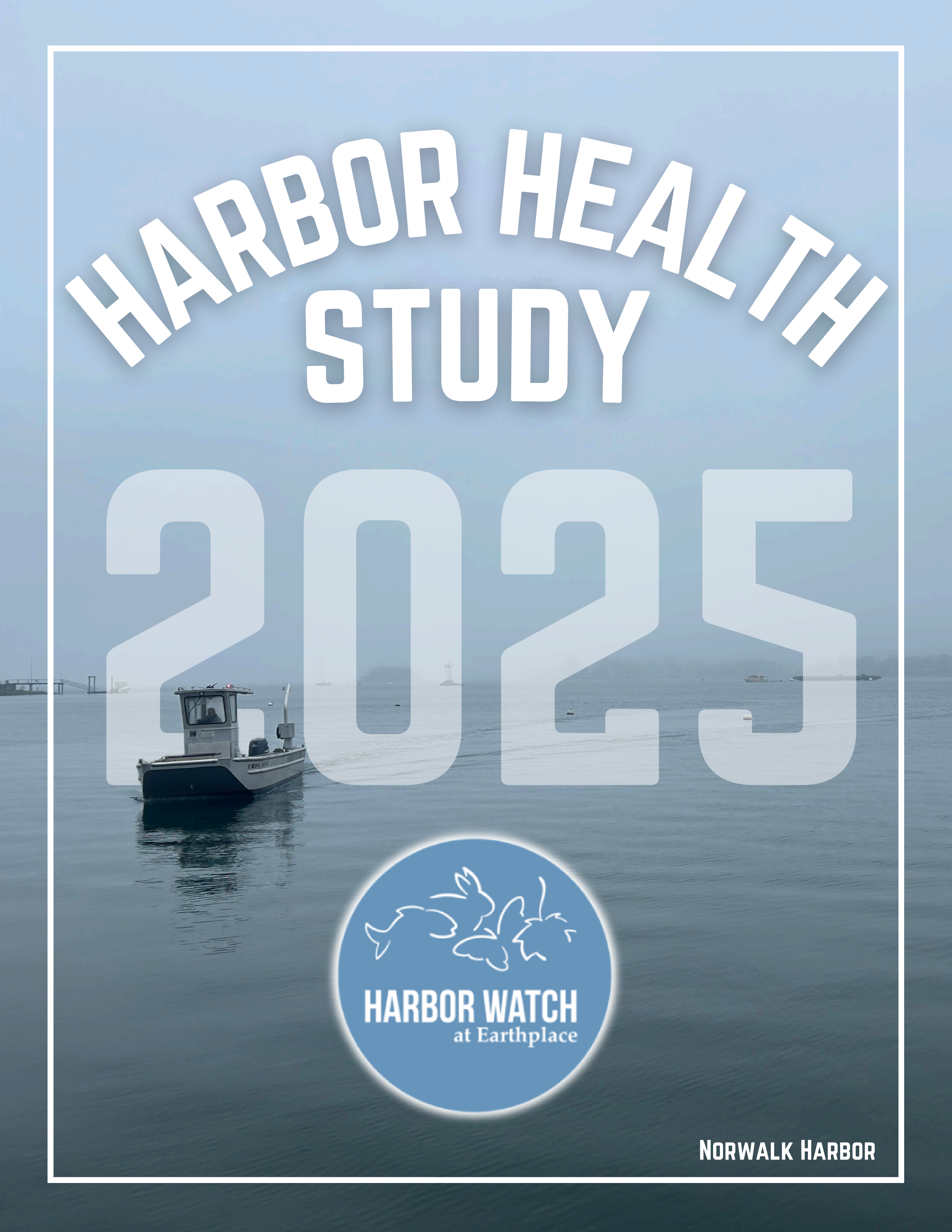
# HARBOR HEALTH STUDY

# 2025



HARBOR WATCH
at Earthplace

NORWALK HARBOR

## Contents

# 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 blend science, conservation, and education into pathways for learning about nature and the environment with access for all.

Since its inception, Harbor Watch has monitored hundreds of sites for a variety of physical and biological parameters and 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.

