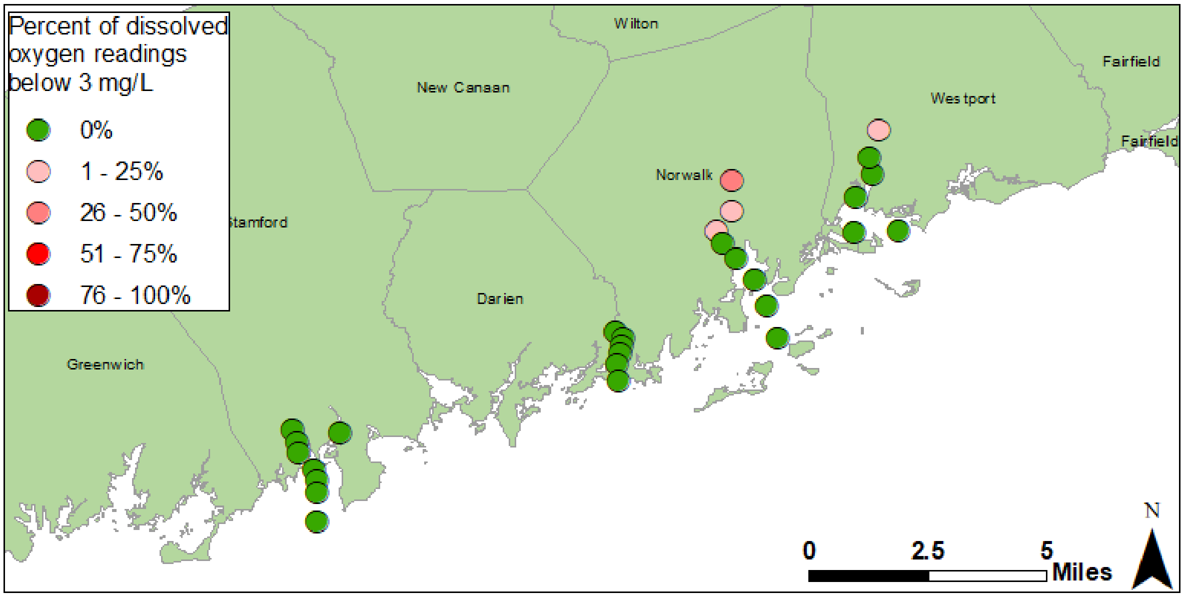


Figure 2.2. 2021 monthly rainfall totals for each geographical area monitored (Greenwich Town Hall Rain Gauge, Norwalk Health Department Rain Gauge, Sikorsky Memorial Airport Rain Gauge).

Observed chlorophyll *a* concentrations can indicate the quantity of phytoplankton in a marine environment and are used as a measure of the primary productivity of the system. Many different environmental conditions affect the abundance of phytoplankton present such as available nutrients, sunlight, temperature, and turbidity. Other influential factors can include harbor flushing rates, water depth, and the number of grazing animals in the water column. Phytoplankton blooms and seasonal die-off cycles should be considered when conducting a chlorophyll *a* assessment of an estuary (Bricker et al., 2003). The chlorophyll *a* results presented here should be considered a preliminary assessment only for the period of sampling (May to October). Additional year-round studies will be needed to fully assess the productivity status of these 7 harbors using chlorophyll *a*.

In recent years, conditions have varied across the harbors studied. In 2017, 81% of all sampling events had dissolved oxygen values at the harbor bottom above 3 mg/L (Crosby et al., 2018b). In 2018, conditions overall had improved, and in the following years, 93% of the observed bottom dissolved oxygen levels in all harbors monitored were observed to be above 3 mg/L each year (Crosby et al., 2018c, 2019b, 2020). In 2021, 97% of all sampling events had dissolved oxygen values at the harbor bottom above 3 mg/L.



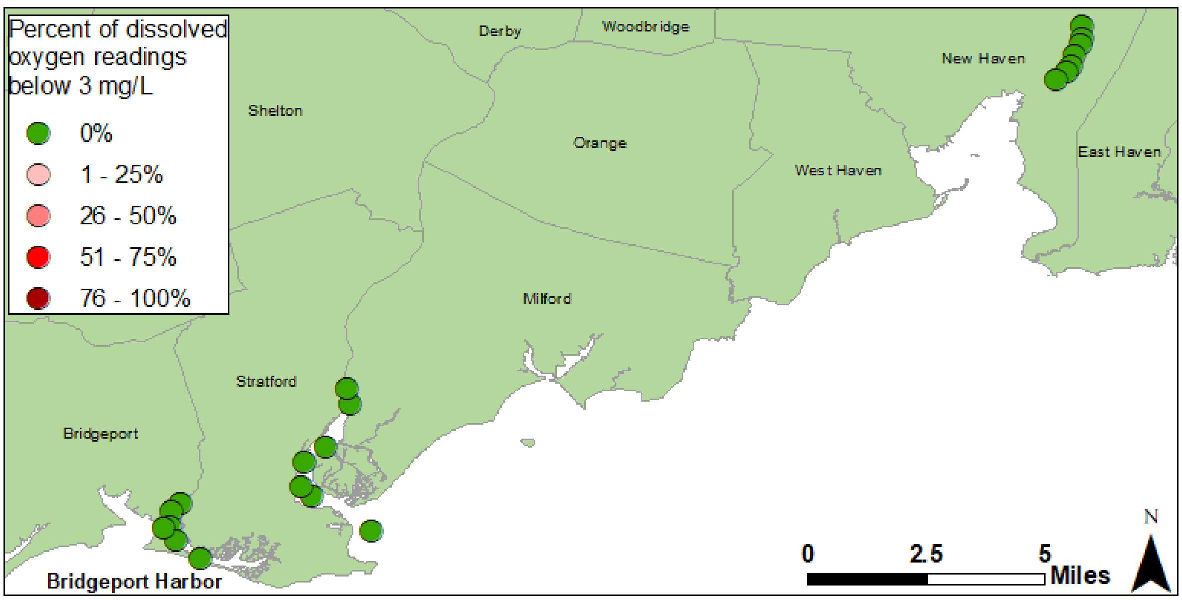


Figure 2.3. Percentage of water column readings where dissolved oxygen values fell below 3 mg/L in 2021 in the western harbors (top) and the eastern harbors (bottom).

Please note: *In the following pages, data for each harbor will be reported. Please note that the duration of the sampling season varied among harbors, such that mean values for the studied parameters may not be directly comparable among them. In particular, some harbors' datasets started later in the summer than others or had wider gaps between sampling events and as a result may have been less likely to capture oxygen-rich and/or low temperature conditions. These temporal differences should be kept in mind when interpreting the data and when comparing results with those of prior years.*

Water Quality Survey Methods

Water Quality Profiling:
Seasonal monitoring was conducted in each of the 7 harbors between April and October by Richard Harris and/or Harbor Watch staff, high school and college interns, employees of Copps Island Oysters and East Norwalk Blue, and volunteers. Each harbor had five to eight monitoring stations which were each tested a minimum of 6 times. Protocols used in all harbor surveys were designed to follow those in Quality Assurance Project Plan (QAPP) RFA #21035 for Fairfield County Embayment Profile Surveys approved by the EPA on 1/26/21. Slight deviations from the QAPP regarding the sampling design were encountered in 2021. Challenges posed by the tides, engine issues, and other reasons resulted in the inability to sample at the planned frequency of at least once per month in each harbor and additionally the season extended one day into April and October. Sampling often began later in the morning than the planned 8am start time that was stated in the QAPP. Also, sampling was not conducted in the outer Norwalk Harbor in 2021.

Testing for each harbor was conducted in the early to mid-morning on each monitoring day. A research vessel, staffed with a project leader (usually Richard Harris) and a crew of trained staff or volunteers proceeded to the first station in the estuary to begin testing. The dissolved oxygen meter was calibrated at the first station according to the manufacturer's recommendation (as in the QAPP). The probe was then securely attached to a weighted PVC platform which facilitated vertical descent of the probe into the water column, especially where strong currents existed. The platform was lowered over the side of the research vessel at each station and readings for dissolved oxygen, salinity, and temperature were recorded at the surface. Then the platform was lowered to a half meter below the surface and readings were recorded again. Readings were then recorded at each full meter interval below the surface until the bottom was reached. Ancillary data collection included readings for barometric pressure (first and last station only), wind speed with a Dwyer wind speed gauge, water clarity with a Secchi disk, air temperature with a Fisherbrand™ pocket thermometer, and a visual estimate of wave height.

Monitoring was typically conducted sequentially for all stations, unless the tide cycle during sampling dictated otherwise. The calibration was checked on the dissolved oxygen meter at the end of each survey to assure that significant calibration drift (± 2%) did not occur. Harbor surveys were completed within approximately 2 hours on each monitoring day.

Chlorophyll a *Sampling:*
Chlorophyll *a* samples were collected a minimum of 4 times for each harbor over the course of the monitoring season. Two water samples were taken at each station using a grab sampler for collecting a surface sample, and a 2.2 liter silicone Kemmerer water sampler for collecting a sample at 2 meters below the surface. All samples were collected in clean, opaque, one-liter plastic bottles, and stored on ice in a cooler. Upon returning to shore, water samples were transported to the water quality lab at East Norwalk Blue in East Norwalk. Using a graduated

cylinder, 50 mL of water from each sample bottle was poured into a filtration apparatus and vacuumed through a 20 mm glass filter. The filter was then folded in half, wrapped in aluminum foil, and labeled with harbor station information and the date of collection. Filters were frozen at -20 °C for storage. The filters were transported in batches on ice in a cooler to the Harbor Watch Laboratory in Westport, CT where they were analyzed by Nicole Spiller. Filtered samples were processed at the Harbor Watch Laboratory using a Turner Trilogy fluorometer employing a testing method modified by Welschmeyer (1994). Results were compared to the estuarine classification system described in Bricker et al., 2003 (Table 2.1).

Table 2.1. Chlorophyll *a* surface concentrations and resulting classifications for estuaries (from Bricker et al., 2003)

Classification	Concentration µg/L
Hyper-eutrophic	> 60 µg/L
High (eutrophic)	> 20 µg/L, ≤ 60 µg/L
Medium (eutrophic)	> 5 µg/L, ≤ 20 µg/L
Low (eutrophic)	> 0 µg/L, ≤ 5 µg/L

Rainfall:

Rainfall data were collected at individual rain stations and reported online. Rainfall for Norwalk, Saugatuck, and Five Mile River Harbors was assessed using the Norwalk Health Department website (Norwalk Health Department Rain Gauge). Stamford, Bridgeport, Stratford, and New Haven rainfall was taken from the Weather Underground website (Weather Underground Historical Weather).

Results and Discussion

A. Stamford Harbor

Stamford Harbor is a large estuary with two freshwater sources discharging to two main channels, the east branch and the west branch. The west branch receives the freshwater discharge of the Rippowam River, whereas the east branch receives approximately 24 million gallons per day in discharge of treated effluent from the Stamford wastewater treatment plant (City of Stamford Website: "The Plant"). With the exception of differences in freshwater input, both east and west branches are similar regarding anthropogenic use of the shoreline. Both channels are largely devoid of natural riparian features, which have long since been replaced by shoreline fill and commercial bulk-heading that has been punctuated with storm drain outfalls. Commercial sand and gravel and industrial facilities are located near the northern ends on both branches (Figure 2.A.1). Industrial uses requiring barge deliveries and tug boat traffic can be heavy at times in these restricted waterways. Down both branches and below the industrial sections, there is a change in land use. The west branch has marinas on both shorelines while the east branch has marinas on its east bank with Kosciuszko Park on the opposite shore.

Figure 2.A.1. Industrial development and barge traffic on the east branch of Stamford Harbor.

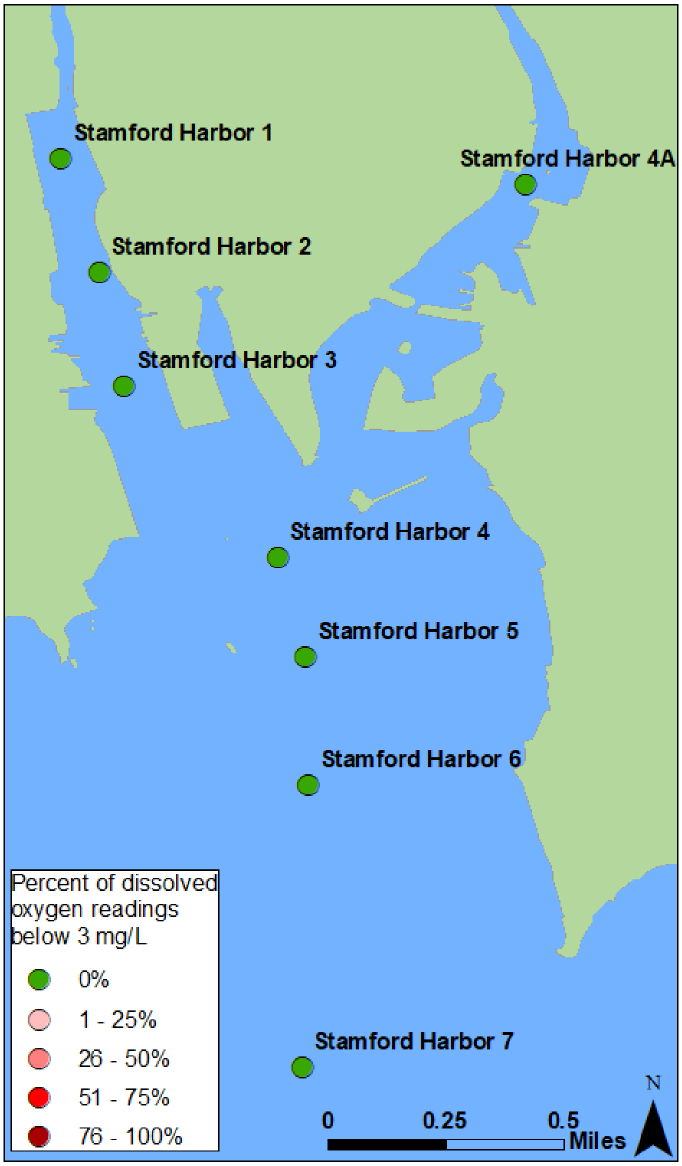


Figure 2.A.2. Map of Stamford Harbor sampling stations for 2021. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L.

Table 2.A.1. Coordinates and descriptions for each sampling station in Stamford Harbor

Site Name	Latitude	Longitude	Description
Stamford Harbor 1	41.041283	-73.545000	Off Sand and Gravel Facility
Stamford Harbor 2	41.037817	-73.543833	Stamford Harbor West Branch Channel Buoy #10
Stamford Harbor 3	41.034350	-73.543083	Stamford Harbor West Branch Channel Buoy #7
Stamford Harbor 4	41.029150	-73.538400	Stamford Harbor West Branch Channel Buoy #1
Stamford Harbor 4A	41.040500	-73.530850	East branch off Woodland Cemetery
Stamford Harbor 5	41.026100	-73.537550	Stamford Harbor Channel Buoy #9
Stamford Harbor 6	41.022183	-73.537450	Stamford Harbor Channel Buoy #7
Stamford Harbor 7	41.013600	-73.537650	No Wake Buoy

Dissolved Oxygen
Profiles of the water column were taken at 8 sites along the length of the Harbor (Figure 2.A.2, Table 2.A.1). Sampling occurred on 6 days during the monitoring season from May through August. Mean dissolved oxygen values in Stamford Harbor ranged from a minimum of 4.68 mg/L on the bottom at Stamford Harbor 1 to a maximum of 7.45 mg/L on the surface at Stamford Harbor 6 (Figure 2.A.3). There were larger mean differences observed between the surface and bottom dissolved oxygen levels in the upper end of the channels than the east lower half of the harbor (Figure 2.A.3). Over the course of the monitoring season, there was a seasonal downward trend in dissolved oxygen values at both the surface and the bottom as the summer progressed (Figure 2.A.4). Thirty-one percent of the bottom dissolved oxygen concentrations observed were less than 5 mg/L, and none were less than 3 mg/L (hypoxic).

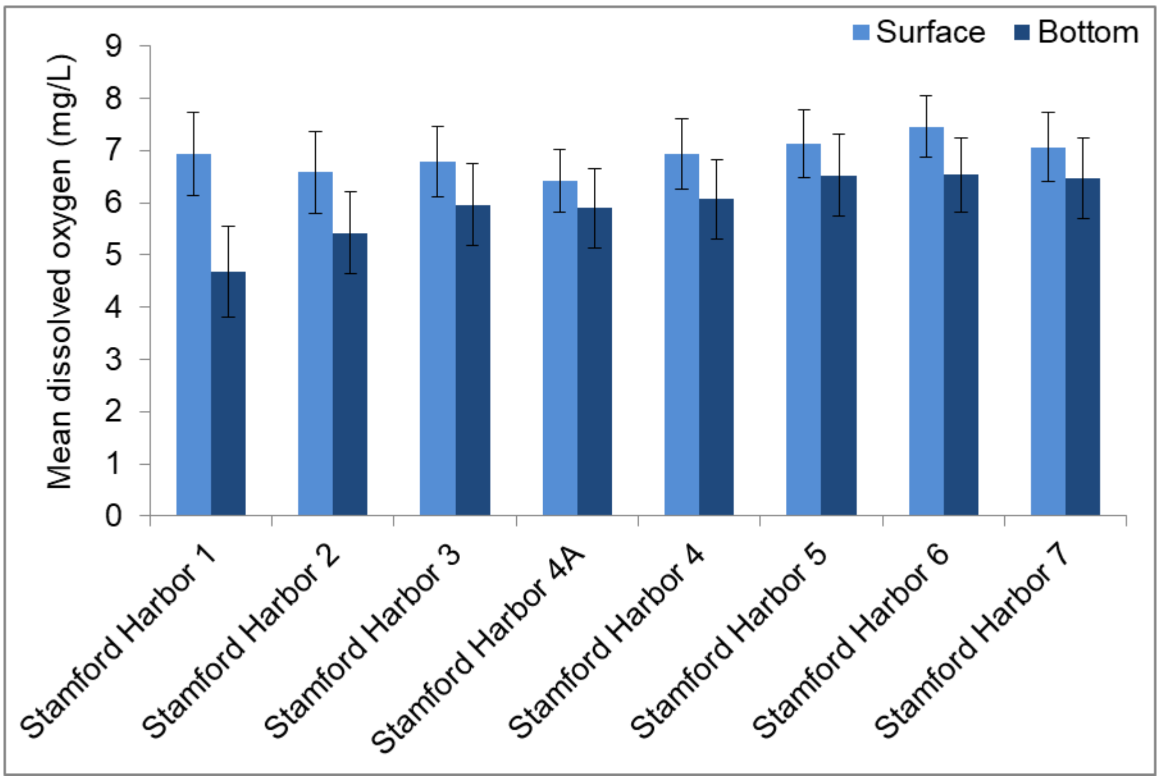


Figure 2.A.3. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in Stamford Harbor in 2021. Error bars represent standard error.

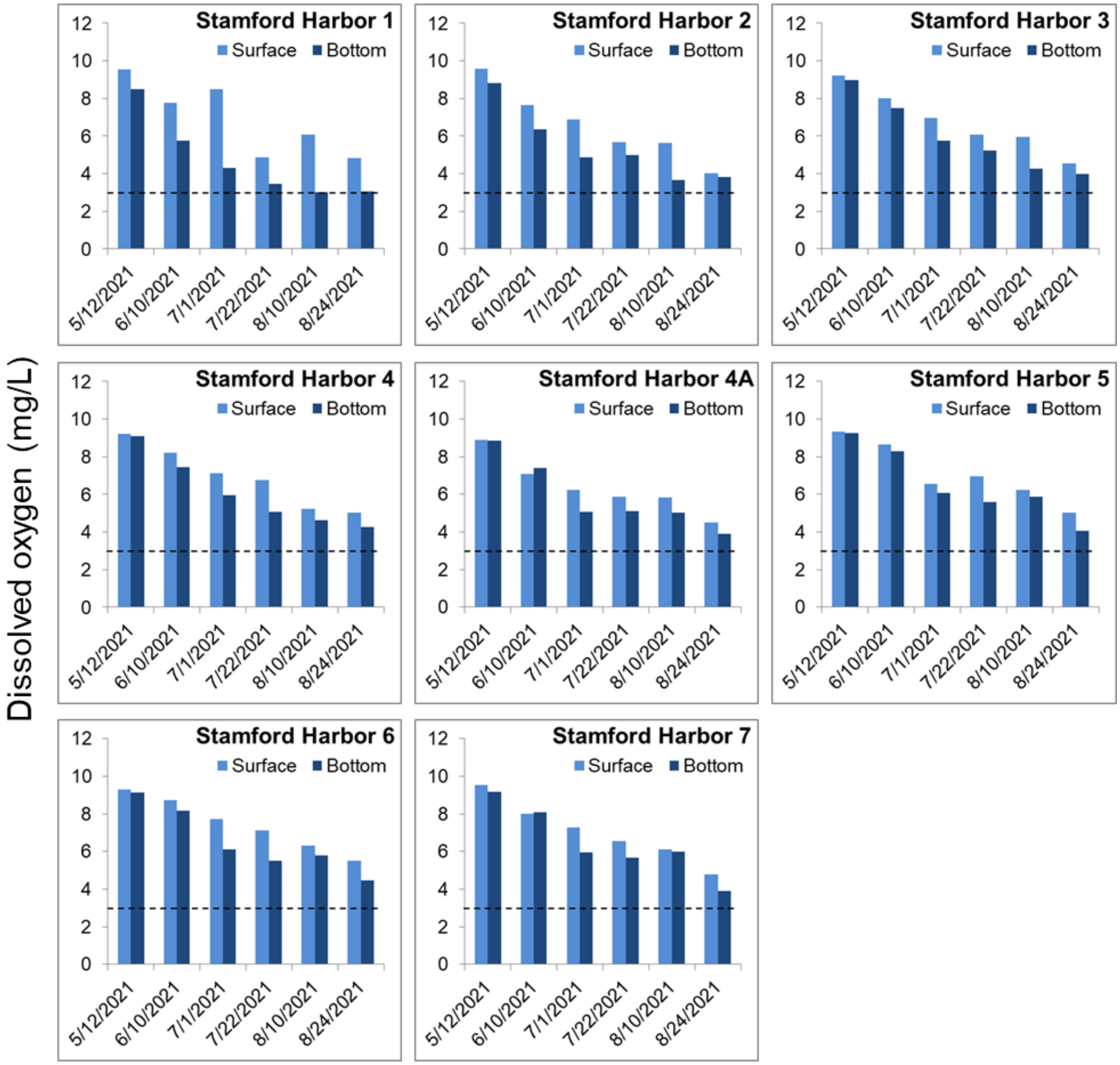


Figure 2.A.4. Surface and bottom dissolved oxygen values at each Stamford Harbor sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Please note x-axis is not to scale.

Chlorophyll a

Chlorophyll *a* samples were taken on 5 of the 6 Stamford Harbor sampling dates (Figure 2.A.5). It is important to note that chlorophyll *a* samples were collected on 6/2/21 independent of dissolved oxygen profile data. The harbor was classified in the medium or highly eutrophic range in 2017, medium eutrophic classification in 2018 and 2019, and medium or highly eutrophic again in 2020 (Table 2.1). In 2021, mean surface chlorophyll *a* values classified the harbor as medium eutrophic (Figure 2.A.5).

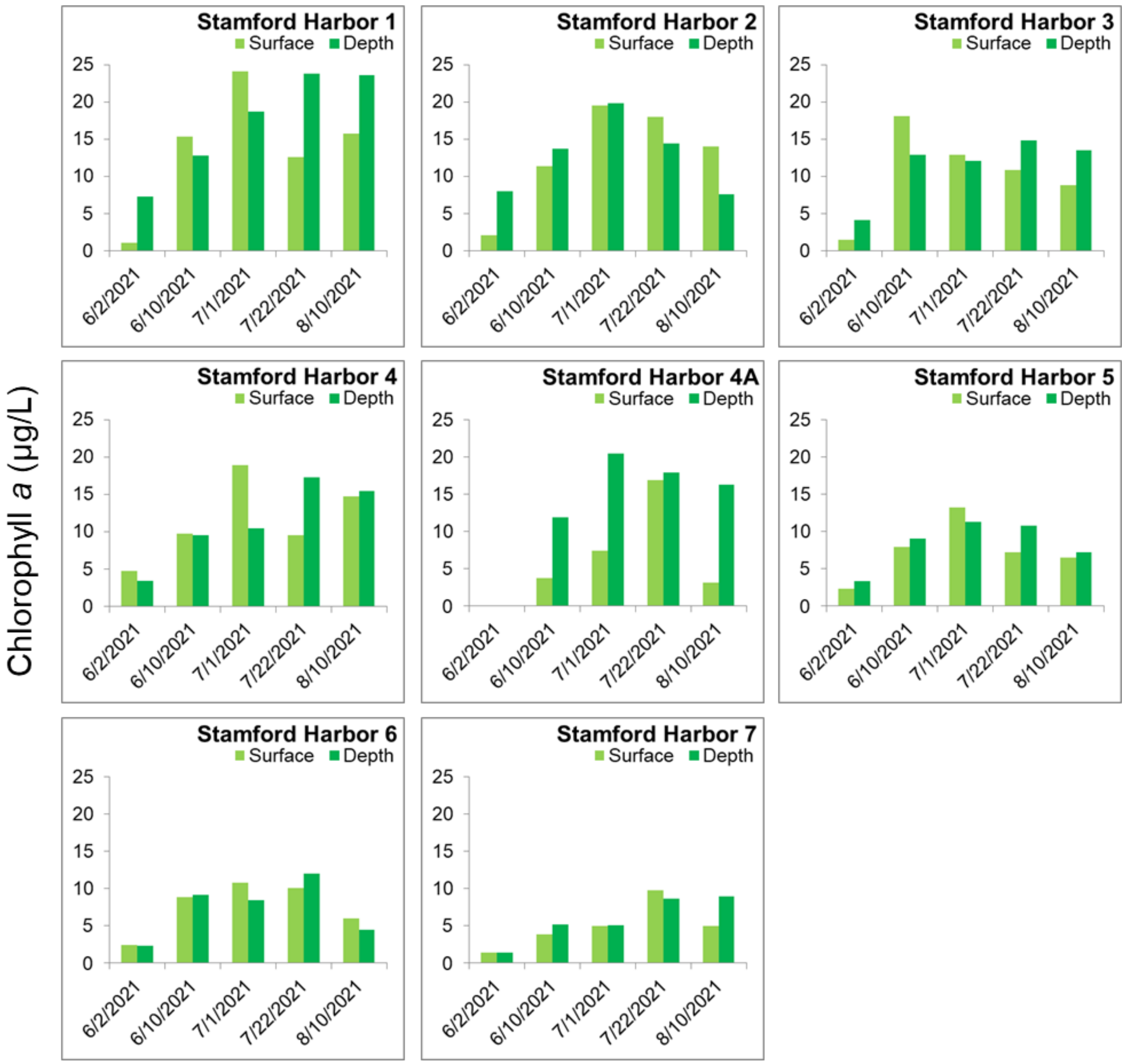


Figure 2.A.5. Surface and depth chlorophyll *a* values in Stamford Harbor in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale.