**Visit www.harborwatch.org for more information!**

*This report includes data on:*
Water quality and demersal fish and invertebrates in Norwalk and Saugatuck Harbors

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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 2025 on the water quality and the fish and invertebrate communities in the Norwalk and Saugatuck Harbors in Connecticut.

Harbor Watch began conducting a dissolved oxygen profile study in Norwalk Harbor in 1986. A fish study of that harbor and Saugatuck 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 [CT DEEP]) Fisheries Bureau. Since then, the Norwalk and Saugatuck Harbors have been monitored seasonally for species diversity and abundance for various periods of time. In 2017, Harbor Watch became a part of the Unified Water Study (UWS), a collective effort led by Save the Sound to monitor water quality parameters, such as dissolved oxygen and chlorophyll, throughout embayments around the Long Island Sound. Starting with Norwalk Harbor and then adding Saugatuck Harbor in 2024, Harbor Watch has monitored the water quality in the embayments annually.

From May through October 2025, water quality data were collected in the Norwalk and Saugatuck Harbors. The parameters monitored include species richness and diversity, dissolved oxygen, temperature, salinity, chlorophyll *a*, and turbidity.

## Water Quality Parameters

### Dissolved Oxygen

The amount of oxygen in the water available for aquatic and marine species.

### Temperature

The degree of heat present. Different species of organisms have different temperature tolerances.

### Salinity

The amount of dissolved salt in the water. Shows the influence of freshwater inputs.

### Chlorophyll

Measures the amount of phytoplankton in the water which is directly related to the amount of nutrients in the water.

### Turbidity

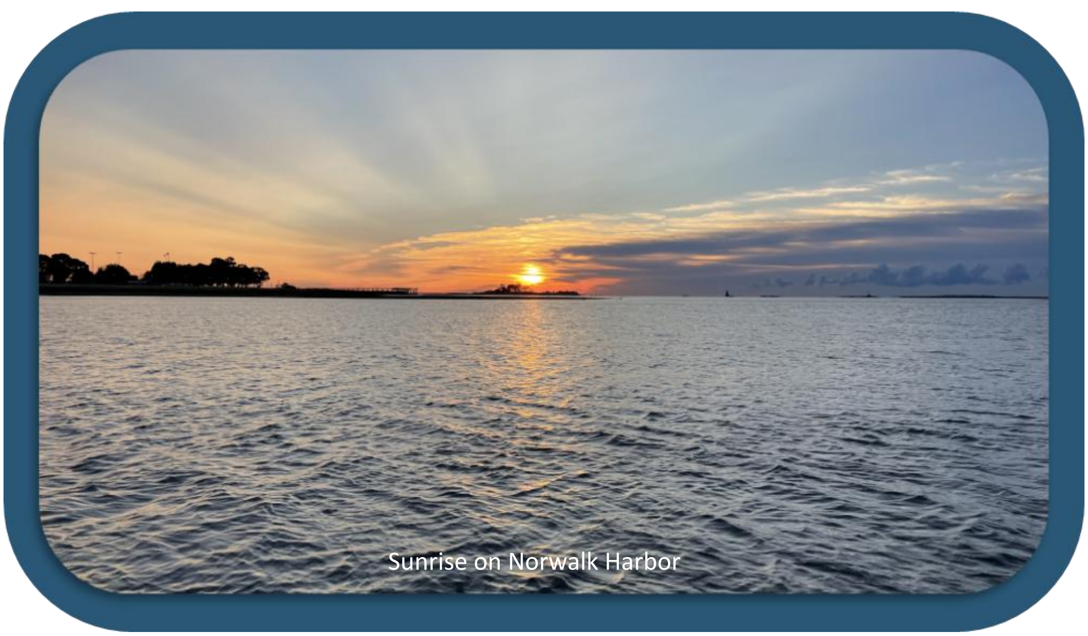
Measures the distance light can travel through water which directly impacts aquatic plant growth and fish survival.

## Estuaries: Where Rivers Meet the Sea

Estuaries, such as Long Island Sound, are some of the most productive ecosystems on Earth, comparable to tropical rainforests (Havens et al., 2012). They are bodies of water and surrounding wetlands usually found where rivers drain into the sea, creating brackish water (a mixture of fresh and salt water). These unique ecosystems are incredibly important because they serve as a nursery to about 75% of the fish caught commercially, in addition to many species of birds and other shore animals (NOAA, 2025). Not only are estuaries habitats where much of life begins, but they also provide food and refuge for many animals and serve as natural filters for runoff after rain events. Additionally, they protect the shoreline from erosion, storm surges, and flooding (NOAA, 2024). Estuaries are also places where we live, recreate, and work. Economically, they contribute billions of dollars a year to the US economy through fishing (commercially and recreationally), trade, and tourism (NOAA, 2024). One of the commercially fished species found in Long Island Sound is Winter Flounder (*Pseudoplueronectes americanus*), which rely on the proper functioning of the entire estuary in order to be healthy and abundant. Due to their sensitivity to stressful environmental conditions, Winter Flounder, as well as other fish species, can be used as indicators of estuarine health.

**Estuaries are home to 75% of the fish caught commercially**

Because of their importance, the US government created the National Estuarine Research Reserve System (NERRS) to protect and study over a million acres of estuarine land and water around the US (NOAA, 2025). In 2022, more than 52,000 acres of the Long Island Sound and surrounding lands in southeastern Connecticut were designated into NERRS (NERRS, n.d.).



Sunrise on Norwalk Harbor

## Norwalk Harbor

Norwalk Harbor is an active estuary, used year-round both commercially and recreationally. With operations active since the 1800s, the harbor is most recognized for its renowned shellfishing industry. Within the local community, the harbor is also known for its beaches, dining, boating, and other attractions. The Norwalk Islands, part of the Stewart B. McKinney National Wildlife Refuge, are positioned just outside the harbor and help to protect the inner harbor from the effects of extreme weather events like hurricanes, as well as serving other valuable and important environmental roles to the harbor (Long Island Sound Partnership, n.d.).

During Harbor Watch's almost 30 years of studying 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 with a noticeable decline in black-crowned night herons, green herons, and snowy egrets (personal observations, R. Harris).


View of the western coastline of Norwalk Harbor

With a dedicated network of volunteers, Harbor Watch has been quantifying the abundance and species composition of fish and invertebrates in the harbor, focusing on demersal species. Sampling was conducted from 1990 through 1994, and then again from 2002 to today. Harbor Watch also has water quality data on dissolved oxygen, salinity, and temperature, spanning back to 1989. These extensive data sets are important because they provide a long-term view of how the harbor has changed over the years.

## Saugatuck Harbor

Saugatuck Harbor is a shallow estuary affected by significant seasonal use. While the harbor is most active during the warmer months due to its well-known beaches, marinas, and recreational boating, it still supports boating activities throughout the whole year. Over time, the harbor has become more challenging to navigate due to increased siltation, likely driven by large storm events. As the area has not been dredged in decades, these deposits have created new navigational hazards at low tide.


View looking south in Saugatuck Harbor

The harbor serves as the drainage basin for the Saugatuck River watershed. This is an extensive watershed, comprised of over 57,000 acres of land and over 240 miles of waterways (Harold, 2006). Harbor Watch has conducted trawling in Saugatuck Harbor every year from 1990-1995, sporadically from 2002-2014, and then resumed in 2024 to date. Additionally, Harbor Watch has collected water quality data on dissolved oxygen, salinity, and temperature periodically since 1993.

Harbor Watch's Research Vessel, RV Sarah Nicole

# Methods

## Embayment Biological Study

The Embayment Biological Study (EBS) conducted in 2025 follows protocols detailed in Quality Assurance Project Plan (QAPP) QA Tracking #25002 for Embayment Biological Study in Fairfield County Harbors approved by CT DEEP on 3/21/25.