Water Clarity

Mean secchi depth readings ranged from a minimum of 1.28m at station Stamford Harbor 1 to a maximum of 1.82m at station Stamford Harbor 7. Mean values increase as the stations move further out into the harbor.

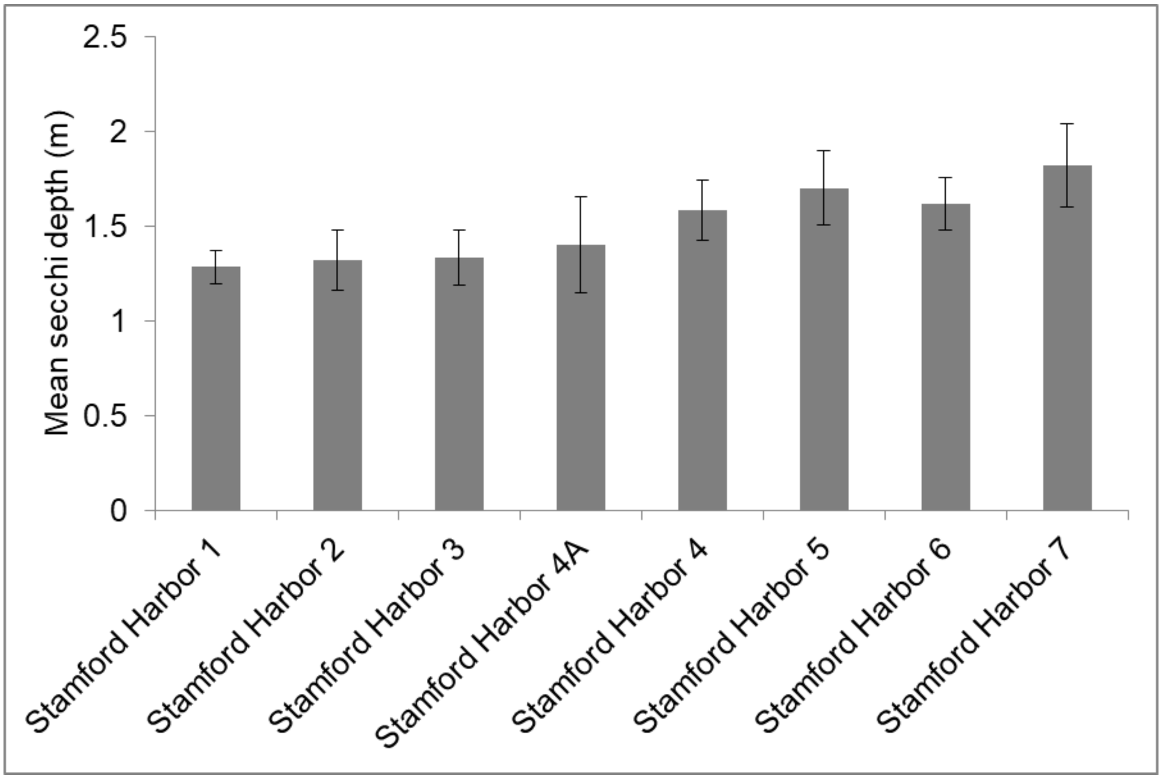
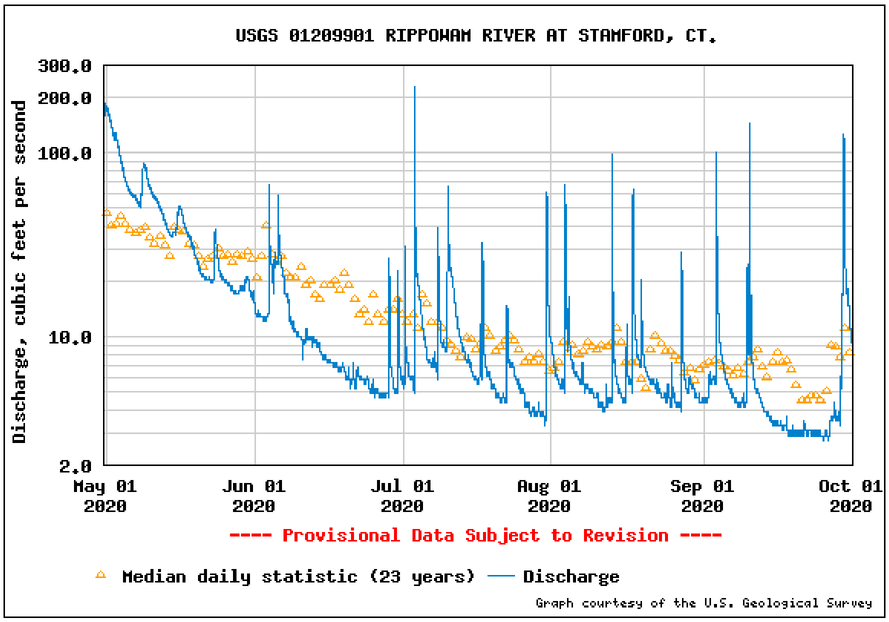


Figure 2.A.6. Mean secchi depth readings in Stamford Harbor in 2021. Error bars represent standard error.

Rippowam River Discharge

The figures below illustrate discharge in cubic feet per second recorded at the United States Geological Survey (USGS) monitoring station on the Rippowam River in Stamford, CT. Yellow triangles represent the daily median value over the last 23 years, and the blue line represents the recorded discharge for a particular date. In the summer of 2021, discharge was observed to be higher than was observed in 2020.



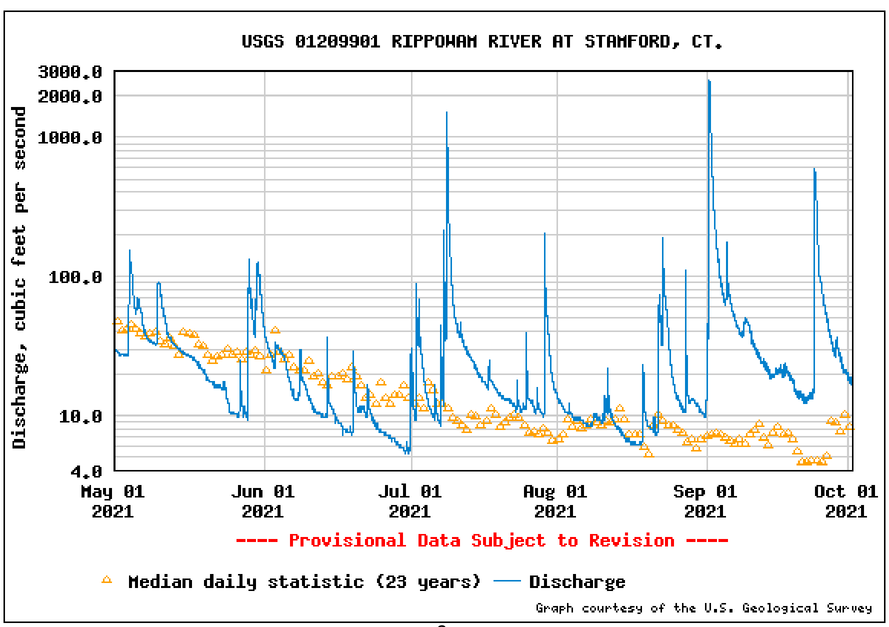


Figure 2.A.7. USGS flow data in ft^3/s for the period of May 1 through October 1, 2020 (top) and 2021 (bottom) for the Rippowam River near Stamford, CT (Graphs courtesy of the U.S. Geological Survey). Please note the difference in scale on the y-axis.

Temperature and Salinity

Temperature differences observed between the surface and the bottom were similar throughout the harbor (Figure 2.A.8). Lower surface salinity at station Stamford Harbor 1 likely reflects seasonal riverine and stormwater inputs to the upper reaches of the harbor on the west branch (Figure 2.A.9). Lower surface salinity at station Stamford Harbor 4A is likely a result of constant fresh water flow of treated sewage effluent, estimated at 24 million gallons per day, to the east branch.

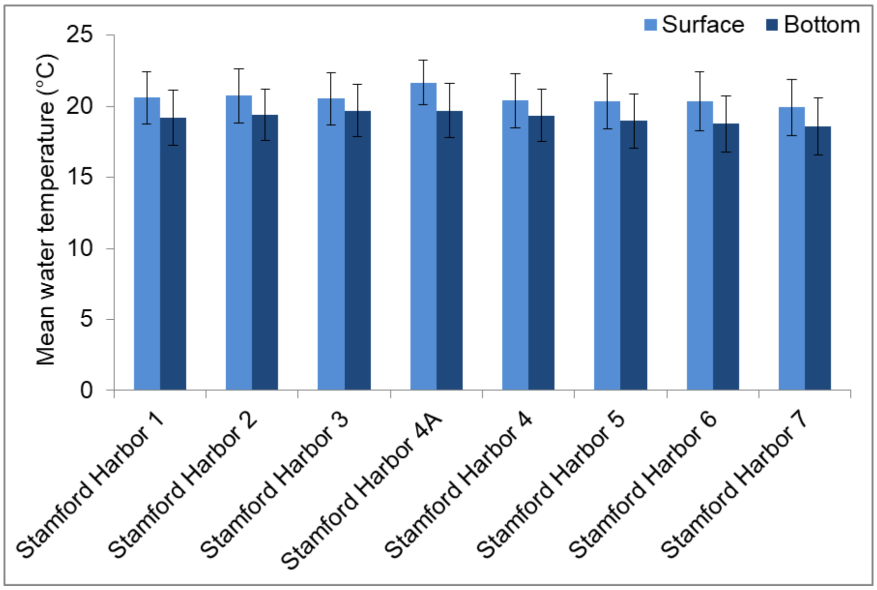


Figure 2.A.8. Mean water temperature at the surface and bottom at each sampling station in Stamford Harbor in 2021. Error bars represent standard error.

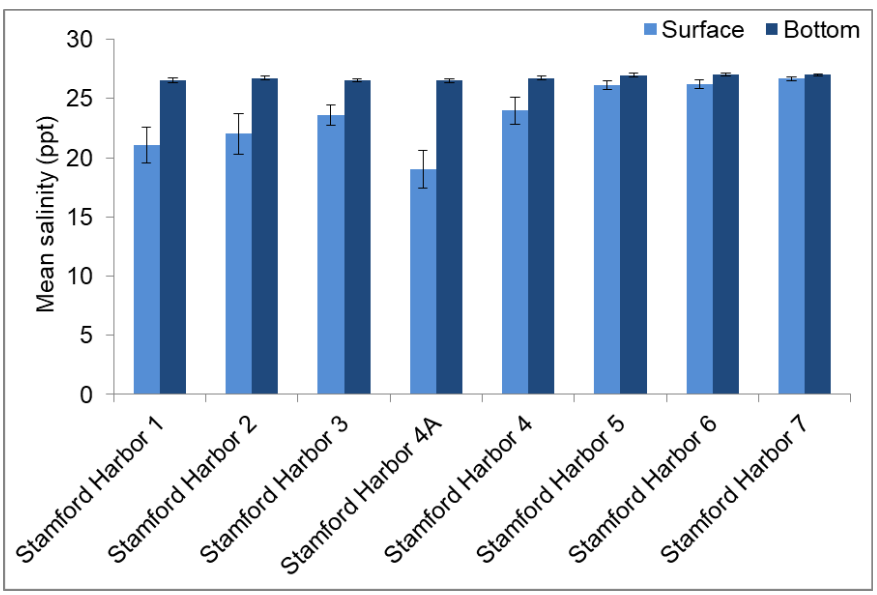


Figure 2.A.9. Mean salinity at the surface and bottom at each sampling station in Stamford Harbor in 2021. Error bars represent standard error.

B. Five Mile River Harbor

Five Mile River Harbor forms the border between the City of Norwalk and the Town of Darien. It is approximately 2 miles long, and is supplied with fresh water from the Five Mile River with headwaters north of New Canaan, Connecticut. An additional source of fresh water to the estuary is Indian Creek, located on the east side of the harbor just north of station Five Mile Harbor 5 (Figure 2.B.1). Very little undeveloped shoreline and natural ecosystems (such as salt marshes) remain, most of which is located in the Tokeneke cut between stations Five Mile River Harbor 2 and Five Mile River Harbor 1. Land use along the shoreline of the harbor consists primarily of marinas and residential areas on the Norwalk side with large residential areas on the Darien side. The east side of the channel has been dredged by the U.S. Coast Guard for slips and moorings up to station Five Mile River Harbor 5, while the west side of the estuary remains too shallow to accommodate most vessels at low tide. In 2020, site Five Mile River Harbor 6 was added upstream of Five Mile River Harbor 5, with limited access only during high tide.

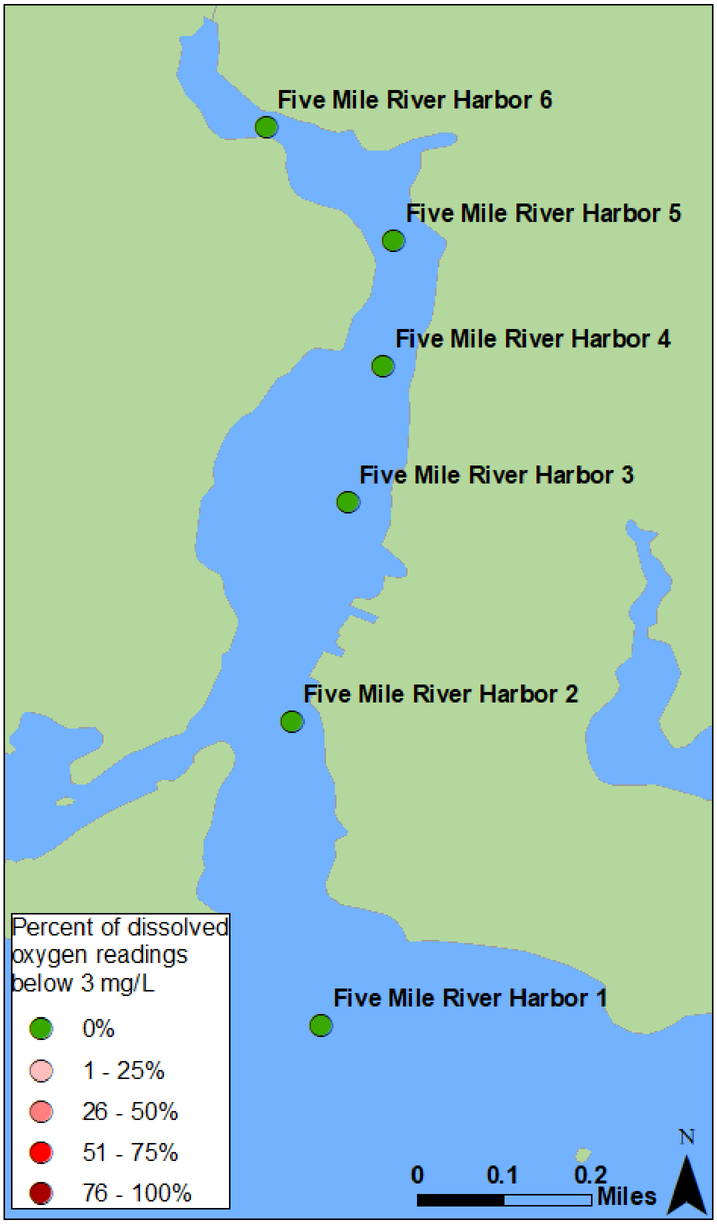


Figure 2.B.1. Map of Five Mile River Harbor sampling stations. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L in 2021.

Table 2.B.1. Coordinates and descriptions for each sampling station in Five Mile River Harbor

Site Name	Latitude	Longitude	Description
Five Mile River Harbor 1	41.056250	-73.445767	Buoy 4
Five Mile River Harbor 2	41.061317	-73.446250	Buoy 6
Five Mile River Harbor 3	41.064967	-73.445317	Five Mile River Works
Five Mile River Harbor 4	41.067233	-73.444733	DownUnder Kayaking dock
Five Mile River Harbor 5	41.069333	-73.444550	Mouth of Indian Creek
Five Mile River Harbor 6	41.071213	-73.446686	Dock at 59 5 Mile River Road

Dissolved Oxygen

Profiles of the water column were taken at 6 sites along the length of the harbor (Figure 2.B.1, Table 2.B.1) on 8 days during the monitoring season from April through August. Dissolved oxygen data from 6/7/21 are not included in this analysis because the calibration drift was greater than the allowable limit on that sampling date. Sampling was not conducted at Five Mile River 6 on 4/28/21 and 5/28/21. Mean dissolved oxygen values in Five Mile River Harbor ranged from a minimum of 5.9 mg/L on the bottom at Five Mile Harbor 6 to a maximum of 7.98 mg/L at the surface at Five Mile River Harbor 1 (Figure 2.B.2). Dissolved oxygen concentrations generally decreased from April through July, and concentrations increased at some sites on the August sampling date (Figure 2.B.3). Three percent of the bottom dissolved oxygen observations were less than 5 mg/L, but no observations fell below 3 mg/L.

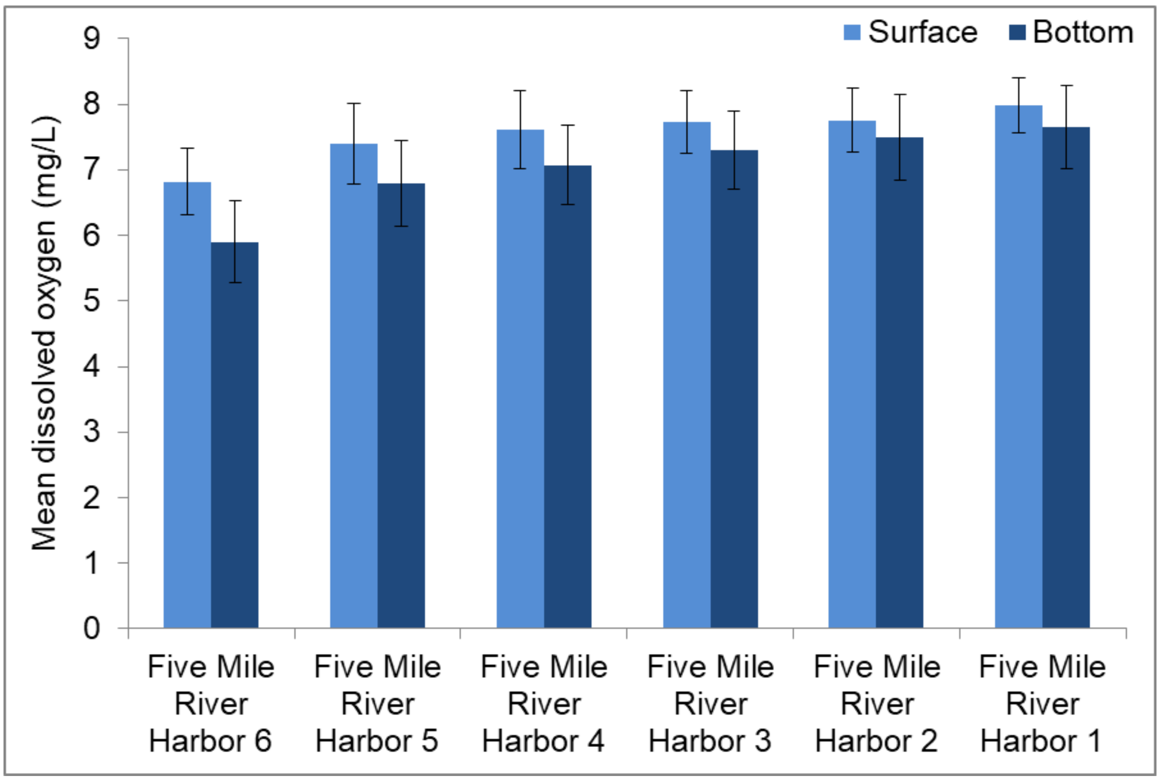


Figure 2.B.2. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in Five Mile River Harbor in 2021. Error bars represent standard error.

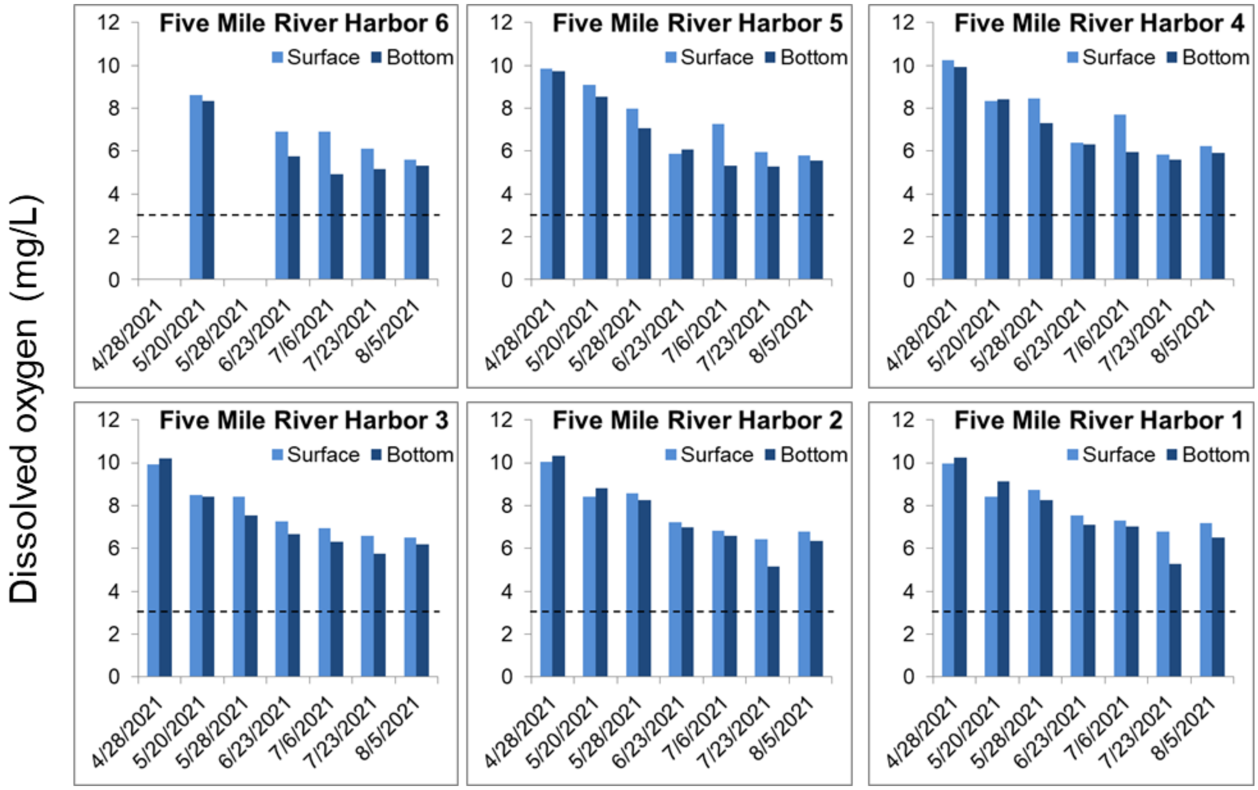


Figure 2.B.3. Surface and bottom dissolved oxygen values at each Five Mile River Harbor sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Station Five Mile River Harbor 6 was not completed on 4/28/21 and 5/28/21 due to inaccessibility. Please note x-axis is not to scale.

Chlorophyll a

Chlorophyll *a* samples were taken on 5 of the 7 sampling days in Five Mile River Harbor. Samples were not taken at Five Mile River Harbor 6 on 5/28/21. In prior years, the harbor was categorized in the medium eutrophic range. In 2020, the harbor was classified as in the highly eutrophic range, largely driven by one outlier in September (Crobsy et al., 2018b, 2019b). 2021 mean surface chlorophyll *a* classified the harbor in the low eutrophic range (Table 2.1). It should be noted that frequently throughout sampling, chlorophyll *a* concentrations from the depth sample were higher than those at the surface.

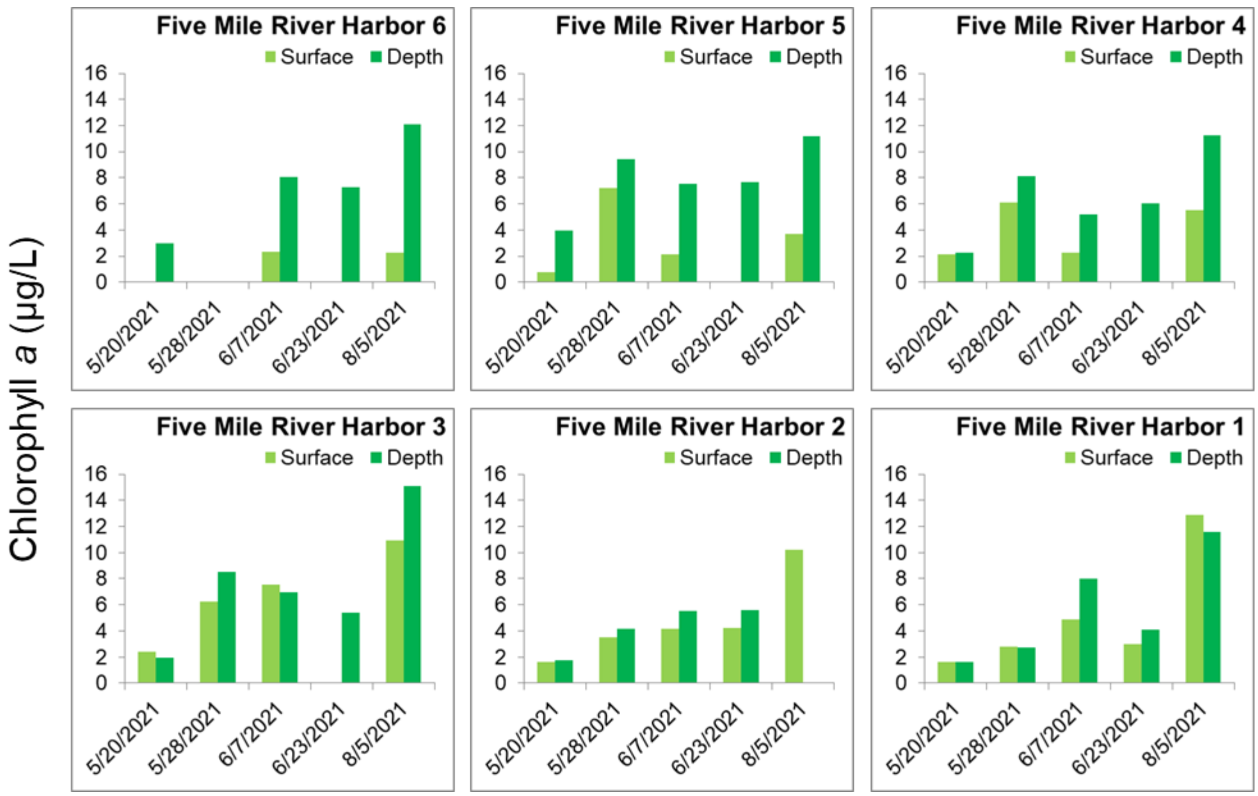


Figure 2.B.4. Surface and depth chlorophyll *a* values in Five Mile River Harbor in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale. Additionally, on 6/23/21 samples were mislabeled resulting in no data available for surface concentrations at stations Five Mile River Harbor 6, Five Mile River Harbor 5, Five Mile River Harbor 4, and Five Mile River Harbor 3.

Water Clarity

Mean secchi depth readings ranged from a minimum of 1.15m at station Five Mile River Harbor 6 to a maximum of 2.67m at station Five Mile River Harbor 1. Mean readings increase steadily along the length of the harbor.

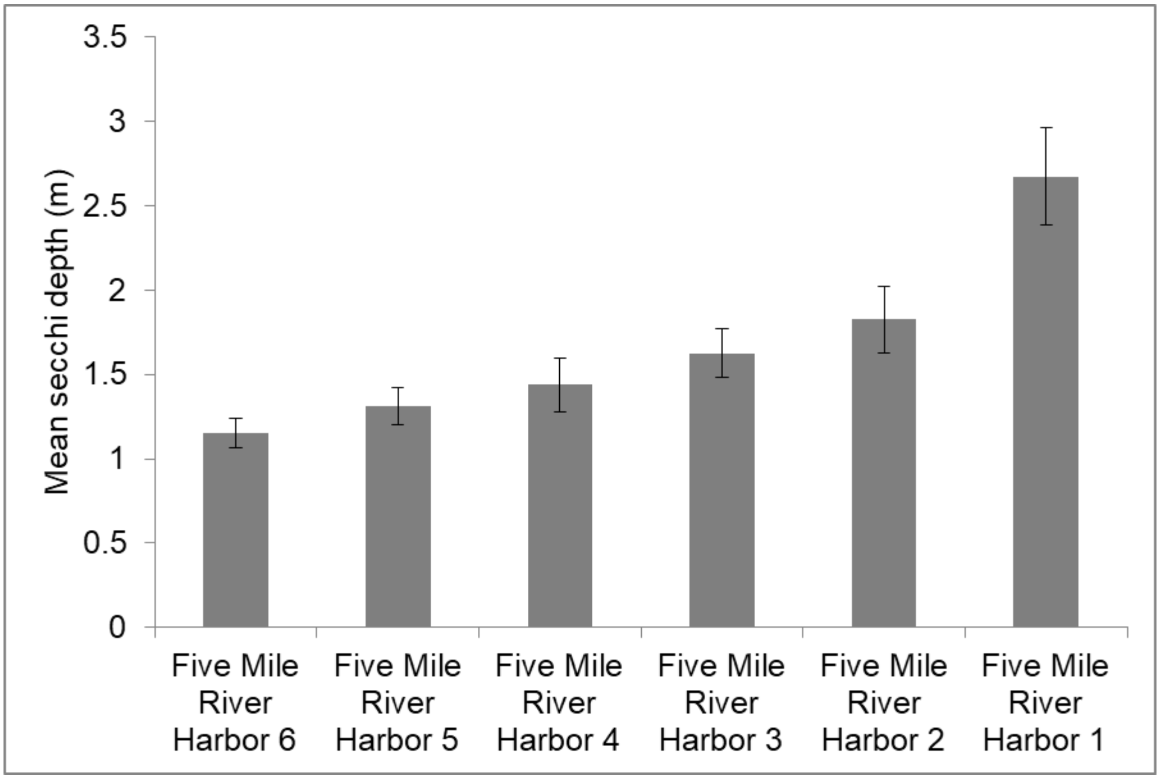
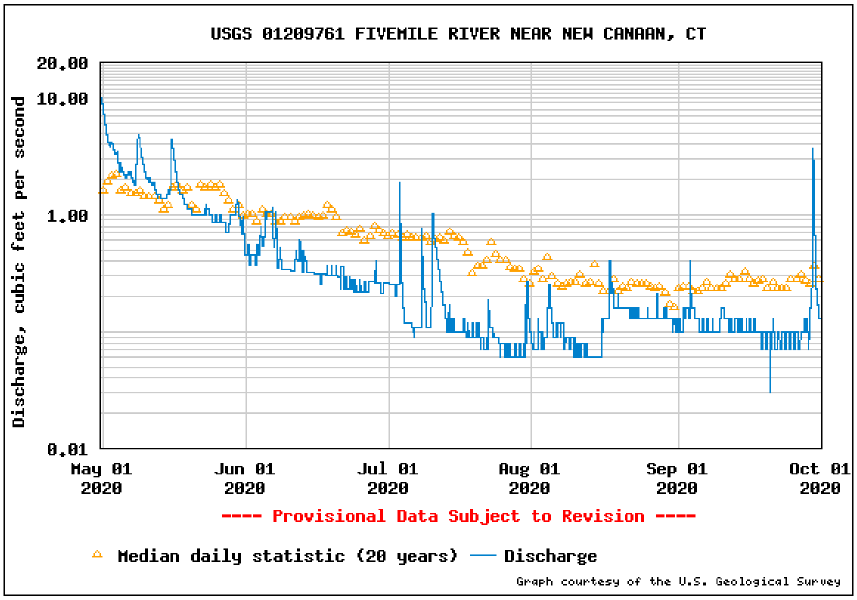


Figure 2.B.5. Mean secchi depth readings in Five Mile River Harbor in 2021. Error bars represent standard error.

Five Mile River Discharge

The figures below illustrate discharge rates recorded at the United States Geological Survey monitoring station on the Five Mile River in New Canaan, CT. Yellow triangles represent the daily median value over the last 20 years, and the blue line represents the recorded discharge for a particular date. In 2020, discharge was typically lower than the daily median statistic. 2021 experienced frequent rain events which increased discharge frequently from May through October.



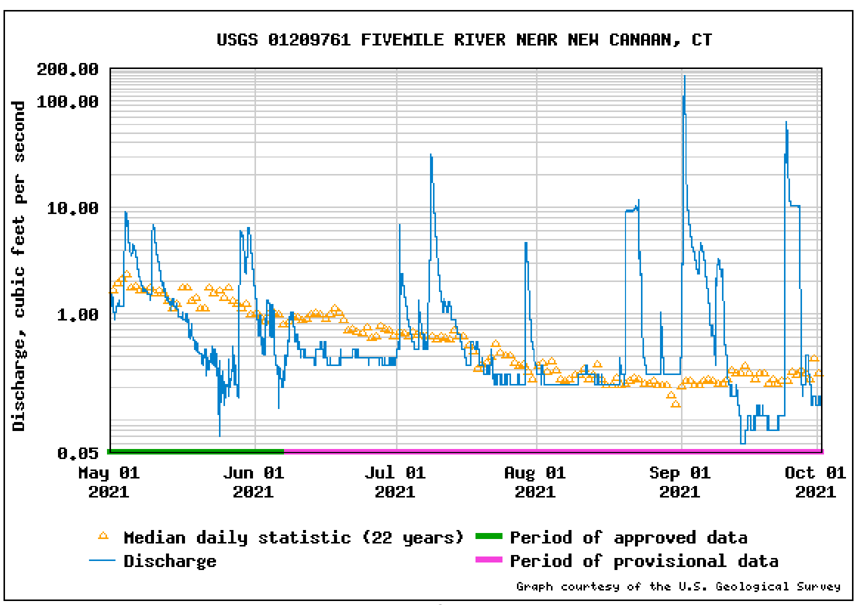


Figure 2.B.6. USGS flow data in ft^3/s for the period of May 1 through October 1, 2020 (top) and 2021 (bottom), respectively for the Five Mile River in New Canaan, CT (Graph courtesy of the U.S. Geological Survey). Please note the difference in scale on the y-axis.

Temperature and Salinity

Mean surface and bottom water temperature in Five Mile River Harbor were similar throughout the harbor (Figure 2.B.7). Lower salinity observed at the surface in the landward end of the estuary reflects the impact of Five Mile River input from the north and Indian Creek input upstream of Five Mile Harbor 5, where the harbor is less well mixed (Figure 2.B.1, Figure 2.B.8). It is important to note that Five Mile River Harbor 6 could only be tested at high tide, which likely resulted in smaller ranges between surface and bottom salinity observations.

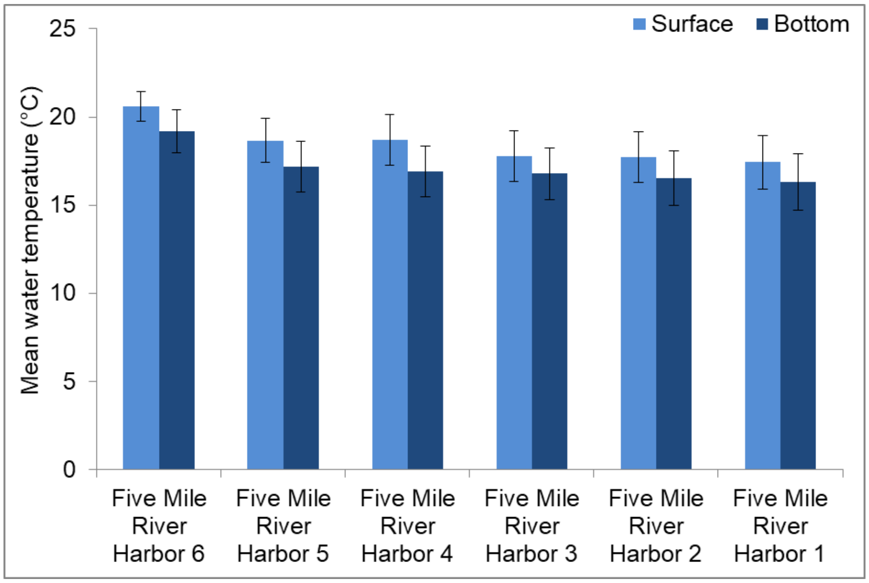


Figure 2.B.7. Mean water temperature at the surface and bottom at each sampling station in Five Mile River Harbor in 2021. Error bars represent standard error.

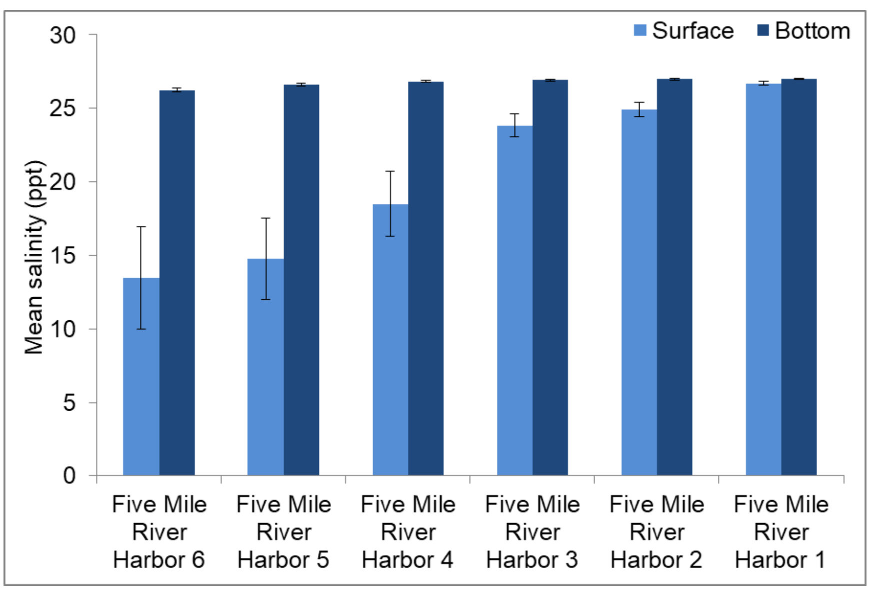


Figure 2.B.8. Mean salinity at the surface and bottom at each sampling station in Five Mile River Harbor in 2021. Error bars represent standard error.

C. Norwalk Harbor

Norwalk Harbor, located in Norwalk, CT, is fed with fresh water from the Norwalk River. The harbor once had extensive wetlands on both shorelines (Figure 2.C.1) which have now been filled in or removed and replaced with hardened shoreline to accommodate the many industrial and commercial businesses located along the shores. Land use around the edges of the harbor includes landfills, marinas, and housing developments ranging from high density apartments to single-family homes. This report will discuss the inner harbor, which includes the length of the estuary from Wall Street to the Norwalk Islands (Figure 2.C.2). The outer harbor, the area from just outside the mouth of Five Mile River Harbor east along the apron of Norwalk Harbor to a point just south of the Norwalk Islands off of Westport, was not monitored in 2021 and will not be discussed in this report.

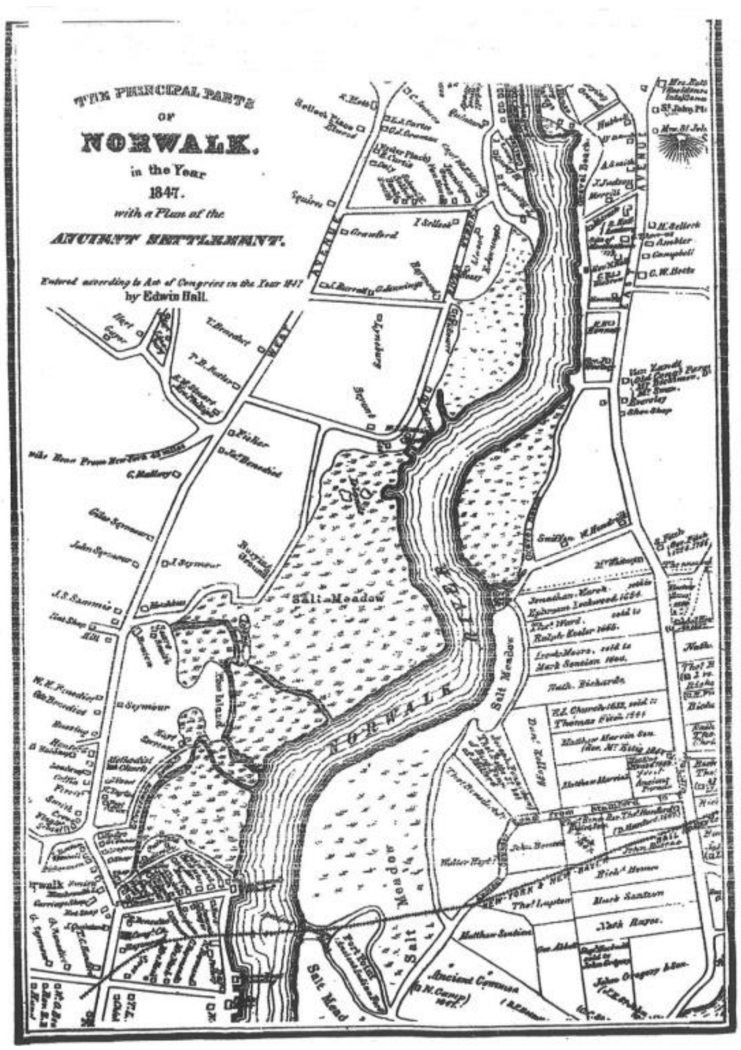


Figure 2.C.1. Norwalk Harbor estuary in 1847. Extensive wetlands once dominated both shorelines. Image credit: Norwalk Historical Society.

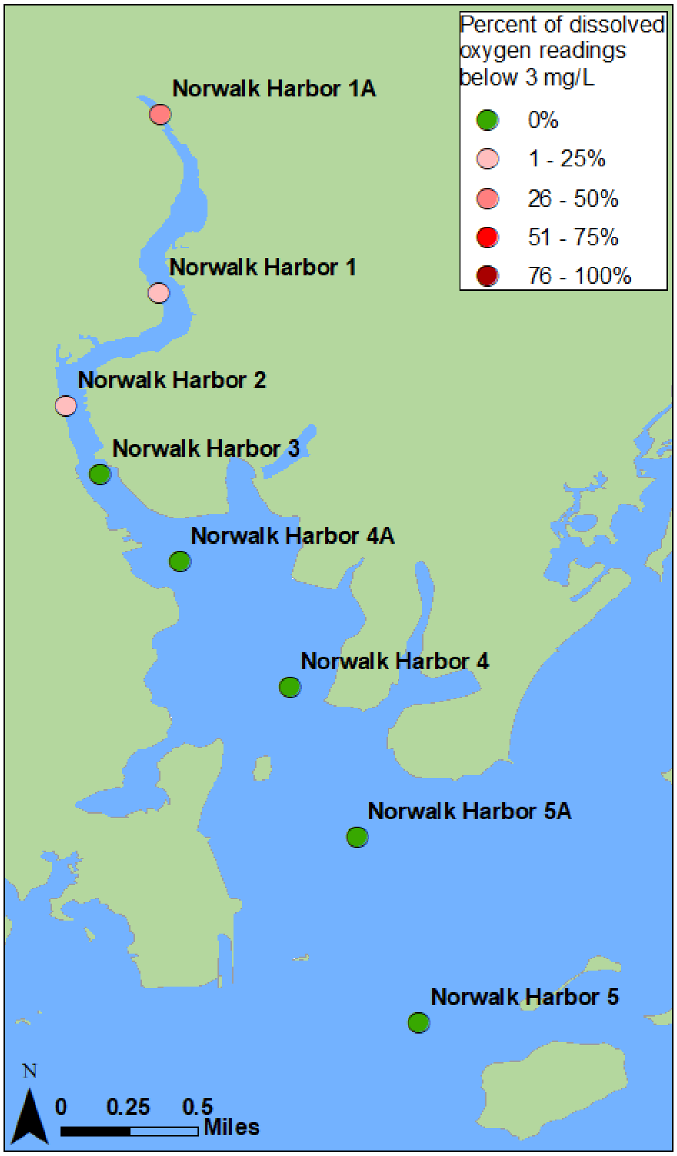


Figure 2.C.2. Map of Norwalk Harbor sampling stations in the inner harbor for 2021. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L.

Table 2.C.1. Coordinates and descriptions for each sampling station in Norwalk Harbor

Site Name	Latitude	Longitude	Description
Norwalk Harbor 1A	41.117389	-73.411056	Wall Street
Norwalk Harbor 1	41.108000	-73.411167	I-95 Bridge
Norwalk Harbor 2	41.102056	-73.416000	Maritime Aquarium dock
Norwalk Harbor 3	41.098472	-73.414194	Public boat launch
Norwalk Harbor 4A	41.093861	-73.410028	Ischoda Yacht Club moorings
Norwalk Harbor 4	41.087278	-73.404250	Buoy 19
Norwalk Harbor 5A	41.079402	-73.400727	Buoy 15
Norwalk Harbor 5	41.069611	-73.397472	Oyster stakes off Chimon Island

Dissolved Oxygen
Profiles were taken in the inner harbor at 8 sampling stations. Sampling occurred 12 times between April and September 2021. Mean dissolved oxygen concentrations ranged from a minimum of 3.20 mg/L on the bottom at station Norwalk Harbor 1A to a maximum of 8.16 mg/L at the surface at station Norwalk Harbor 2 (Figure 2.C.3). Station Norwalk Harbor 1A had the widest range between surface and bottom mean dissolved oxygen concentrations in Norwalk Harbor. Twenty-four percent of bottom dissolved oxygen observations were less than 5 mg/L, and 12% were less than 3 mg/L.

Wide ranges in dissolved oxygen concentrations at the surface and bottom were observed in most of the upstream sampling locations (Figure 2.C.3, Figure 2.C.4). At the sampling locations further seaward, the differences in dissolved oxygen concentrations were smaller, presumably from the larger width of the harbor and increased mixing reducing stratification. The upper 3 stations, Norwalk Harbor 1A, Norwalk Harbor 1, and Norwalk Harbor 2, likely had a highly stratified water column throughout the season based on limited mixing time with the flow of fresh water entering the harbor from the Norwalk River (Figure 2.C.3, Figure 2.C.9). Station Norwalk Harbor 1A was the most impaired water in the harbor for dissolved oxygen, consistent with past years.

During the summer months, the 3 most inland harbor sites have historically experienced prolonged periods of hypoxia due to their limited flushing, reduced mixing time with river water, and prolonged exposure to a variety of inputs from storm drain networks and anthropogenic waste on the harbor bottom. The stations south of Norwalk Harbor 4A exhibit less stratification as the fresh water becomes more brackish with exposure time and better flushed by the tides. Typically, dissolved oxygen concentrations tend to decrease when air temperature rises as the summer progresses. There was evidence of a slight recovery in dissolved oxygen concentrations in September (Figure 2.C.4).

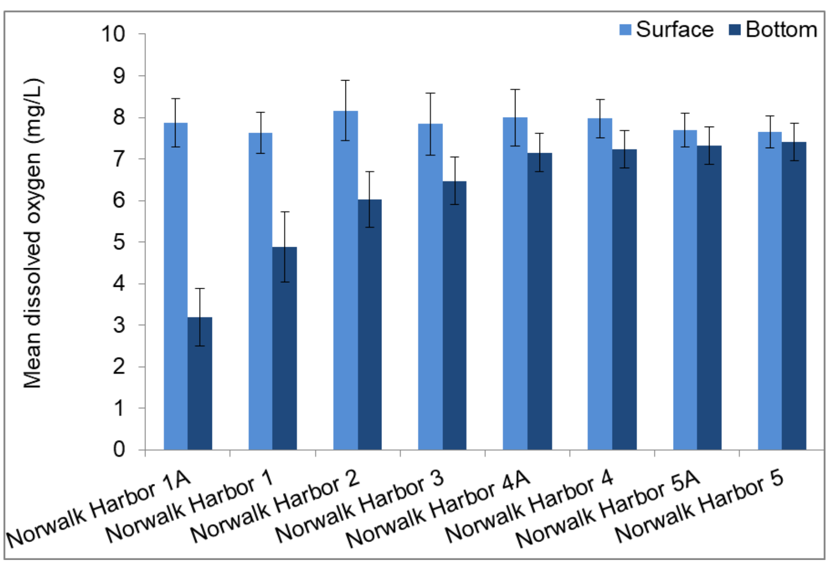


Figure 2.C.3. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in Norwalk Harbor during 2021. Error bars represent standard error.

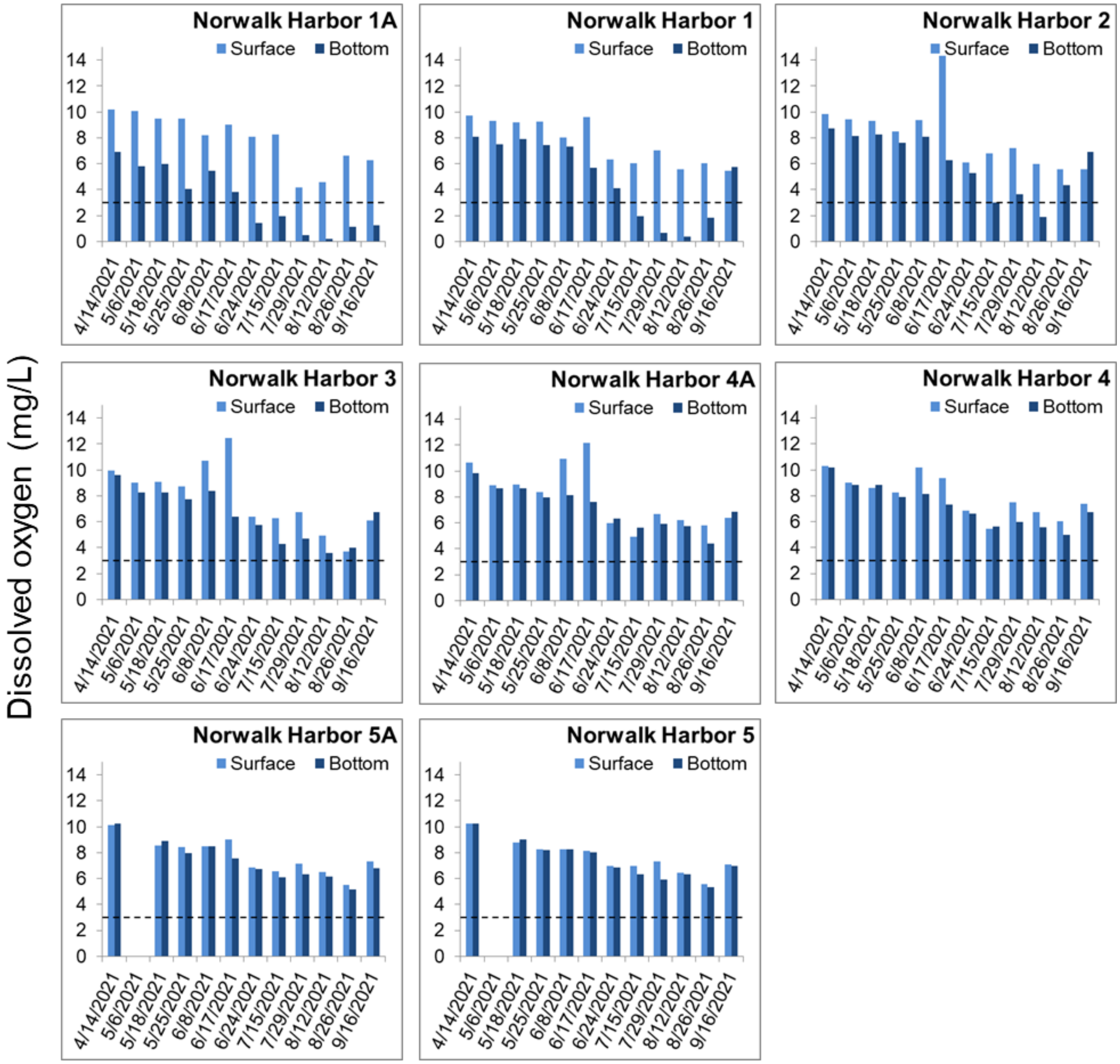


Figure 2.C.4. Surface and bottom dissolved oxygen values at each Norwalk Harbor sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Stations Norwalk Harbor 5A and Norwalk Harbor 5 were not completed on 5/6/21 due to high winds. Please note x-axis is not to scale.

Chlorophyll a

Water samples for chlorophyll *a* monitoring were collected during 5 of the 12 monitoring days. Mean surface chlorophyll *a* in the harbor during the 2021 sampling season classified the harbor as medium eutrophic (Table 2.1). This classification is the same as in 2020 (Crosby et al., 2020). It should be noted that chlorophyll *a* concentrations taken at depth in the upper harbor stations in 2021 were in the medium and high eutrophic range.

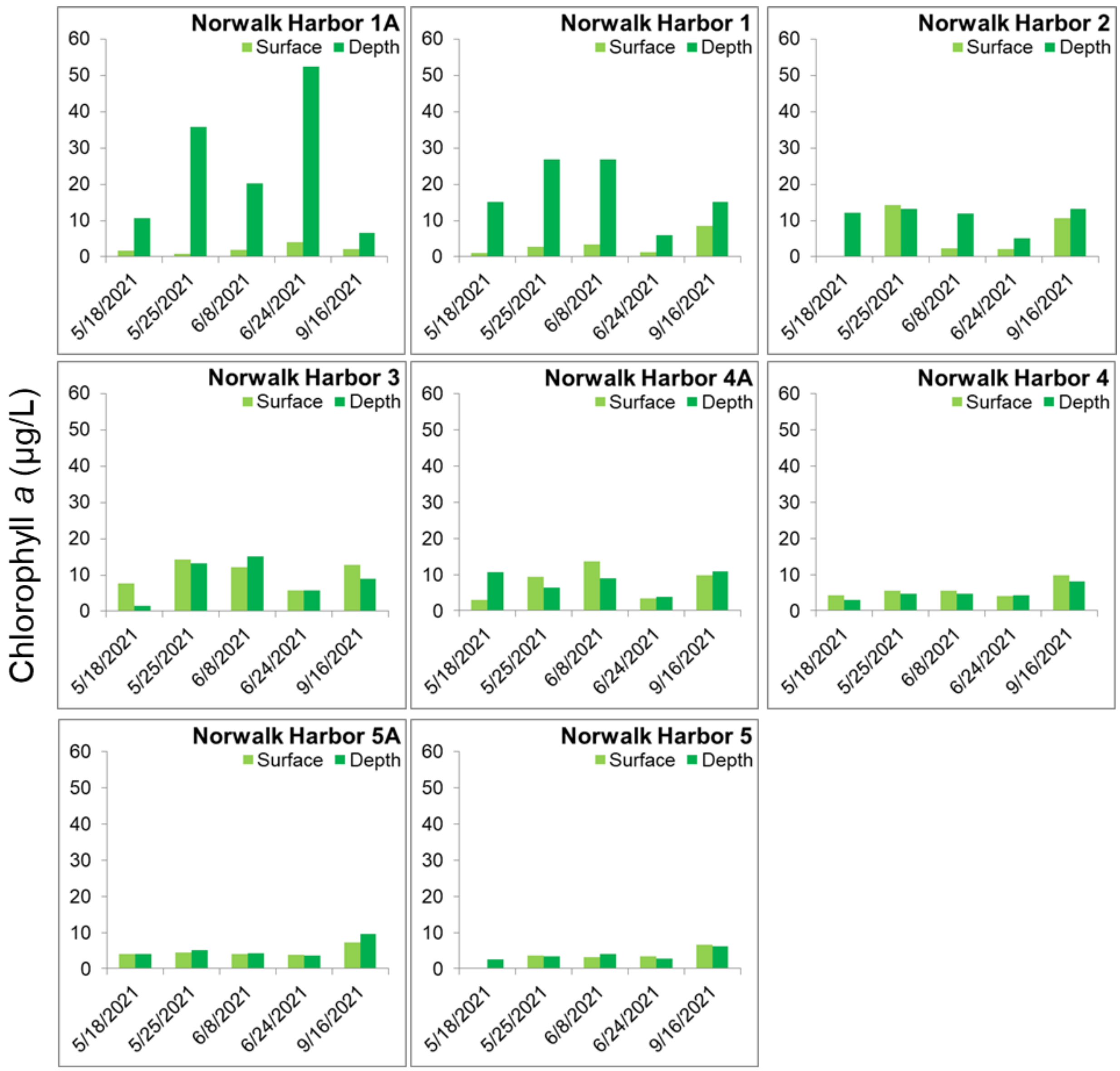


Figure 2.C.5. Surface and depth chlorophyll a values in Norwalk Harbor in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale.

Water Clarity

Mean secchi depth readings ranged from a minimum of 1.18m at station Norwalk Harbor 3 to a maximum of 1.76m at station Norwalk Harbor 5. Secchi readings in the upper harbor stations are similar, and progressively increase as the stations get closer to the outer harbor.

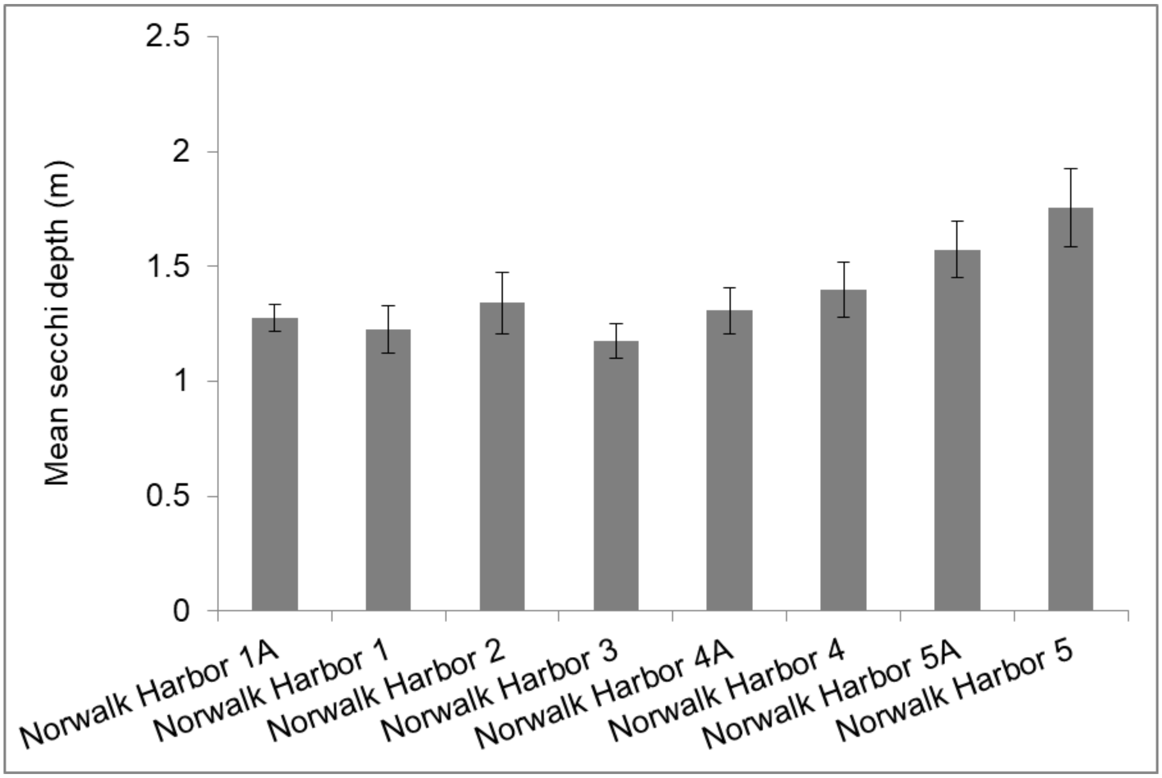
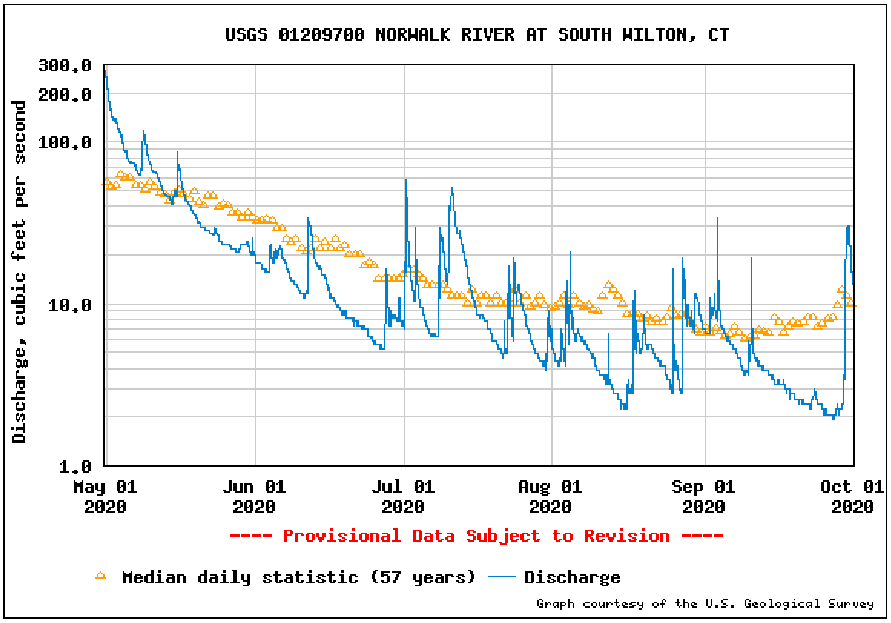


Figure 2.C.6. Mean secchi depth readings in Norwalk Harbor in 2021. Error bars represent standard error.

Norwalk River Discharge

The figures below illustrate discharge in cubic feet per second recorded at the United States Geological Survey monitoring station on the Norwalk River in South Wilton, CT. Yellow triangles represent the daily median value over the last 57 years, and the blue line represents the recorded discharge for a particular date. Discharge in 2021 was recorded to be higher than in 2020 and had larger rainfall events (Figure 2.C.7).



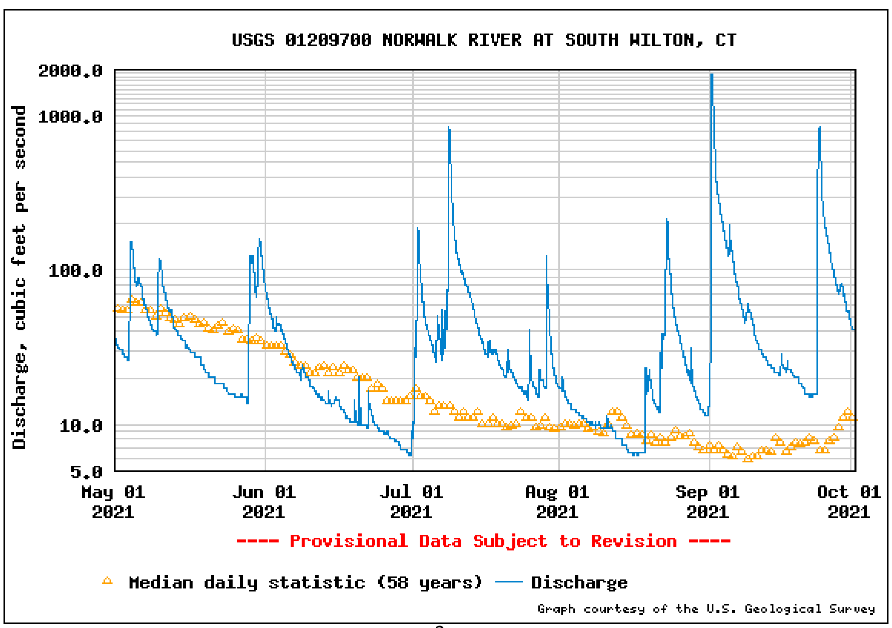


Figure 2.C.7. USGS flow data in ft^3/s for the period of May 1 through October 1, 2020 (top) and 2021 (bottom), respectively for the Norwalk River in South Wilton, CT (Graph courtesy of the U.S. Geological Survey). Please note the difference in scale on the y-axis.

Temperature and Salinity

Norwalk Harbor 1A was the only station where mean water temperature was cooler at the surface than the bottom (Figure 2.C.8). Salinity was lower at the surface than the bottom at all stations, with the largest difference observed at the inner harbor stations, reflecting the impact of the riverine inputs from the north where the harbor is less well mixed (Figure 2.C.9). This salinity stratification was more pronounced at station Norwalk Harbor 1A, where the fresh water river discharge meets the toe of the tidal wedge, than it was at the other stations studied.

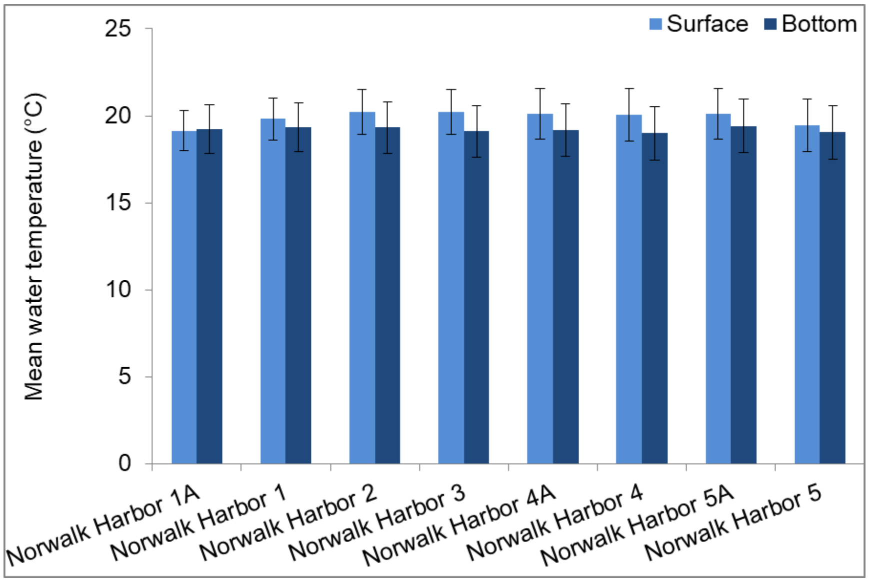


Figure 2.C.8. Mean water temperature at the surface and bottom at each sampling station in Norwalk Harbor in 2021. Error bars represent standard error.

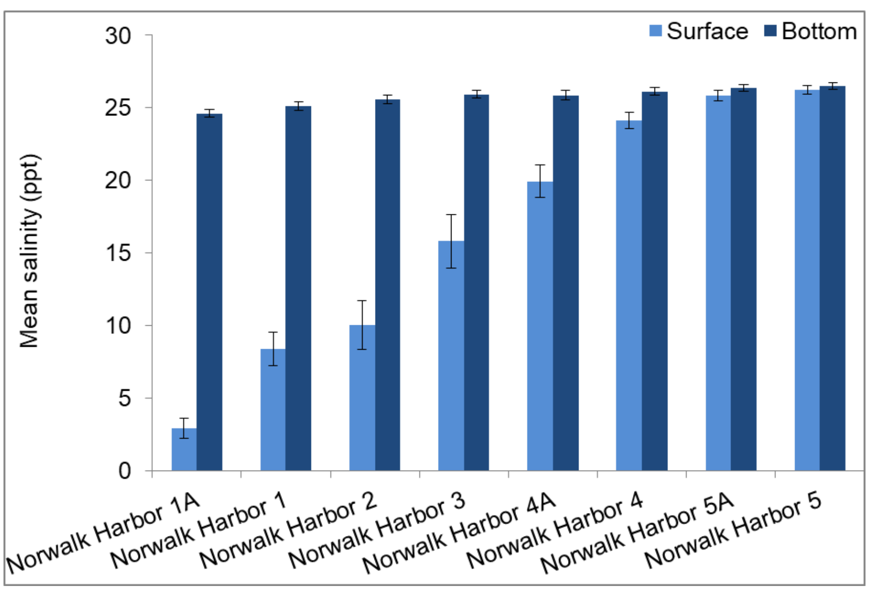


Figure 2.C.9. Mean salinity at the surface and bottom at each sampling station in Norwalk Harbor in 2021. Error bars represent standard error.

D. Saugatuck Harbor

Situated at the mouth of the Saugatuck River, Saugatuck Harbor is approximately three miles long and relatively narrow with the exception of two basins. The first of these is a large basin located just to the north of station Saugatuck Harbor 6 (Figure 2.D.1, Figure 2.D.2). The second smaller basin is located just to the north of station Saugatuck Harbor 4 (Figure 2.D.2). The combined effect of these basins on ebb tide provides a strong flushing current for the estuary. The estuary then broadens into a wide but shallow harbor just to the south of station Saugatuck Harbor 3 (Figure 2.D.2). The land area on both sides of the upper estuary and the main harbor is mostly developed. The commercial area of the Town of Westport borders the northeastern side of the harbor above the Route 1 bridge. From this point moving southward the east bank of the harbor is residential up to the Longshore Country Club area and the Compo Boat Basin Marina. The west bank of the harbor is developed with a mixture of commercial businesses including a rowing club and a few small marinas. The Saugatuck Shores area on the western bank of Saugatuck Harbor is developed with single-family homes and two yacht clubs. Some salt marshes are present along the harbor margins south of the Canal Street bridge and just to the north of the I-95 bridge. Much of the shoreline has been filled for development but several large strip marshes are also still present along the western bank as the harbor opens into a larger basin near the mouth (Figure 2.D.2).

Figure 2.D.1. Looking upstream at the first basin from Saugatuck Harbor 6.

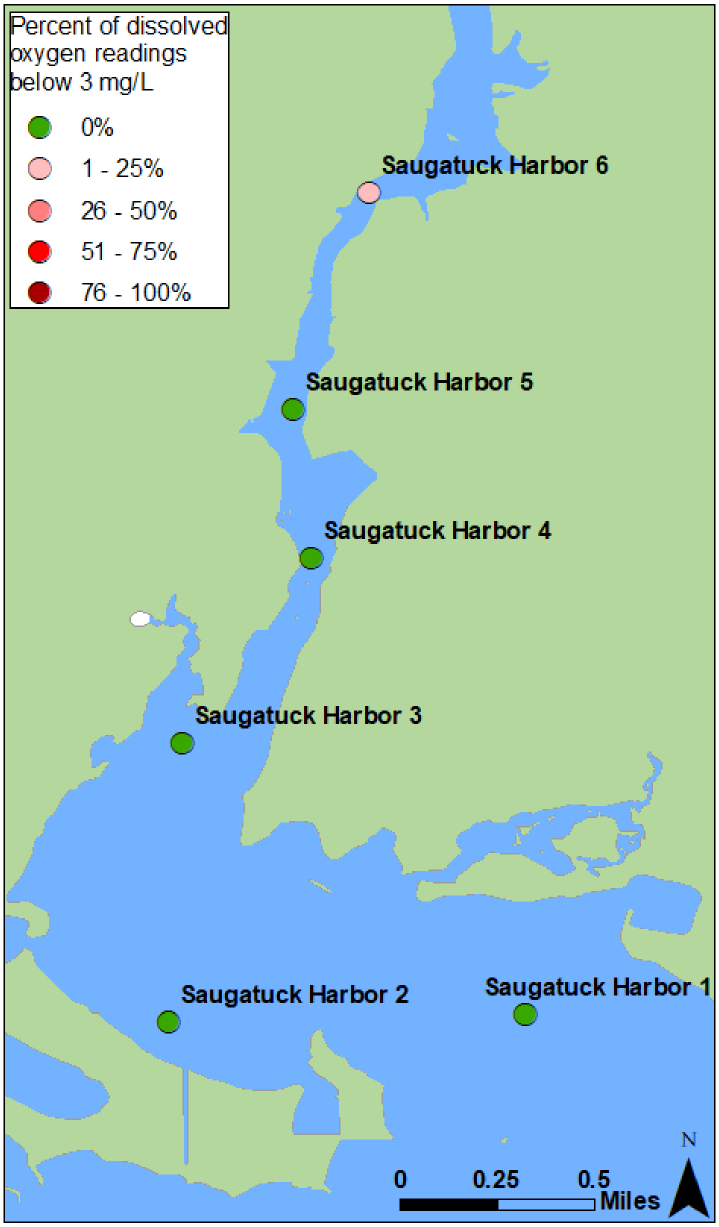


Figure 2.D.2. Map of Saugatuck Harbor sampling stations in 2021. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L.

Table 2.D.1. Coordinates and descriptions for each sampling station in Saugatuck Harbor

Site Name	Latitude	Longitude	Description
Saugatuck Harbor 1	41.102050	-73.360533	Buoy 9
Saugatuck Harbor 2	41.101733	-73.373833	Buoy 18
Saugatuck Harbor 3	41.112167	-73.373317	Buoy 27
Saugatuck Harbor 4	41.119067	-73.368517	Metro North Railroad bridge
Saugatuck Harbor 5	41.124617	-73.369233	VFW marina (in the channel)
Saugatuck Harbor 6	41.132683	-73.366383	Sunoco (in the channel)

Dissolved Oxygen

Profiles were taken at 6 stations on 10 sampling days from May through September 2021. Mean dissolved oxygen values ranged from a minimum of 6.06 mg/L at the bottom of station Saugatuck Harbor 6 to a maximum of 8.00 mg/L at the surface of station Saugatuck Harbor 3 (Figure 2.D.3). Dissolved oxygen dropped throughout the monitoring season, with lowest values observed on 8/25/21 at the majority of sampling sites (Figure 2.D.4). Twenty percent of bottom dissolved oxygen observations fell below 5 mg/L, and 2% fell below 3 mg/L.

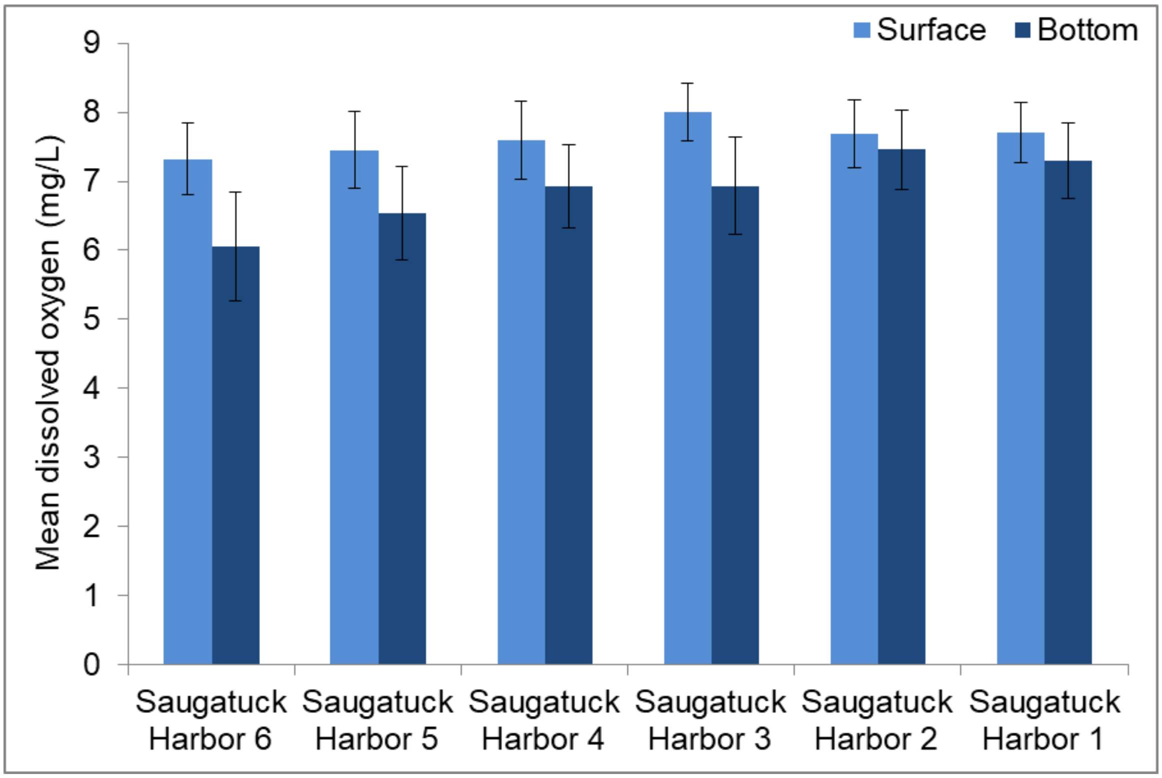


Figure 2.D.3. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in Saugatuck Harbor in 2021. Error bars represent standard error.

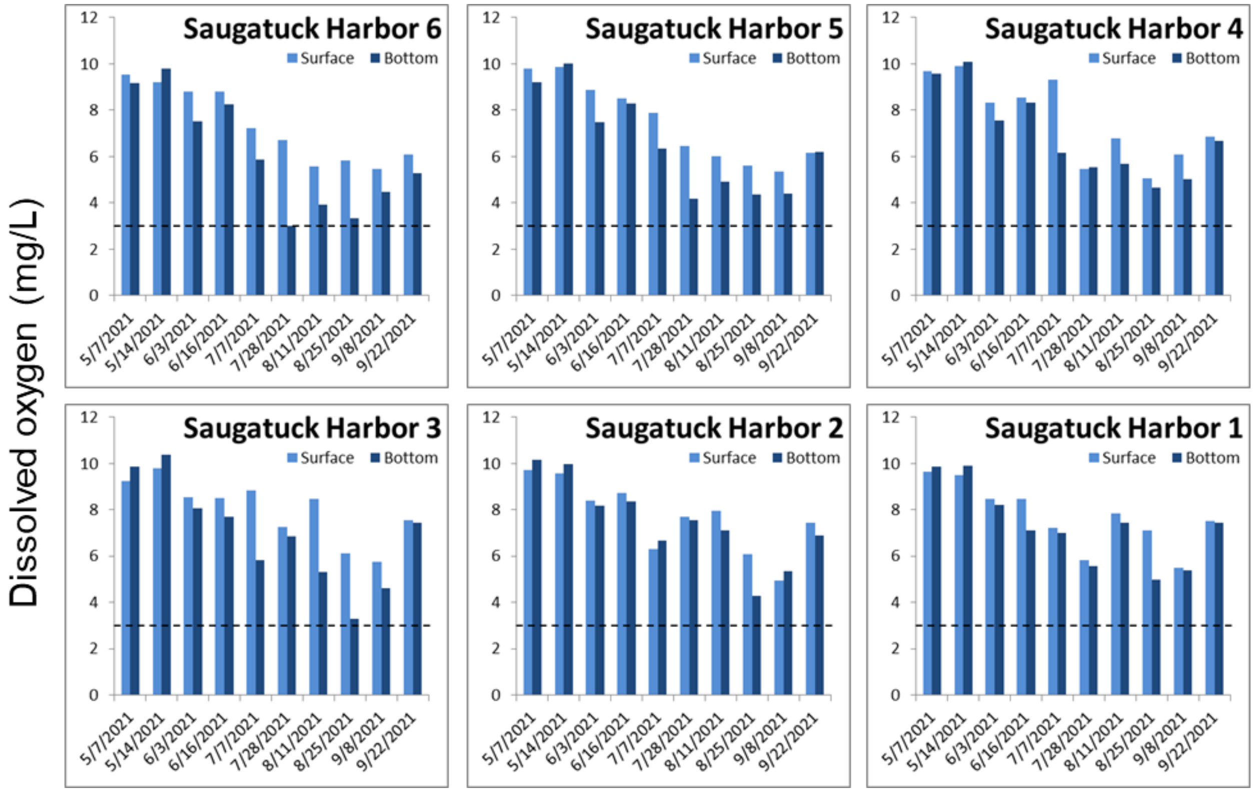


Figure 2.D.4. Surface and bottom dissolved oxygen values at each Saugatuck Harbor sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Please note x-axis is not to scale.

Chlorophyll a

Chlorophyll *a* sampling was conducted on 8 of the 10 monitoring days. Mean surface chlorophyll *a* concentration classified Saugatuck Harbor as medium eutrophic, the same classification as in 2020 (Table 2.1; Crosby et al., 2020). It should be noted that there were spikes in surface concentrations at the upper 4 stations that individually would be classified as high to hyper eutrophic.

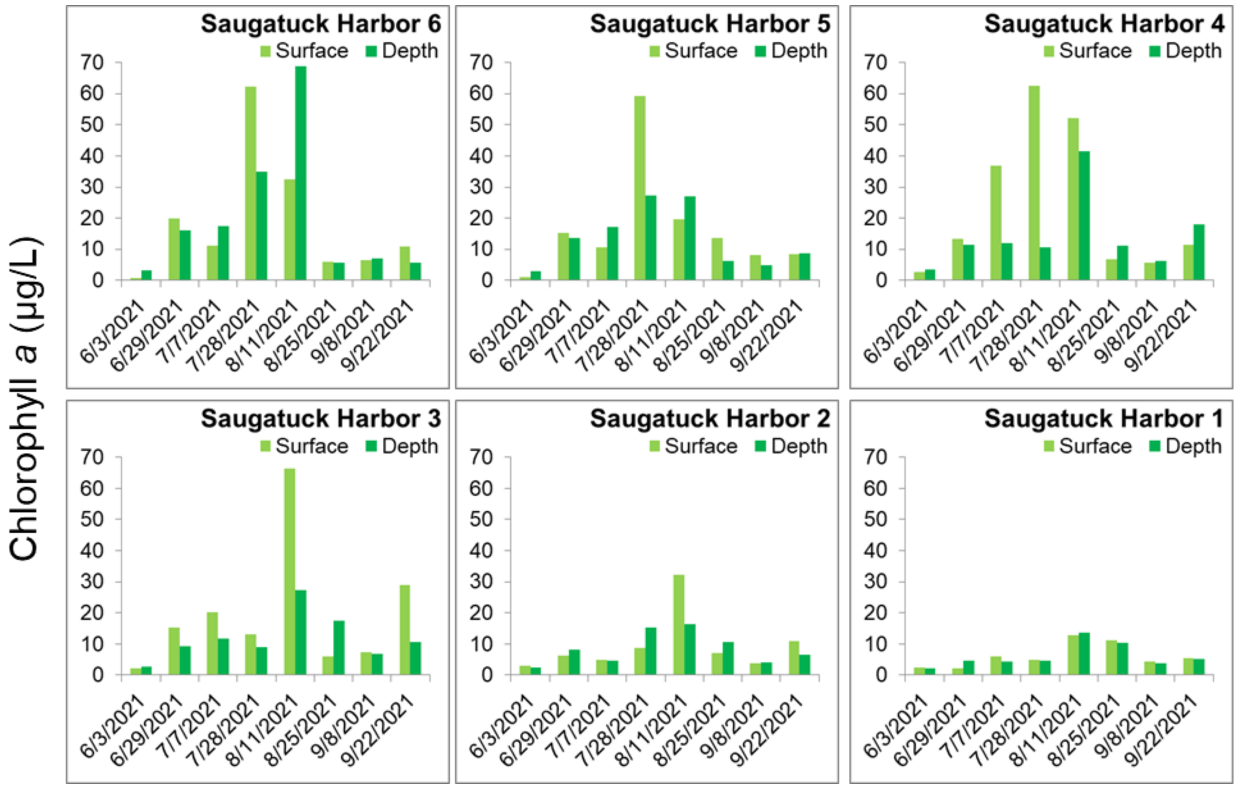


Figure 2.D.5. Surface and depth chlorophyll a values in Saugatuck Harbor in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale.

Water Clarity

Mean secchi depth readings ranged from a minimum of 0.99m at station Saugatuck Harbor 6 to a maximum of 1.96m at station Saugatuck Harbor 1. Mean secchi readings steadily increase from the inner harbor stations to the outer harbor stations.

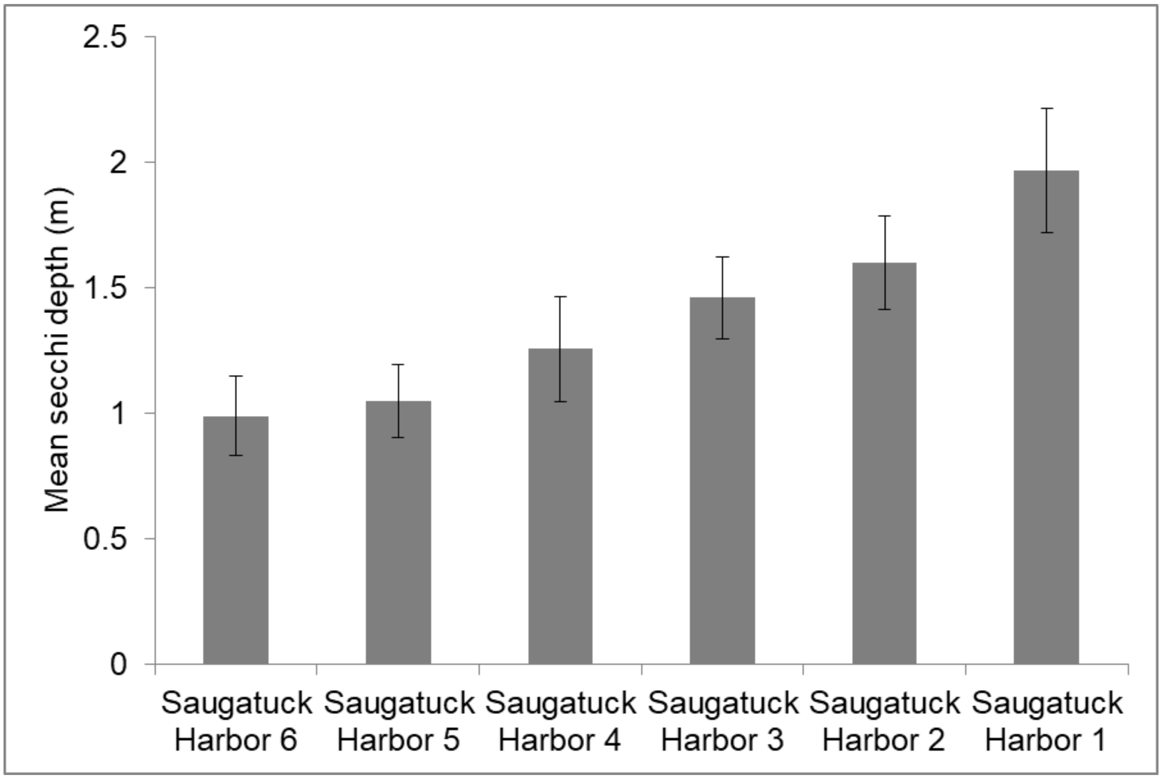
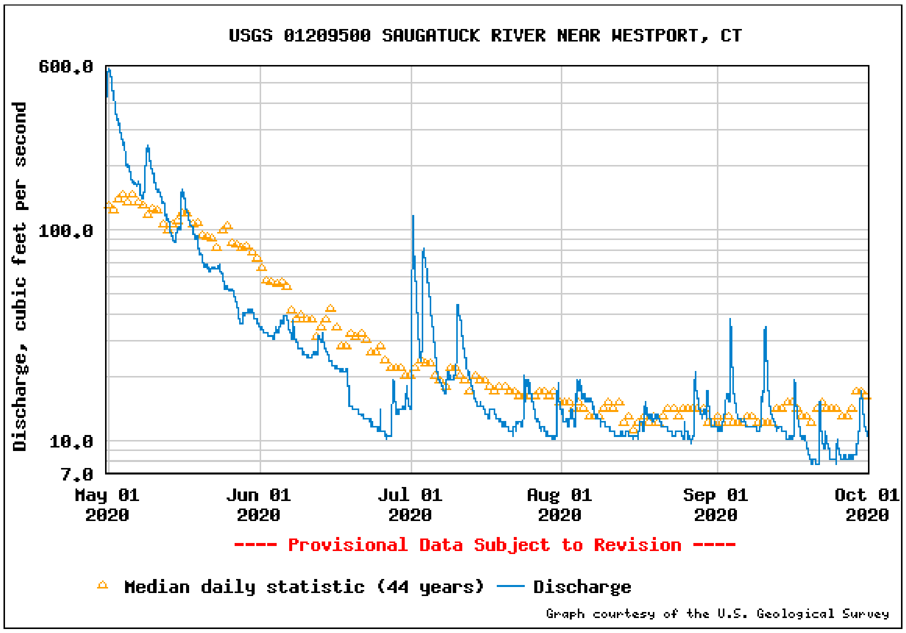


Figure 2.D.6. Mean secchi depth readings in Saugatuck Harbor in 2021. Error bars represent standard error.

Saugatuck River Discharge

The figures below illustrate discharge in cubic feet per second recorded at the United States Geological Survey monitoring station on the Saugatuck River near Westport, CT. Yellow triangles represent the daily median value over the last 44 years, and the blue line represents the recorded discharge for a particular date. Rainfall events in 2021 were larger and more frequent than those experienced in 2020, especially toward the end of the monitoring season, resulting in more discharge.



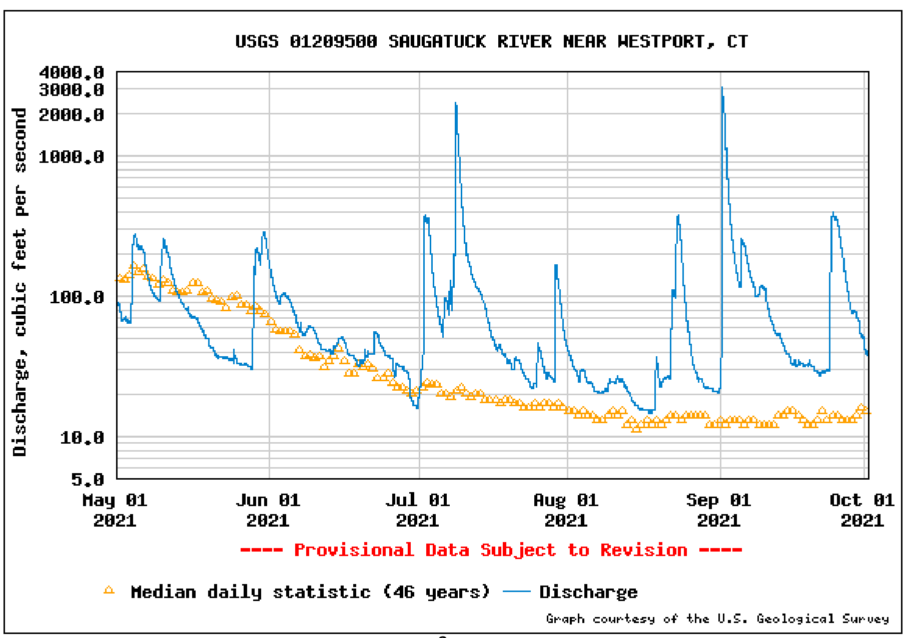


Figure 2.D.7. USGS flow data in ft^3/s for the period of May 1 through October 1 for the 2020 (top) and 2021 (bottom) respectively for the Saugatuck River near Westport, CT (Graphs courtesy of the U.S. Geological Survey). Please note the difference in scale on the y-axis.

Temperature and Salinity
Mean water temperatures were similar at both the surface and the bottom (Figure 2.D.8). Salinity was lower at the surface than the bottom at all stations and that difference was most pronounced in the inner harbor stations, reflecting the impact of the increased riverine inputs from the north where the harbor is less well mixed (Figure 2.D.8, Figure 2.D.9).

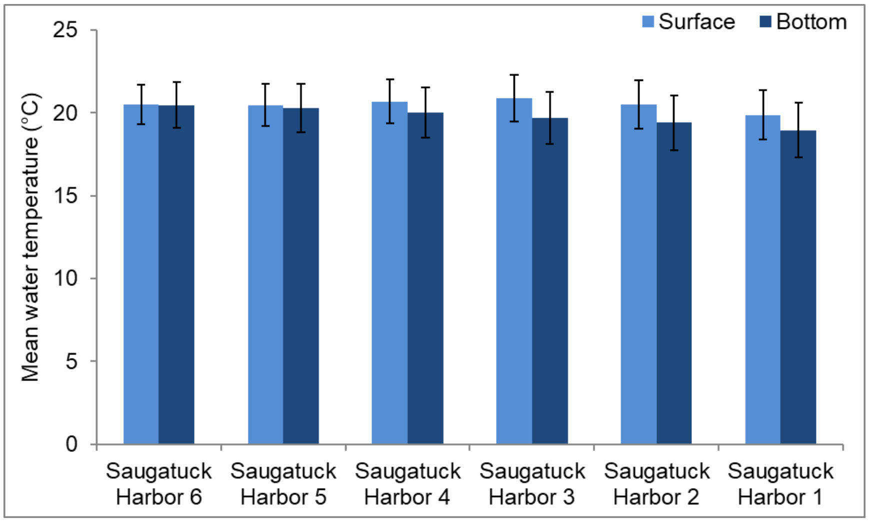


Figure 2.D.8. Mean water temperature at the surface and bottom at each sampling station in Saugatuck Harbor in 2021. Error bars represent standard error.

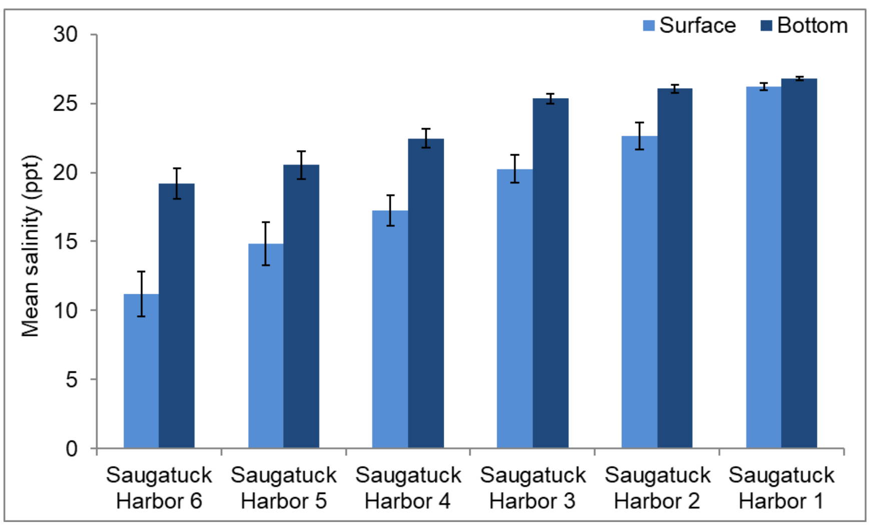


Figure 2.D.9. Mean salinity at the surface and bottom at each sampling station in Saugatuck Harbor in 2021. Error bars represent standard error.

E. Bridgeport Harbor (Johnsons Creek and Lewis Gut sections)

Johnsons Creek is a short ¼ mile channel that starts at the discharge area of Bruce Brook and extends to the south-western end of Lewis Gut (Figure 2.E.1). Johnsons Creek flows southwest past a series of petroleum storage tanks and 2 marinas on both banks down to the remains of the swing bridge at the entrance to Bridgeport Harbor (Figure 2.E.1, Figure 2.E.2, Figure 2.E.3). Johnsons Creek waters mix with those of Lewis Gut during tidal cycles. The 2 water bodies present a significant contrast in terms of development and shoreline habitat features. On the one hand, Lewis Gut possesses features that support an environmentally sound embayment and is surrounded by a natural shoreline. As an added benefit, the bordering extensive wetlands serve to improve water quality. On the other hand, Johnsons Creek is commercially developed with a highly developed shoreline and receives the discharge from a tributary (Bruce Brook) with a known history of impairment (Figure 2.E.3; Crosby et al., 2019a).

Lewis Gut extends 2 miles to the east behind a barrier beach known as Pleasure Beach on its western end and Long Beach on its eastern end. The barrier beach and the waters of Lewis Gut have been spared the impact of man-made development over time because a fire destroyed the only bridge that connected the barrier beach to the mainland. A noteworthy environmental feature of Lewis Gut is the extensive *Spartina alterniflora*-dominated salt marsh which flanks the northern edge and eastern end of Lewis Gut. While supported by more natural features along its immediate shoreline than Johnsons Creek, Lewis Gut is still part of a highly developed watershed (Figure 2.E.3).

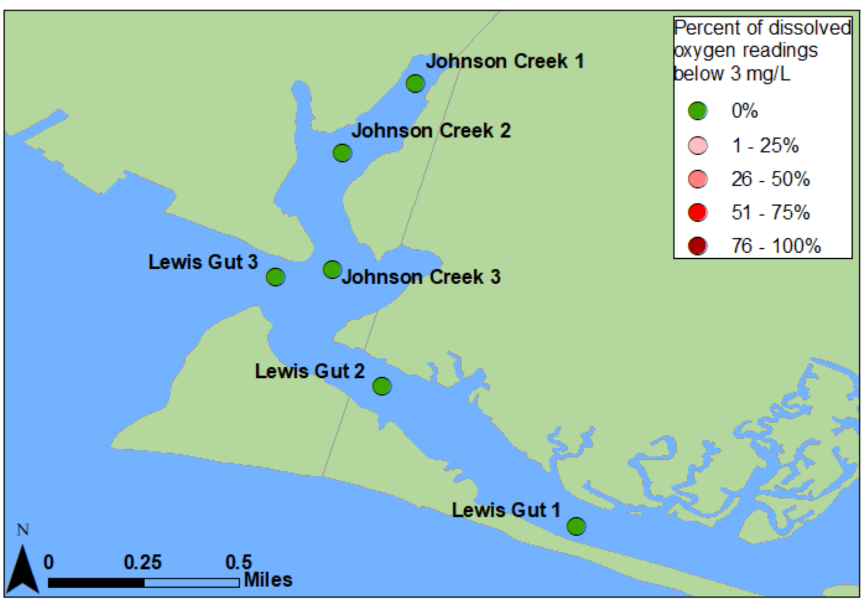


Figure 2.E.1. Map of Johnsons Creek and Lewis Gut sampling stations in 2021. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L.

Table 2.E.1. Coordinates and descriptions for each sampling station in Johnsons Creek and Lewis Gut

Site Name	Latitude	Longitude	Description
Johnsons Creek 1	41.172900	-73.160583	Off of East End Yacht Club
Johnsons Creek 2	41.170250	-73.163367	Mid-channel off PC Metals
Johnsons Creek 3	41.165833	-73.163750	Nun Buoy #4
Lewis Gut 1	41.156083	-73.154467	Lewis Gut east end
Lewis Gut 2	41.161383	-73.161867	Lewis Gut
Lewis Gut 3	41.165517	-73.165917	Swing Bridge east side

Figure 2.E.2. Looking down Johnsons Creek, which has many commercial land uses on its borders. The swing bridge in the background is where Johnsons Creek meets Lewis Gut.

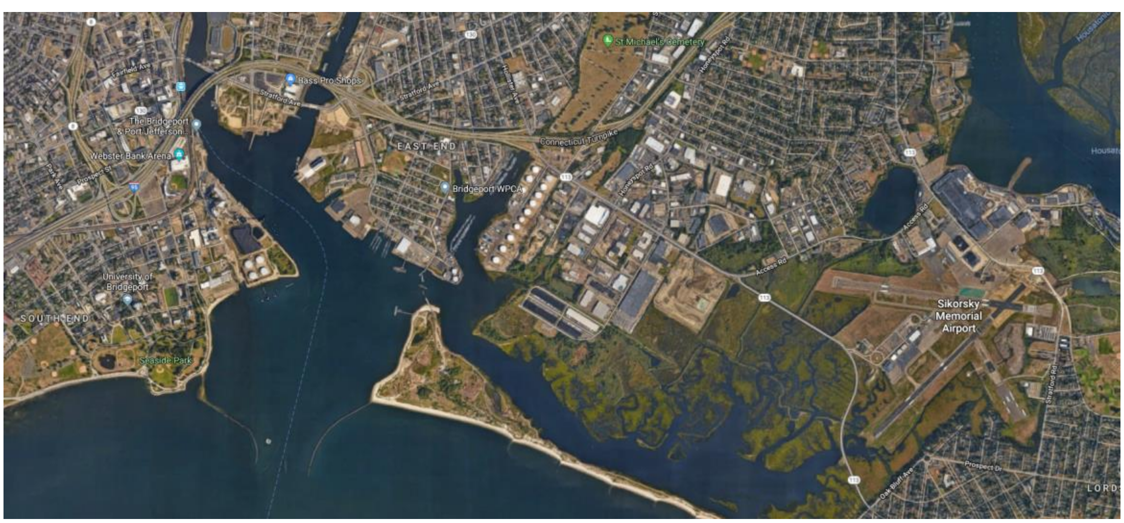


Figure 2.E.3. An aerial view of a highly industrialized Johnsons Creek in contrast to the more natural immediate setting around Lewis Gut (photo source: Google Maps).

Dissolved Oxygen

Dissolved oxygen data were collected at 6 sites on 6 sampling dates from May through September. There was a large gap in sampling from 6/4/21 to 8/31/21 which is when dissolved oxygen concentrations tend to seasonally drop with increased air temperatures*. **Because of this, mean values may appear to be higher than what actually occurred, and caution should be taken when comparing values across years.*** Mean dissolved oxygen ranged from a minimum of 6.32 mg/L at station Johnsons Creek 1 and a maximum of 7.70 mg/L at station Johnsons Creek 3 (Figure 2.E.4). The similarity of dissolved oxygen concentrations at the surface and the bottom in Lewis Gut is due in part to the waters being better mixed in this section of the harbor than in Johnsons Creek. Dissolved oxygen values were lowest at the end of August and early September after which they increased prior to the last sampling event (Figure 2.E.5). Fourteen percent of the bottom dissolved oxygen observations were below 5 mg/L, and none were below 3 mg/L.

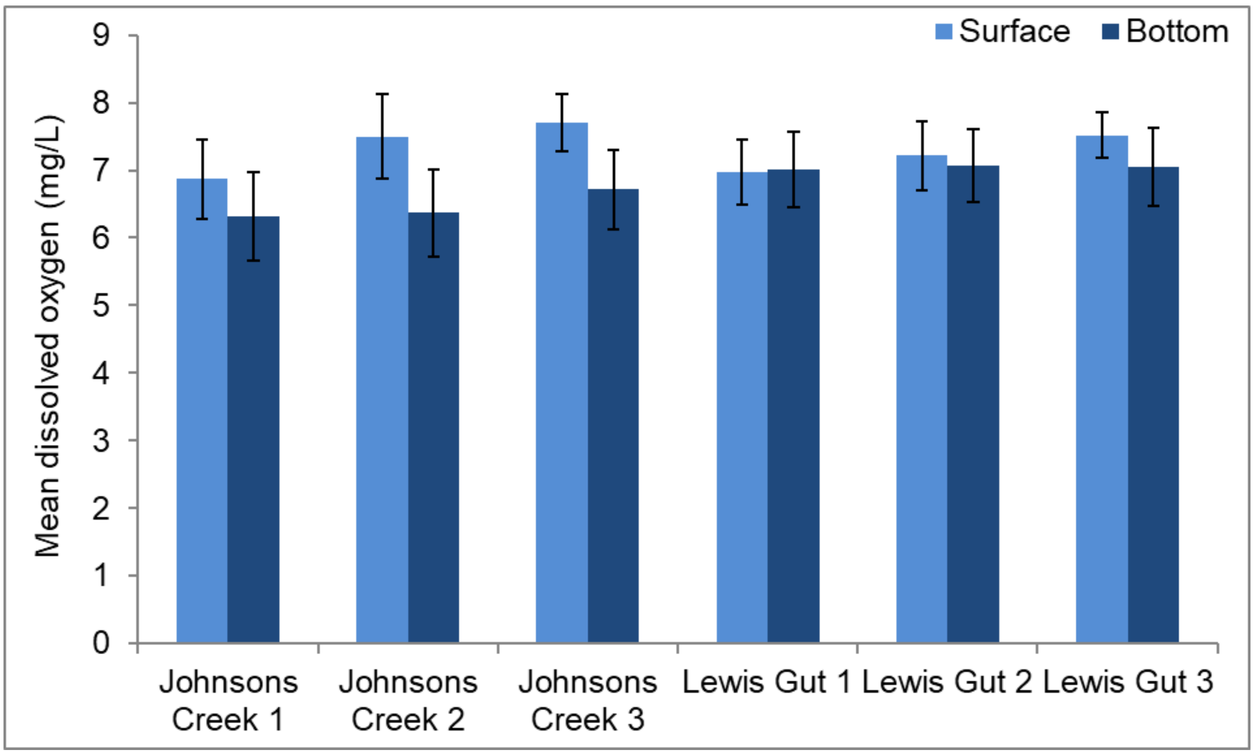


Figure 2.E.4. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in Johnsons Creek and Lewis Gut in 2021. Error bars represent standard error.

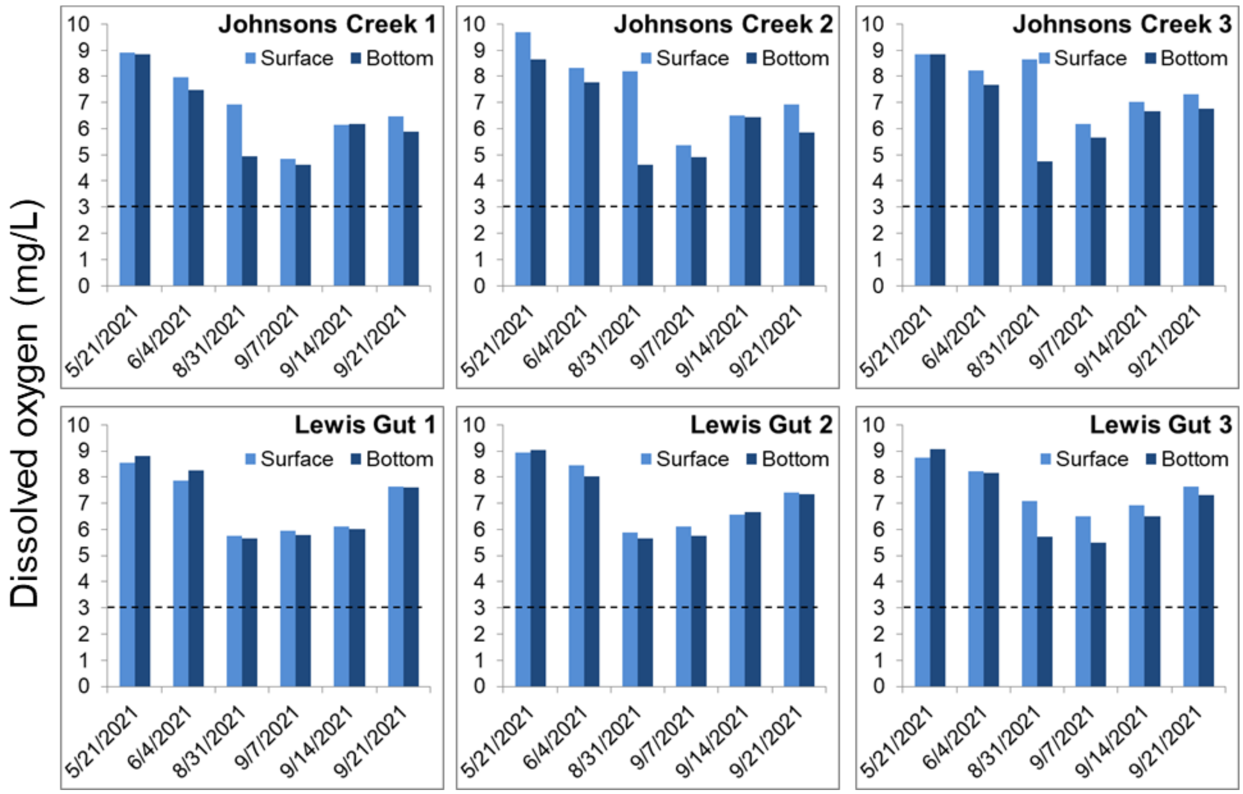


Figure 2.E.5. Surface and bottom dissolved oxygen values at each Johnsons Creek and Lewis Gut sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Please note x-axis is not to scale.

Chlorophyll a

Chlorophyll *a* samples were taken on 4 of the 6 sampling days in Johnsons Creek and Lewis Gut (Figure 2.E.6). Johnsons Creek and Lewis Gut can be classified as having medium eutrophic characteristics based on mean surface chlorophyll *a* concentrations (Table 2.1). Results are similar to those observed in past years (Crosby et al., 2020).

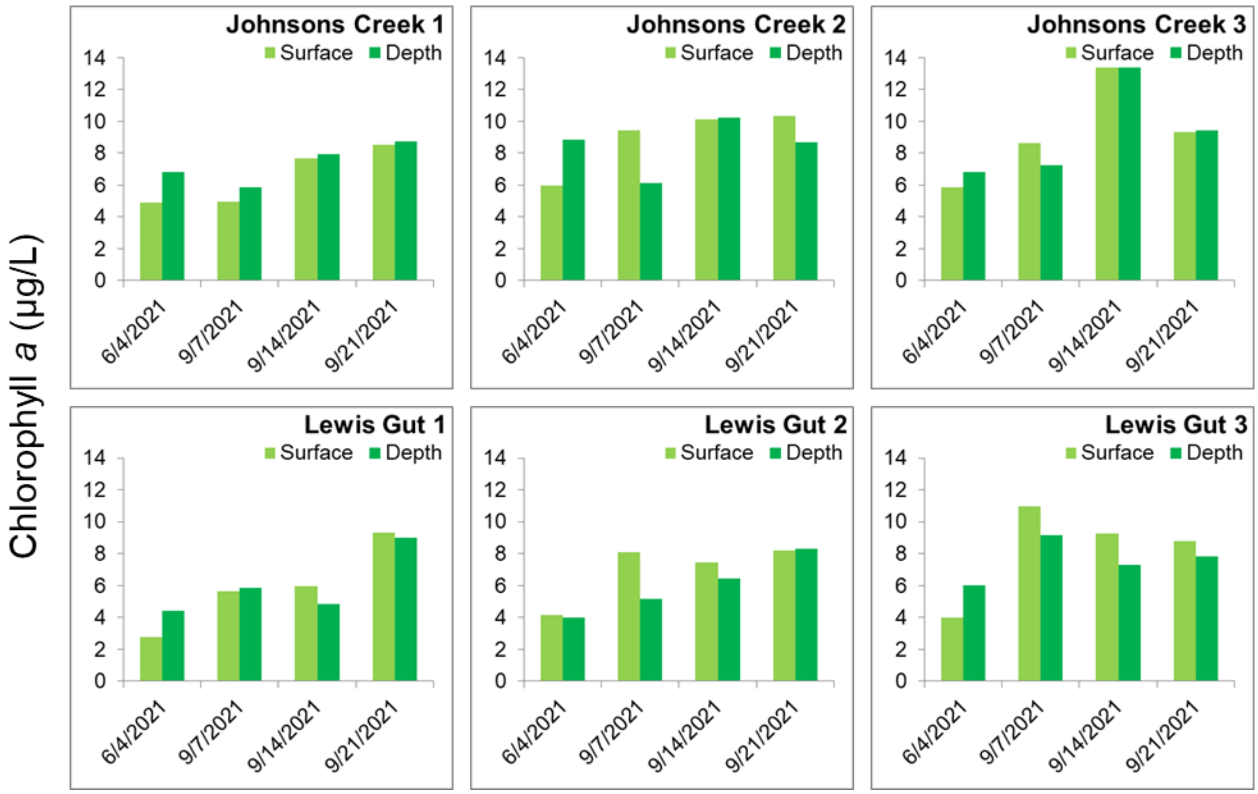


Figure 2.E.6. Surface and depth chlorophyll *a* values in Johnsons Creek and Lewis Gut in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale.

Water Clarity
Mean secchi depth readings ranged from a minimum of 1.52m at stations Johnsons Creek 1 to a maximum of 2.15m at station Lewis Gut 3. Mean secchi readings in Johnsons Creek are similar at all stations. Mean secchi readings in Lewis Gut increase from the inner stations to the outer stations.

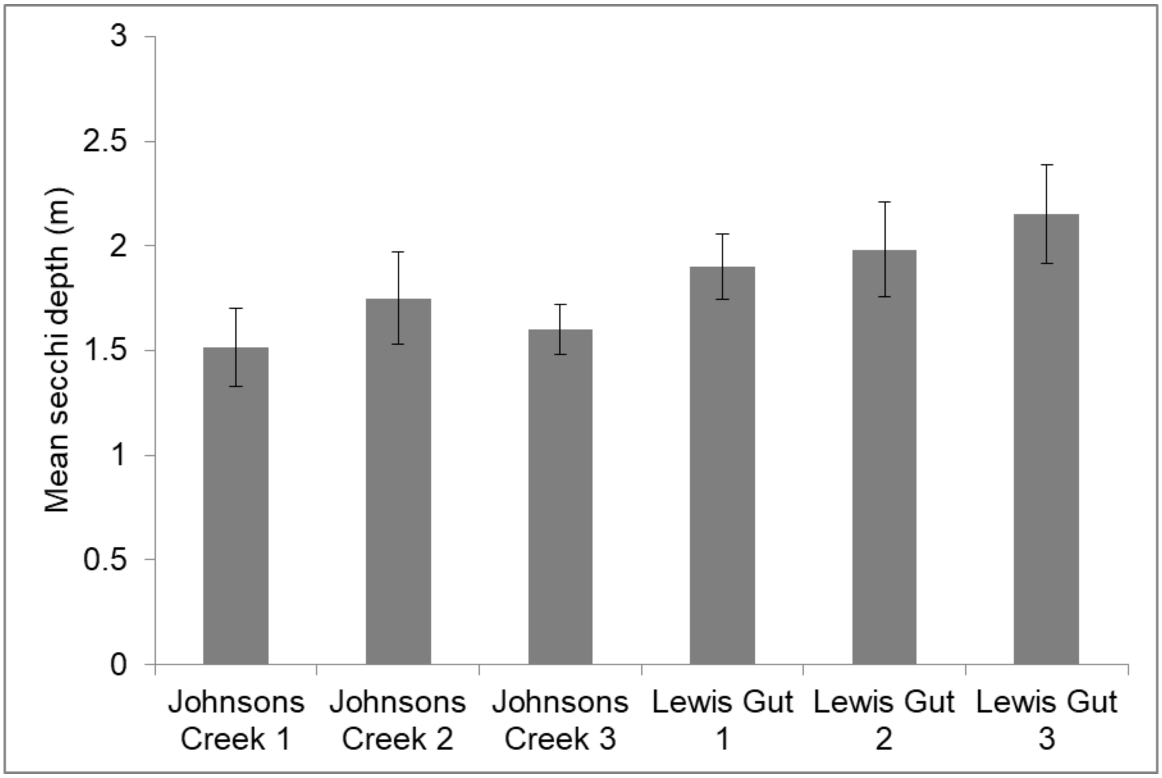


Figure 2.E.7. Mean secchi depth readings in the Johnsons Creek and Lewis Gut in 2021. Error bars represent standard error.

Temperature and Salinity
Temperature of the water in Johnsons Creek and Lewis Gut on average was cooler at the harbor bottom at all sites (Figure 2.E.8). Salinity was lower at the surface than the bottom in the Johnsons Creek stations, where the harbor is impaired by Bruce Brook and is less well mixed. There was no notable salinity gradient in Lewis Gut (Figure 2.E.9).

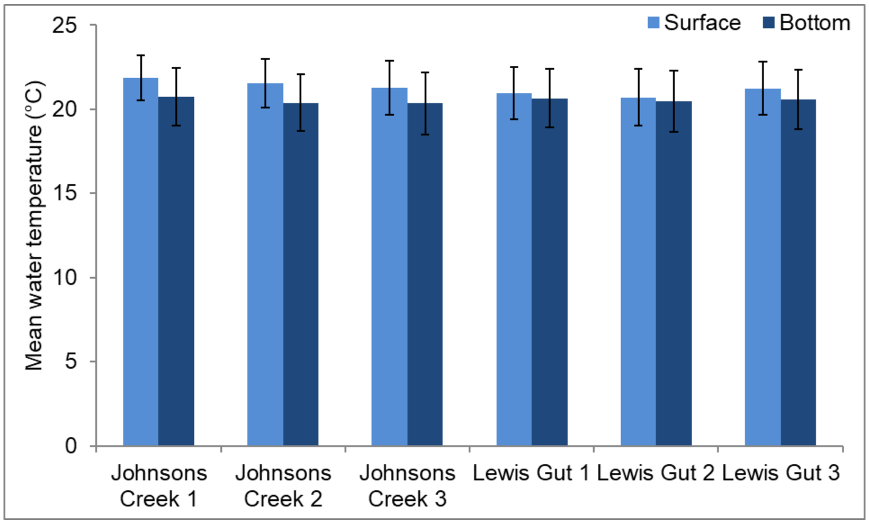


Figure 2.E.8. Mean water temperature at the surface and bottom at each sampling station in Johnsons Creek and Lewis Gut in 2021. Error bars represent standard error.

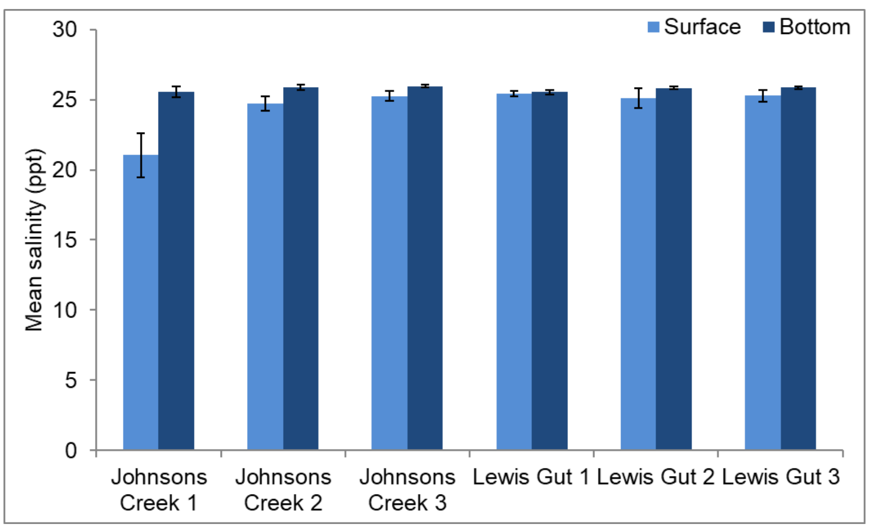


Figure 2.E.9. Mean salinity at the surface and bottom at each sampling station in Johnsons Creek and Lewis Gut in 2021. Error bars represent standard error.

F. Housatonic River

Developmental pressures on the east and west shorelines of the Housatonic River estuary offer a contrast in land use. The fully-developed west bank from the mouth of the estuary north to the I-95 Bridge contains two small parks, an abandoned engine plant, a closed Air and Space Center, Sikorsky Memorial Airport, a waste water treatment plant and three marinas (R. Harris, personal observations; Figure 2.F.1). The east bank's land use is different; the Charles E. Wheeler Wildlife Management Area includes a 625 acre tidal marsh at the mouth of the estuary and is protected from wave action by a barrier beach. Land use heading north is largely residential before reaching the I-95 Bridge, with a power plant to the north of the bridge (Figure 2.F.1). Flushing of the harbor is promoted by the wetlands as well as strong freshwater river currents. Flood tides are very strong and turbulent in this harbor due to the configuration of the outer harbor and the large crescent shape of the surrounding shoreline (Figure 2.F.2). As a result of these dynamic currents, the water column is well mixed throughout the harbor, as was observed at all 7 stations for dissolved oxygen, water temperature, and salinity (see figures on following pages). The estuary is fished by many different shellfish companies for seed oysters and many boats can be seen on its waters when the seed oyster season is open. The estuary was also notable for observations of the invasive Chinese Mitten Crab (*Eriocheir sinensis*) since 2019 by oyster fisherman. This crab is an invasive species from China and is known to cause great damage to river banks and structures if environmental conditions allow it to proliferate.

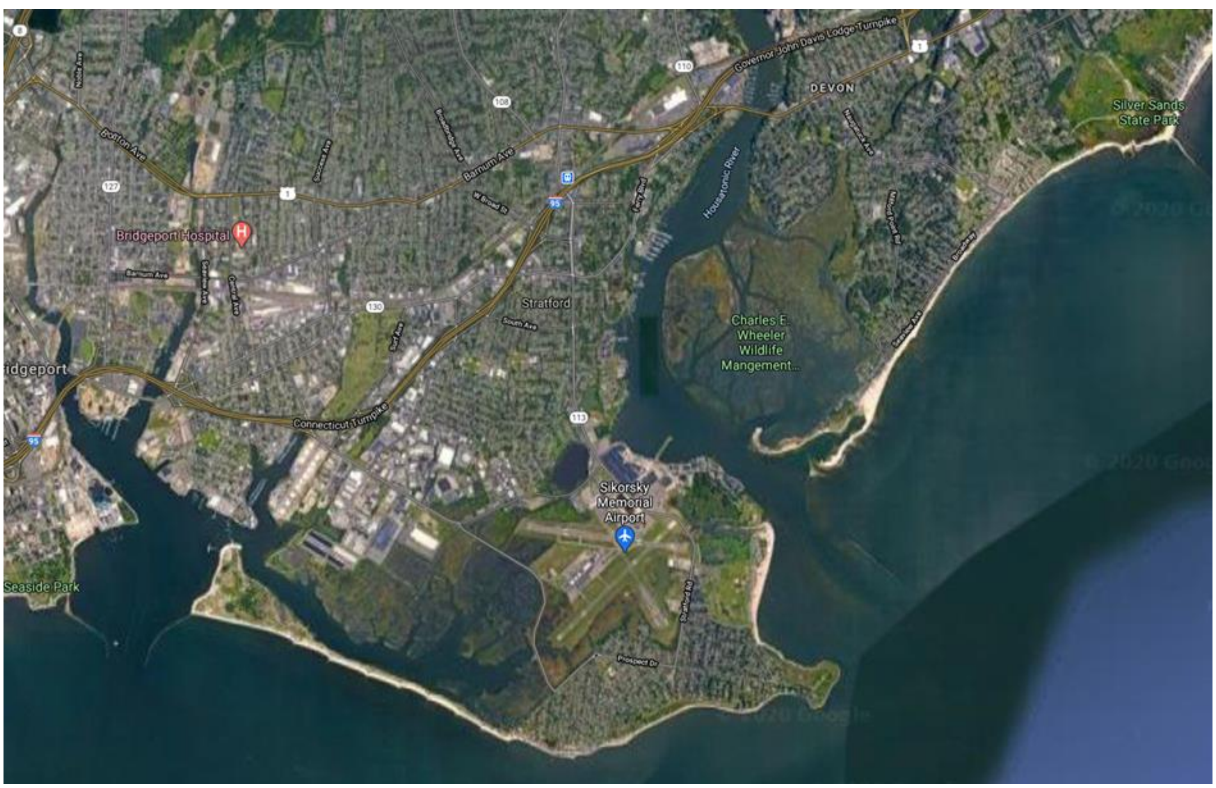


Figure 2.F.1. Aerial image of the Housatonic River and surrounding development and wildlife management area (photo source: Google Maps).

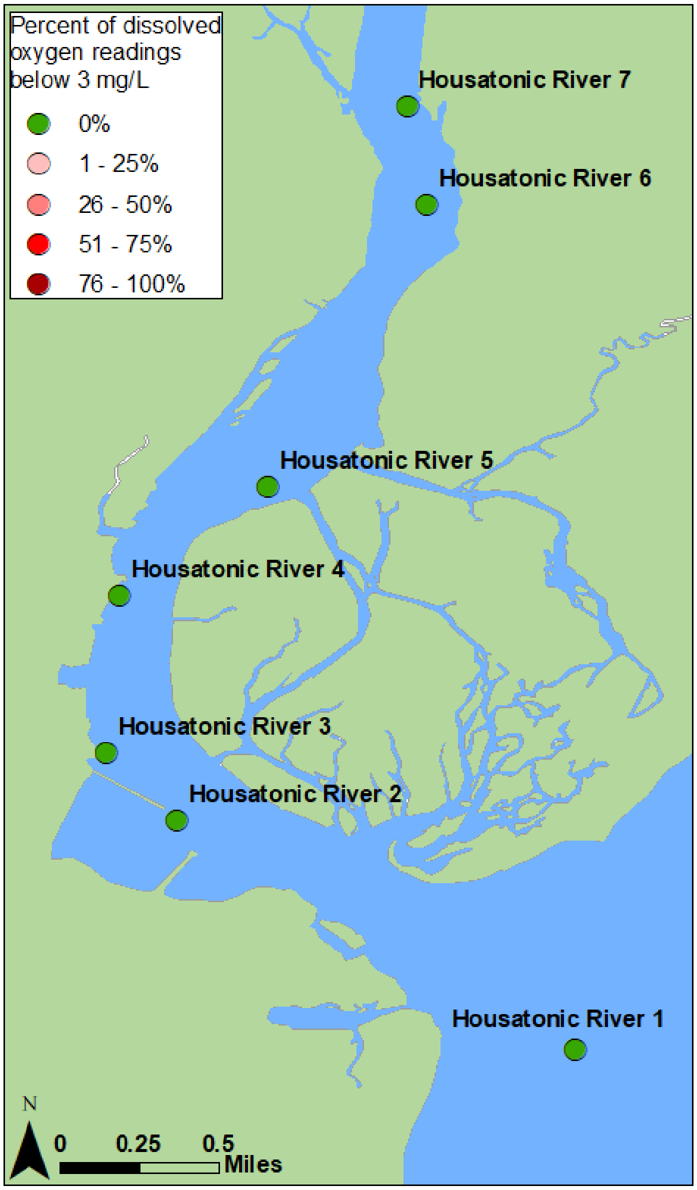


Figure 2.F.2. Map of Housatonic River sampling stations in 2021. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L.

Table 2.F.1. Coordinates and descriptions for each sampling station in Housatonic River

Site Name	Latitude	Longitude	Description
Housatonic River 1	41.164533	-73.102183	Nun buoy #4
Housatonic River 2	41.174983	-73.120333	Engine Plant Point
Housatonic River 3	41.178033	-73.12355	Nun buoy #14
Housatonic River 4	41.18525	-73.122917	Pilings
Housatonic River 5	41.190217	-73.11615	Can buoy #21
Housatonic River 6	41.203067	-73.10895	Nun buoy #24
Housatonic River 7	41.20755	-73.109833	Nun buoy #28

Dissolved Oxygen

Seven stations were monitored in Housatonic River on 6 days from June through October. Mean dissolved oxygen concentrations ranged from a minimum of 7.05 mg/L at the bottom of station Housatonic River 3 to a maximum of 7.77 mg/L at the surface of station Housatonic River 1 (Figure 2.F.3). Dissolved oxygen concentrations did not fluctuate much throughout the course of the monitoring season (Figure 2.F.4). All bottom dissolved oxygen observations exceeded 5 mg/L.

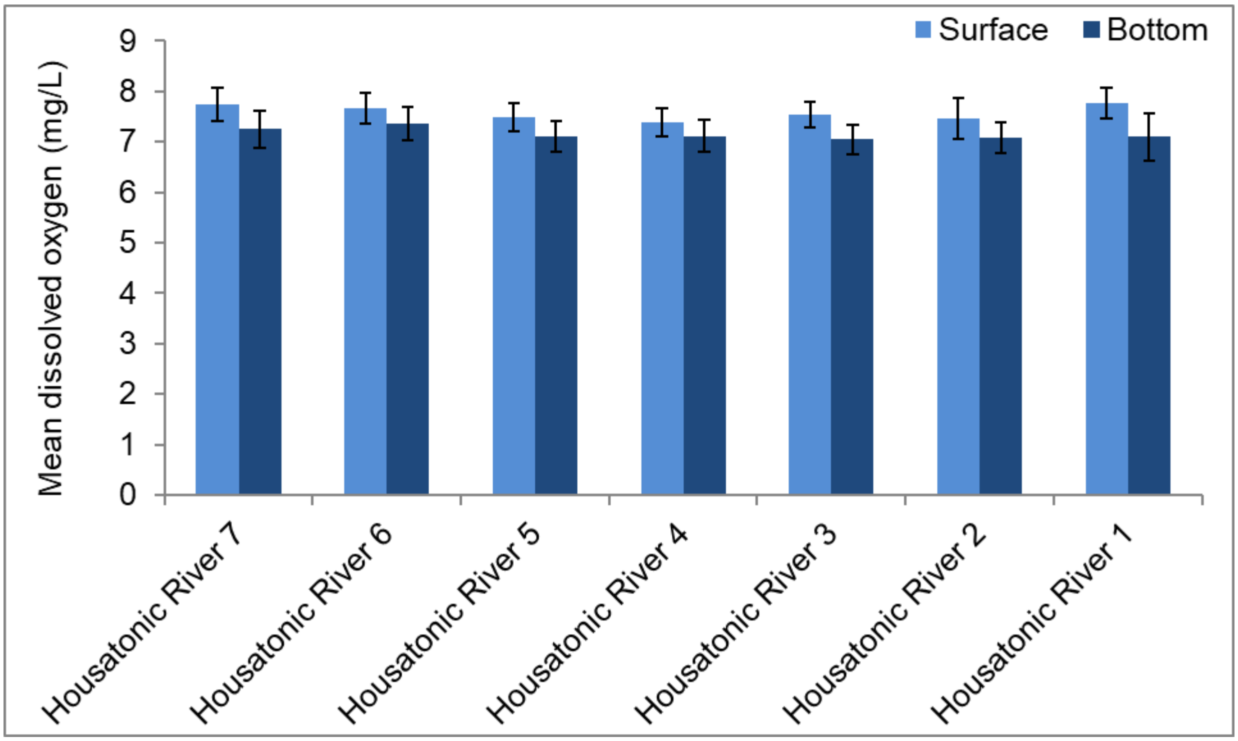


Figure 2.F.3. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in the Housatonic River in 2021. Error bars represent standard error.

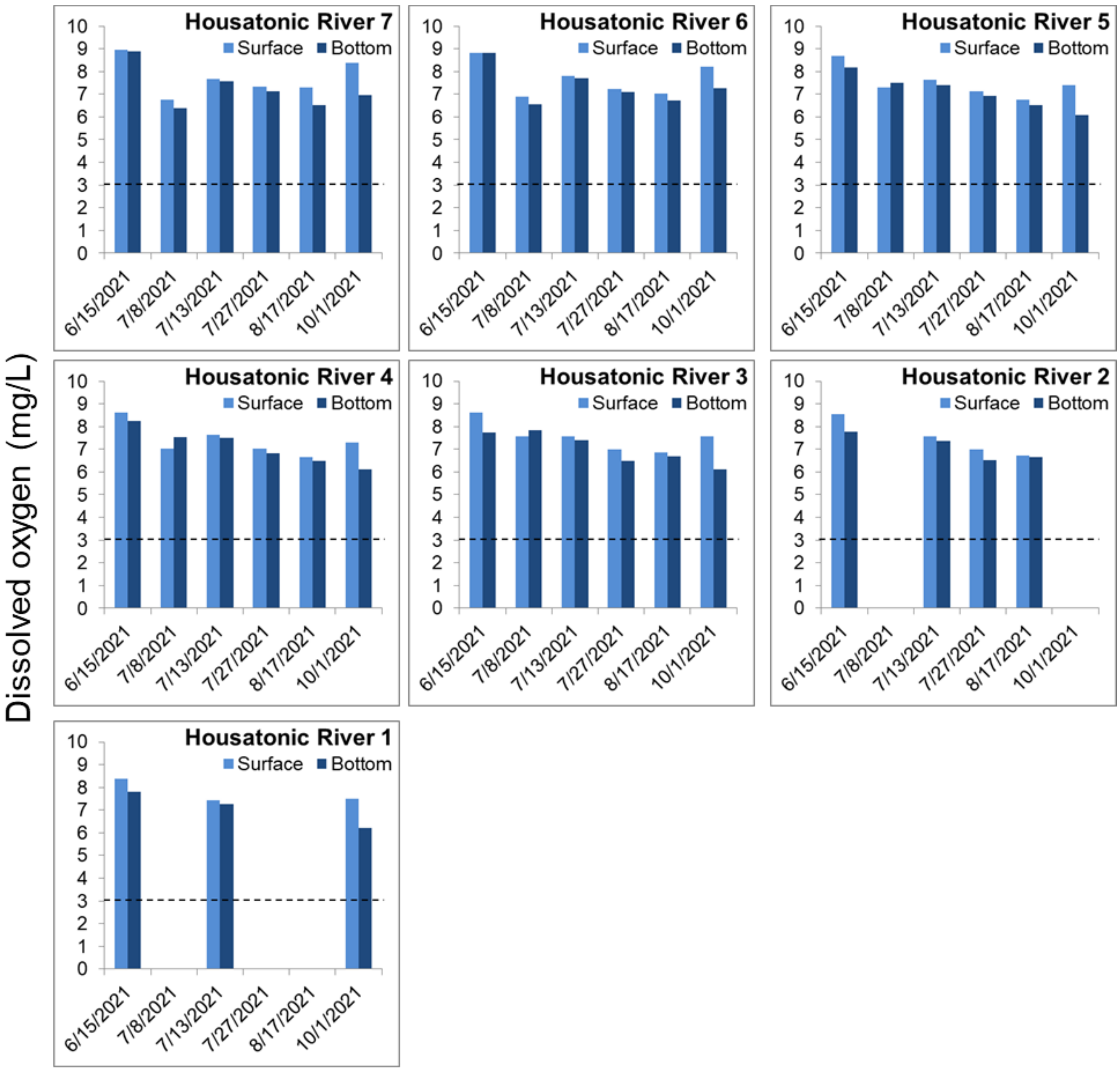


Figure 2.F.4. Surface and bottom dissolved oxygen values at each Housatonic River sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Stations Housatonic River 2 and Housatonic River 1 were not completed on 7/8/21, 7/27/21, 8/17/21, and/or 10/1/21 due to fast currents. Please note x-axis is not to scale.

Chlorophyll a

Samples were obtained on 5 of the 6 monitoring days in Housatonic River (Figure 2.F.5). Stations Housatonic River 2 and Housatonic River 1 were not sampled on 7/8/21. Mean surface chlorophyll *a* concentrations in Housatonic River can be characterized as low eutrophic (Table 2.1). This is lower than prior years (Crosby et al., 2020).

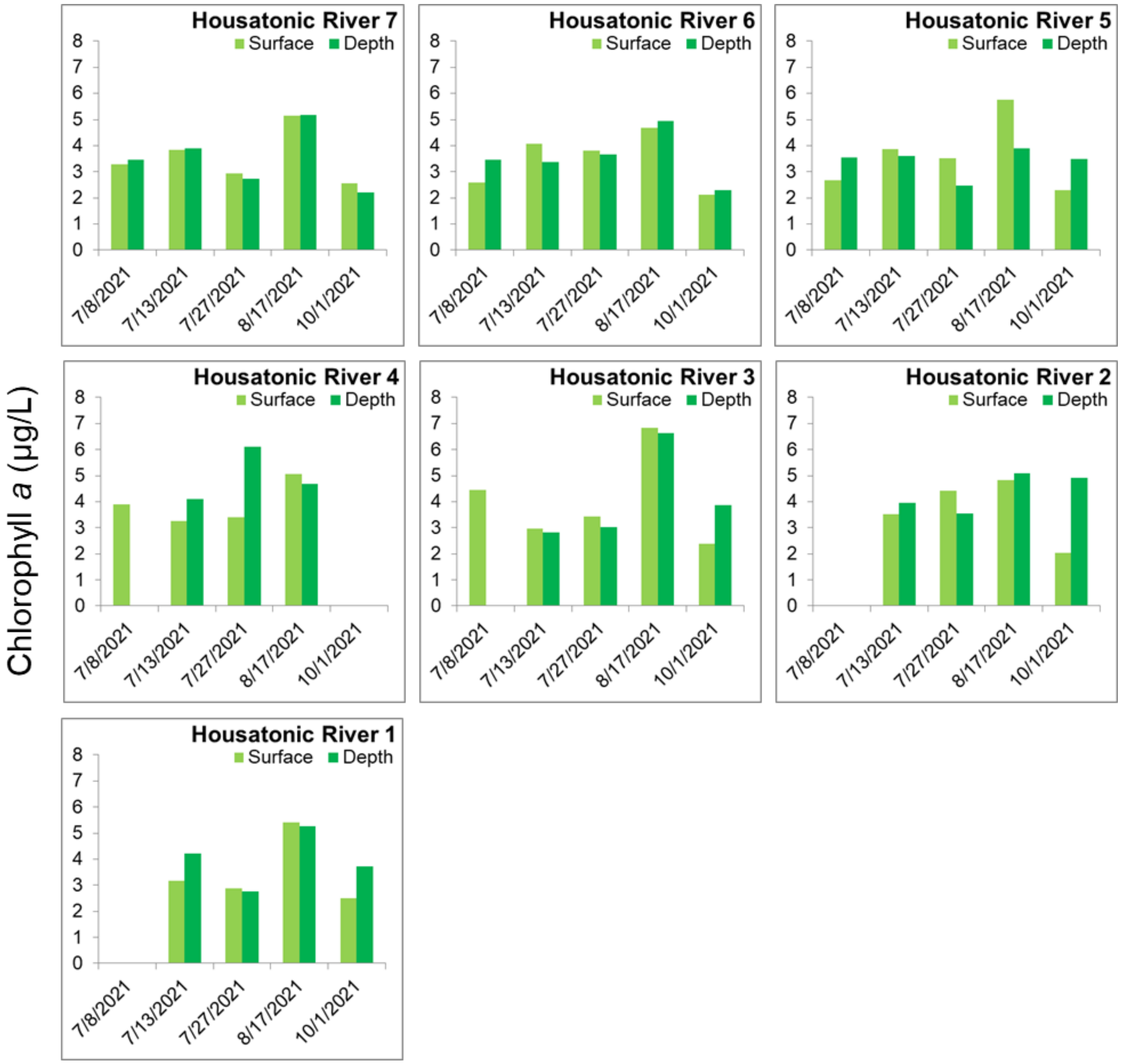


Figure 2.F.5. Surface and depth chlorophyll *a* values in Housatonic River in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale. Additionally, on 7/8/21 samples were mislabeled resulting in no data available for depth concentrations at stations Housatonic 3 and Housatonic 4. On 7/8/21 high winds prevented monitoring at stations Housatonic River 1 and Housatonic River 2. Also no samples were taken for station Housatonic River 4 on 10/1/21.

Water Clarity
Mean secchi depth readings ranged from a minimum of 1.28m at stations Housatonic River 1 and Housatonic River 2 to a maximum of 1.5m at station Housatonic River 4. Mean secchi readings were similar at all stations.

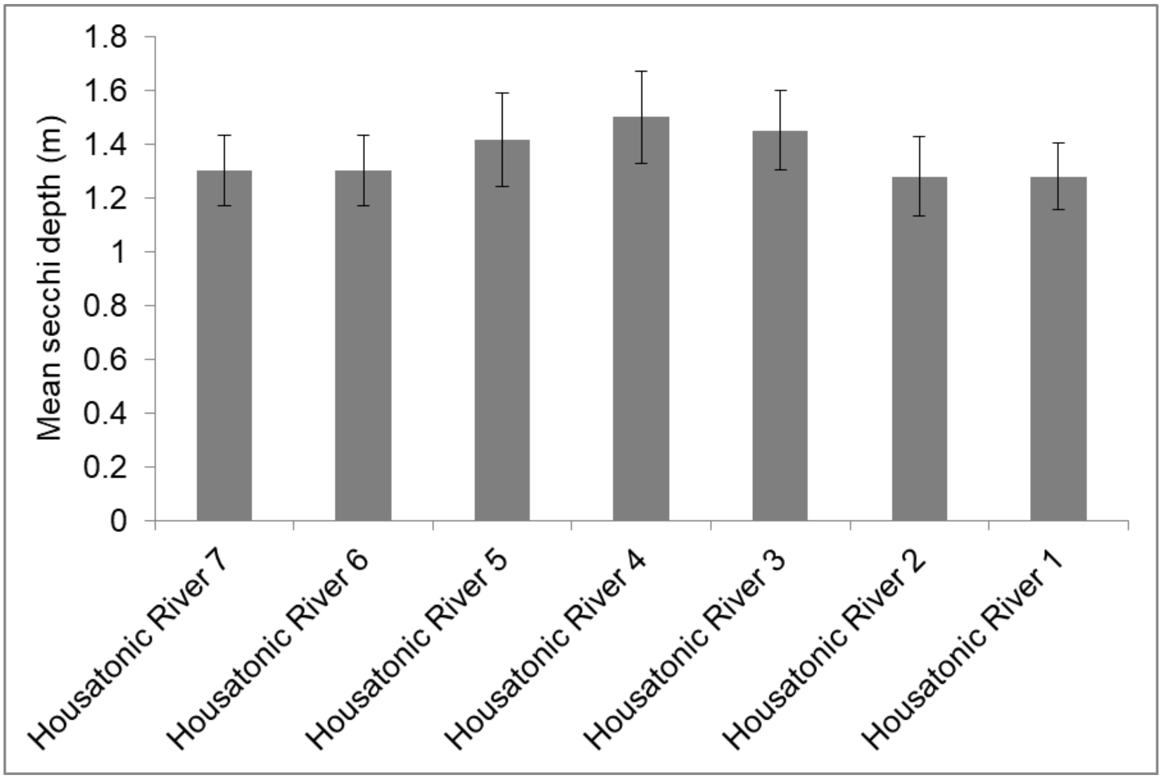
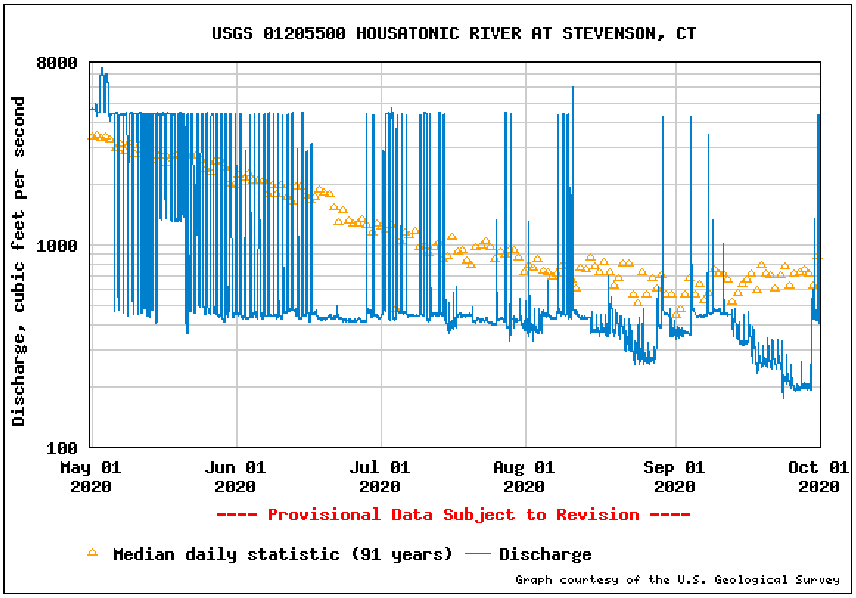


Figure 2.F.6. Mean secchi depth readings in the Housatonic River in 2021. Error bars represent standard error.

Housatonic River Discharge

The figures below illustrate discharge in cubic feet per second recorded at the United States Geological Survey monitoring station on the Housatonic River in Stevenson, CT. Yellow triangles represent the daily median value over the last 91 years, and the blue line represents the recorded discharge for a particular date. Discharge in 2021 followed a similar pattern to 2020 in May and June, but shifts to higher discharge from July through September due to numerous and frequent large precipitation events.



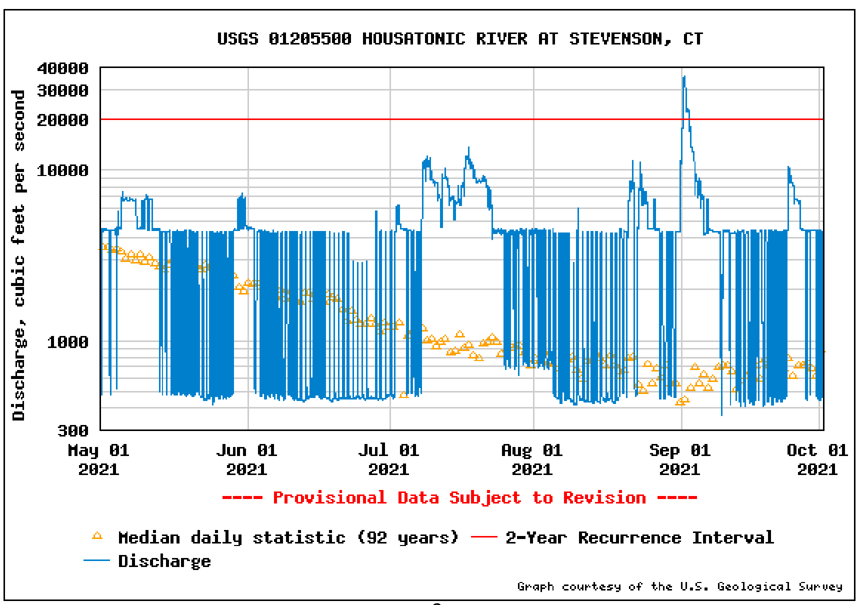


Figure 2.F.7. USGS flow data in ft^3/s for the period of May 1 through October 1, 2020 (top) and 2021 (bottom), respectively for the Housatonic River in Stevenson, CT (Graphs courtesy of the U.S. Geological Survey). Please note the difference in scale on the y-axis.

Temperature and Salinity

Mean water temperature in Housatonic River was similar throughout the water column in 2021, with temperature further upstream being slightly warmer than at the mouth of the harbor (Figure 2.F.8). Mean salinity was lower at the surface than the bottom at all stations due to the influence of fresh water from the Housatonic River (Figure 2.F.9). Variability in the observed salinity values was driven by extremely low salinity values observed at all sites on 7/13/21 likely caused by an extreme rainfall event on 7/9/21 that occurred within the large Housatonic Watershed. Salinity values in the upper river were again impacted by a second large rainfall event in mid-July.

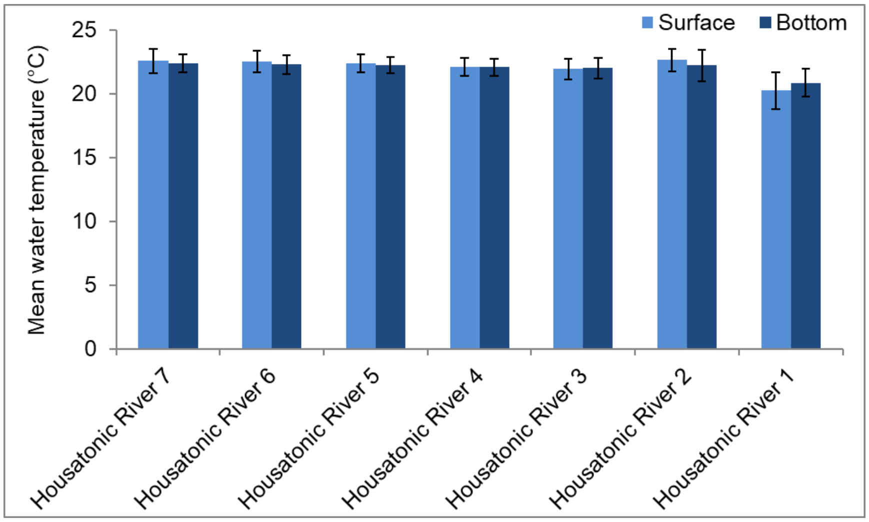


Figure 2.F.8. Mean water temperature at the surface and bottom at each sampling station in the Housatonic River in 2021. Error bars represent standard error.

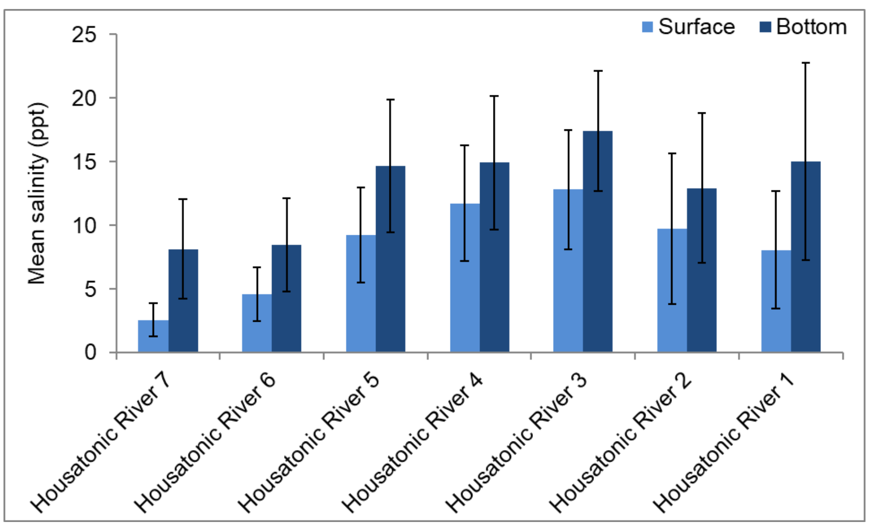


Figure 2.F.9. Mean salinity at the surface and bottom at each sampling station in the Housatonic River in 2021. Error bars represent standard error.

G. New Haven Harbor (Quinnipiac River section)

New Haven Harbor is an important estuary for the shellfish industry because it is a spawning ground for oysters. The Quinnipiac River supplies the fresh water flow at the northern end of the estuary, meeting the harbor near the I-91 bridge. The southern end of the estuary widens to a broad but shallow embayment south of the Ferry Street Bridge. The constricted area at the lower end of the basin (station Housatonic River 4) provides excellent tidal flushing for the whole basin on ebb tide. The upper portion of the estuary between the Ferry Street bridge and the I-91 bridge was studied for this water quality survey. Approximately 1.5 miles long by 0.25 miles wide, this portion of the estuary is a semi-enclosed basin. A protected wetland, the 35-acre Quinnipiac Meadows - Eugene B. Fargeorge Preserve, is located on the eastern shoreline along the upper portion of the estuary (Figure 2.G.1). The lower portion on the eastern shore, south of the Grand Avenue Bridge, is occupied by Copps Island Oysters harvesting facility and a barge refurbishing company. The land use on the western shore includes a marina and residential areas. The area south of the Grand Avenue Bridge is navigable by large vessels while the area north of the bridge becomes very shallow at low tide and is navigable only by small boats.

Figure 2.G.1. View of the large flushing basin in New Haven Harbor with extensive wetlands on the eastern shore.

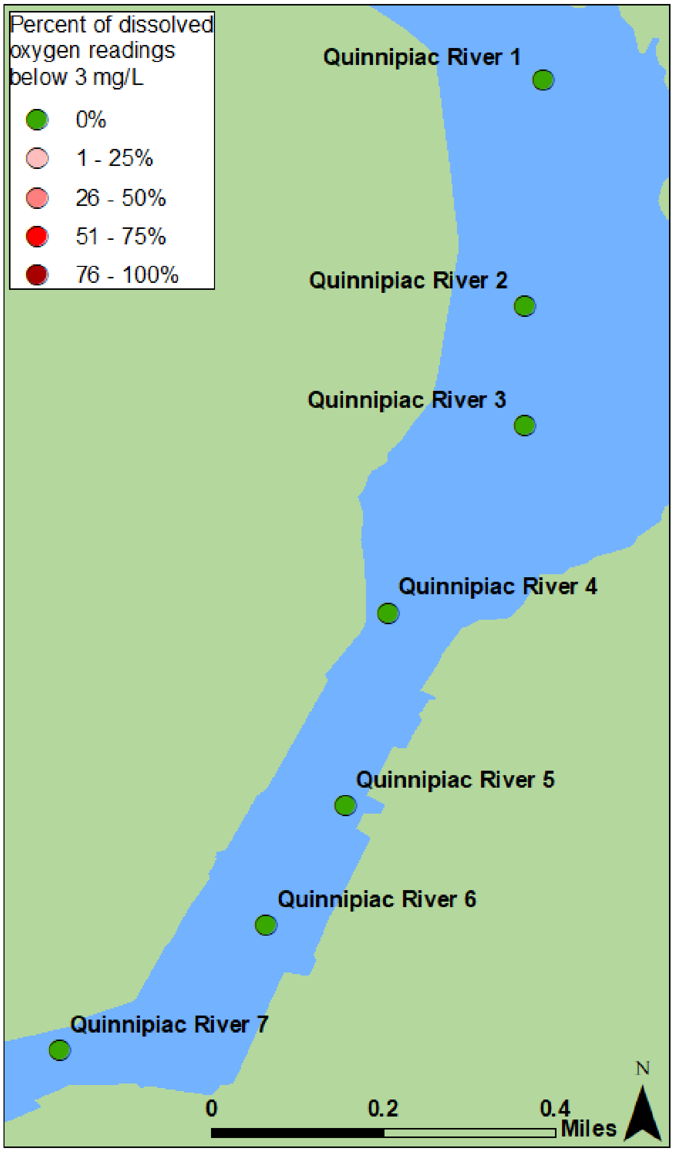


Figure 2.G.2. Map of Quinnipiac River sampling stations in 2021. Color of dots represents the % of sampling events with dissolved oxygen levels less than 3 mg/L.

Table 2.G.1. Coordinates and descriptions for each sampling station in Quinnipiac River

Site Name	Latitude	Longitude	Description
Quinnipiac River 1	41.318350	-72.885483	Mid-channel just north of Quinnipiac Meadows
Quinnipiac River 2	41.314550	-72.885783	Off of the Anastasio's Boathouse Cafe
Quinnipiac River 3	41.312550	-72.885800	Mid-channel south of Waucoma Yacht Club
Quinnipiac River 4	41.309409	-72.888093	Upstream from the Grand Ave Bridge
Quinnipiac River 5	41.306167	-72.888817	South end of the shell pile on Quinnipiac Ave
Quinnipiac River 6	41.304167	-72.890133	Four pilings
Quinnipiac River 7	41.302067	-72.893617	Ferry Street Bridge

Dissolved Oxygen

Seven stations were monitored in the Quinnipiac River on 6 days, from May through September, but no monitoring was conducted during the month of June. Sampling was not completed at sites Quinnipiac River 6 and Quinnipiac River 7 on 7/20/21 due to engine issues. Mean dissolved oxygen concentrations ranged from a minimum of 5.72 mg/L on the bottom at station Quinnipiac River 3 to a maximum of 6.74 mg/L at the surface at station Quinnipiac River 6 (Figure 2.G.3). Dissolved oxygen values followed expected seasonal trends with the lower concentrations observed during warmer months of July and August. Twenty-eight percent of the bottom dissolved oxygen observations fell below 5 mg/L while no bottom dissolved oxygen values fell below 3 mg/L.

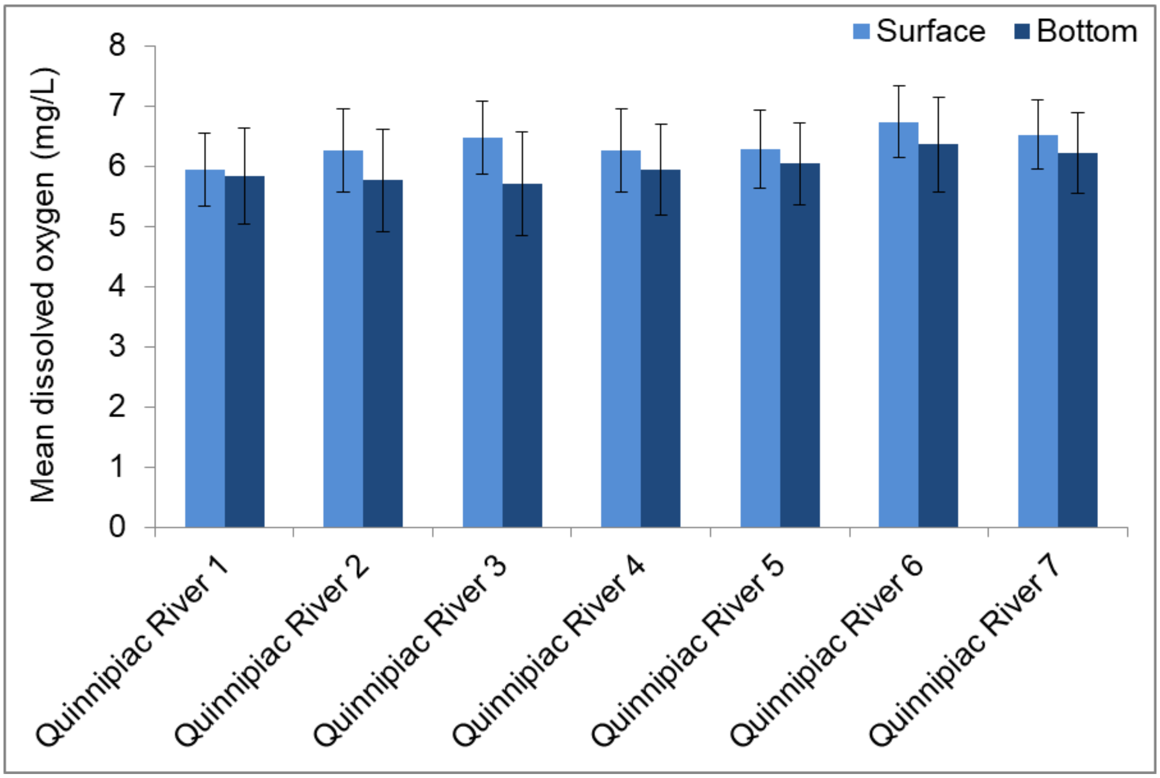


Figure 2.G.3. Mean dissolved oxygen concentrations at the surface and bottom at each sampling station in the Quinnipiac River in 2021. Error bars represent standard error.

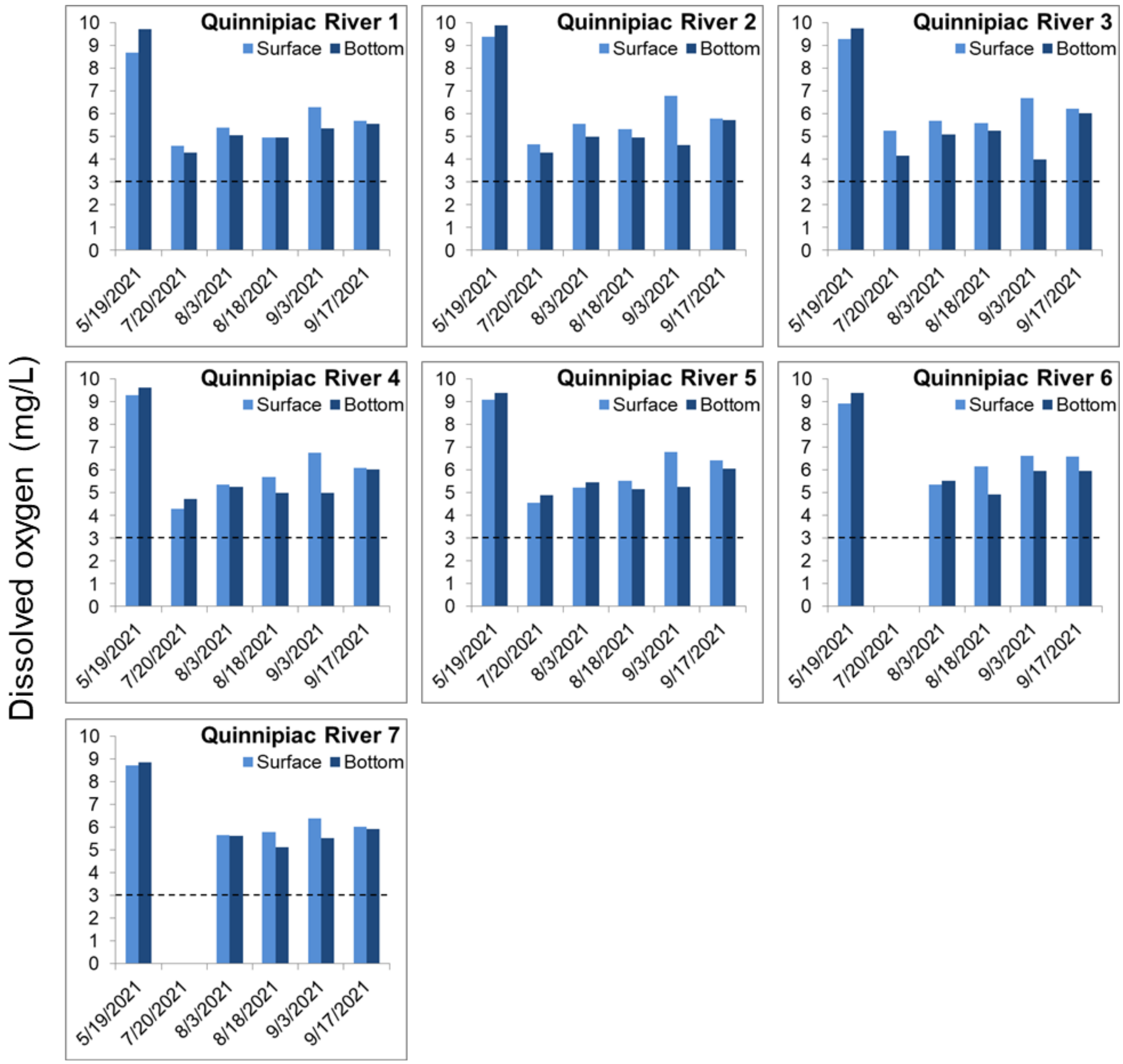


Figure 2.G.4. Surface and bottom dissolved oxygen values at each Quinnipiac River sampling station on each monitoring date during the 2021 season. The dotted line represents hypoxic conditions (3 mg/L). Stations Quinnipiac River 6 and Quinnipiac River 7 were not completed on 7/20/21 due to engine issues. Please note x-axis is not to scale.

Chlorophyll a

Samples were collected on 4 of the 6 monitoring days in the Quinnipiac River (Figure 2.G.5). Stations Quinnipiac River 6 and Quinnipiac River 7 were not monitored on 7/20/21. Mean surface chlorophyll *a* concentrations in the Quinnipiac River can be characterized as medium eutrophic (Table 2.1). This is a higher classification than the low eutrophic classification in 2020 (Crosby et al., 2020).

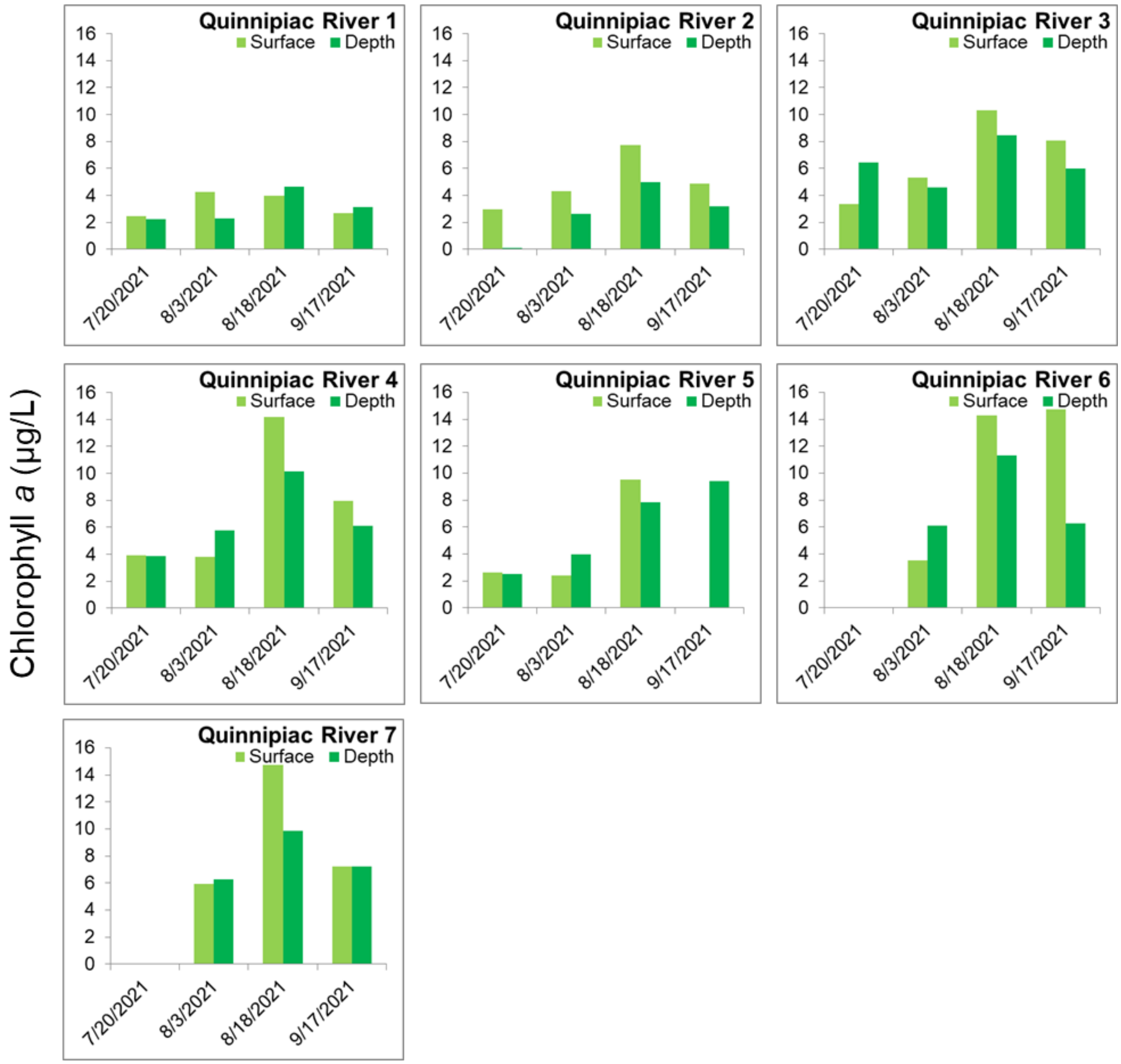


Figure 2.G.5. Surface and depth chlorophyll *a* values in the Quinnipiac River in 2021. Light green bars represent surface samples and dark green bars represent samples collected at depth, which was either at 2m below the surface or the bottom if the depth during sampling was < 2m. Please note x-axis is not to scale. Samples were not taken on 7/20/21 at stations Quinnipiac River 6 and Quinnipiac River 7 due to engine issues.

Water Clarity
Mean secchi depth readings ranged from a minimum of 1.22m at station Quinnipiac River 6 to a maximum of 1.7m at station Quinnipiac River 7. Mean secchi readings were similar at all stations.

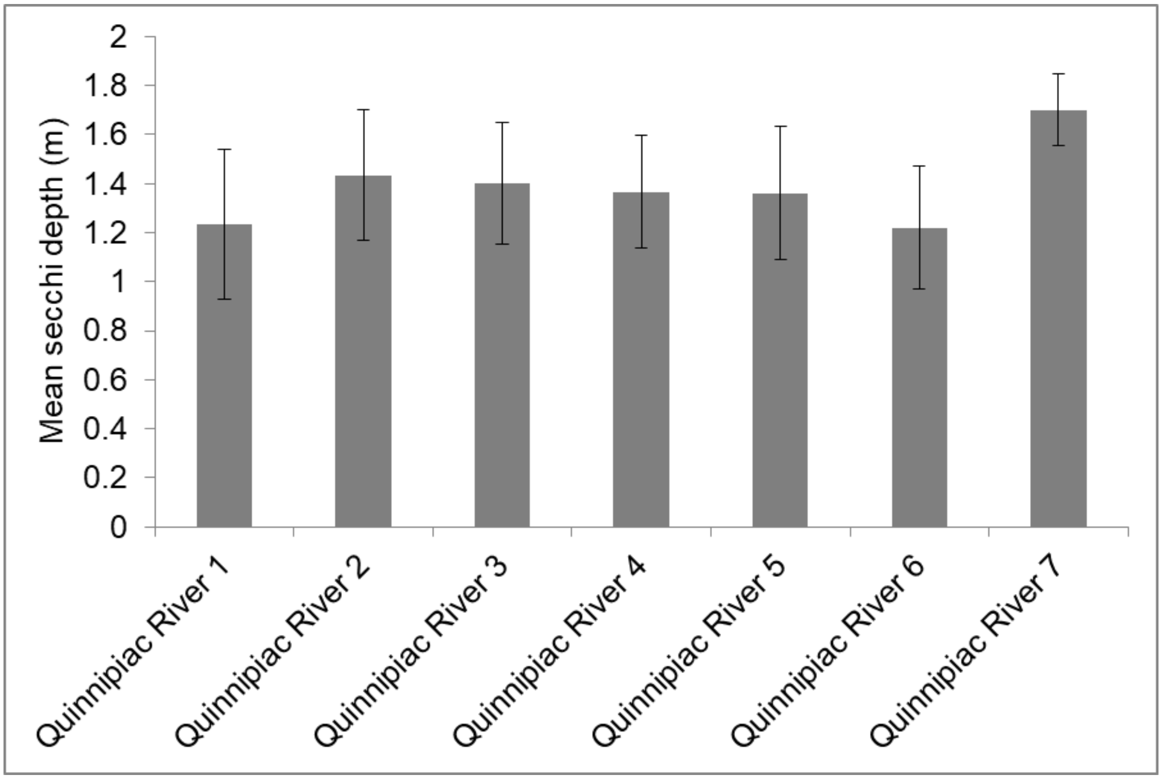
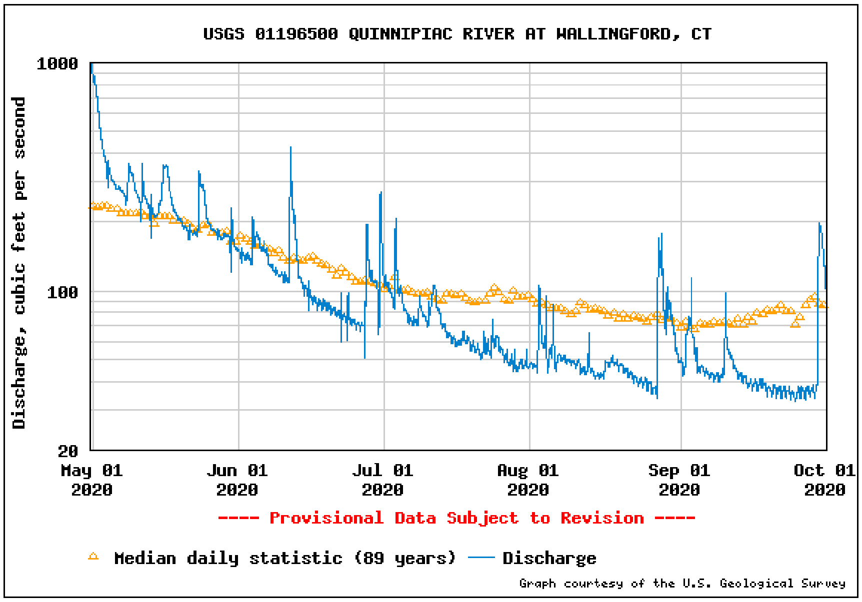


Figure 2.G.6. Mean secchi depth readings in the Quinnipiac River in 2021. Error bars represent standard error.

Quinnipiac River Discharge

The figures below illustrate discharge in cubic feet per second recorded at the United States Geological Survey monitoring station on the Quinnipiac River in Wallingford, CT. Yellow triangles represent the daily median value over the last 89 years, and the blue line represents the recorded discharge for a particular date. During 2021, the watershed experienced numerous and large precipitation events specifically from July through September which caused discharge to be much higher than what was observed in 2020 as well as against the median daily statistic.



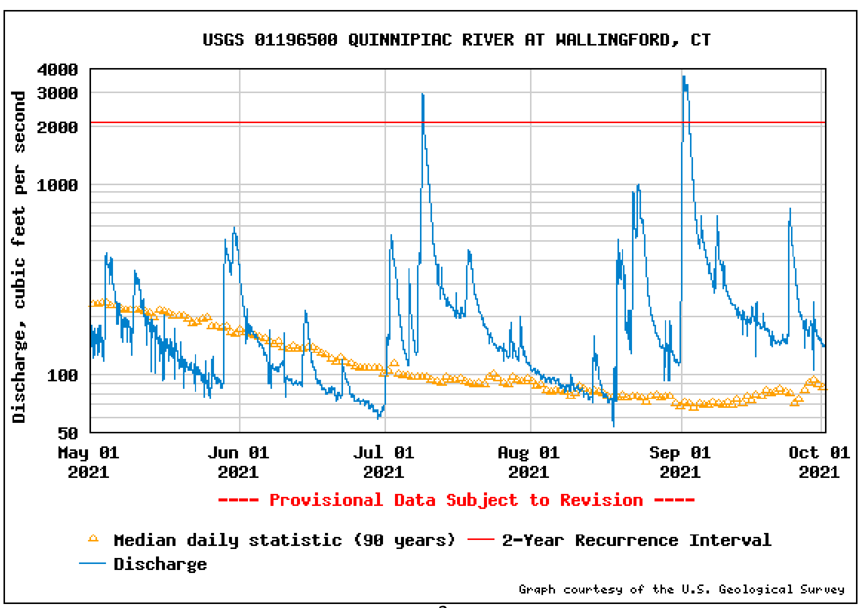


Figure 2.G.7. USGS flow data in ft^3/s for the period of May 1 through October 1, 2020 (top) and 2021 (bottom), respectively for the Quinnipiac River in Wallingford, CT (Graphs courtesy of the U.S. Geological Survey). Please note the difference in scale on the y-axis.

Temperature and Salinity

Mean water temperature in the Quinnipiac River was observed to be similar throughout the water column in 2021 (Figure 2.G.8). Salinity was slightly lower at the surface than the bottom at all stations due to fresh surface water from the Quinnipiac River (Figure 2.G.9).

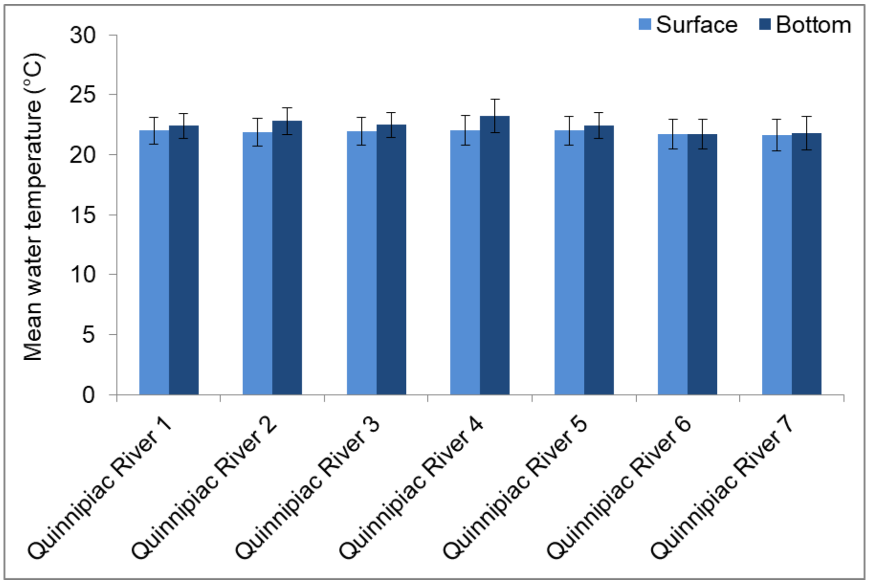


Figure 2.G.8. Mean water temperature at the surface and bottom at each sampling station in the Quinnipiac River in 2021. Error bars represent standard error.

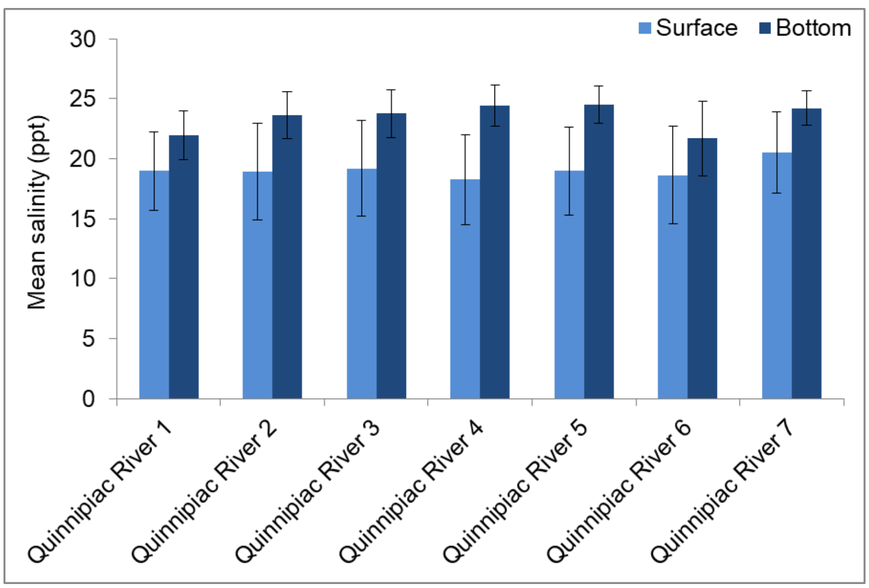


Figure 2.G.9. Mean salinity at the surface and bottom at each sampling station in the Quinnipiac River in 2021. Error bars represent standard error.

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