Harbor Watch conducted trawls on the research vessel Sarah Nicole, a 24' Seamule equipped with an electric pot hauler for trawl retrieval. From May to September in the Norwalk Harbor and May to early October in the Saugatuck Harbor, a crew of two Harbor Watch staff members, who served as captain and deck hand, and up to six additional staff and/or trained volunteers, who assisted the deck hand, trawled in each harbor. A grid system, established by CT DEEP in 1990, boxed off both harbors into 300m$^2$ sampling areas. Norwalk Harbor has a total of 20 boxes and Saugatuck Harbor has 24 boxes (Figure M1). During each trawling session, typically a minimum of six of the sampling area "boxes" were selected to trawl. An attempt was made to sample from each of the upper harbor (Norwalk Harbor: boxes A-F, Saugatuck Harbor: boxes A-E), middle harbor (Norwalk Harbor: boxes G-N, Saugatuck Harbor: boxes F-M, P-R), and outer harbor (Norwalk Harbor: boxes O-T, Saugatuck Harbor: boxes N, O, S-X) on each sampling day. When the research vessel was positioned within the selected box using a Garmin navigational system, the 1m beam trawl was launched off the port 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.

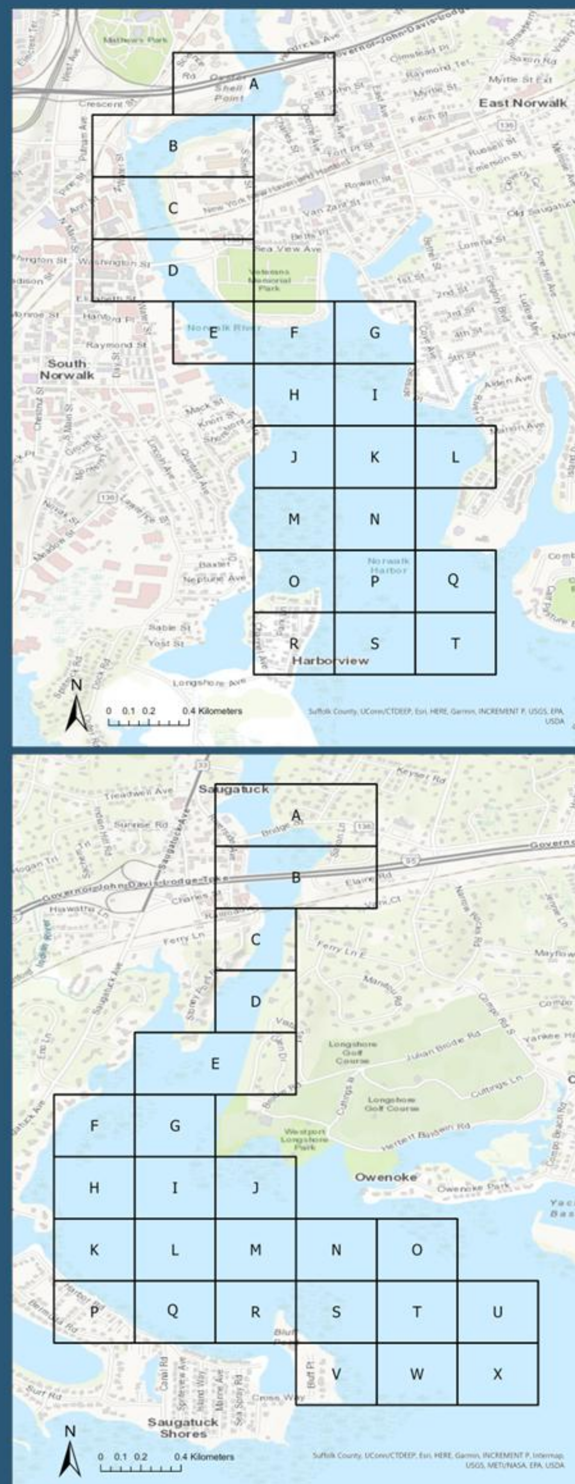



**Figure M1**. Location of trawling sampling areas or "boxes" within Norwalk Harbor (top map) and Saugatuck Harbor (bottom map).

Each box was trawled for three minutes at three miles per hour. Coordinates, time, and surface water temperature were recorded where the trawl was launched. At the end of the three minutes, coordinates and time were recorded and the trawl was pulled back onto the boat using the pot hauler. The net was removed from the trawl beam 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. Any trash found in the trawls was also marked for presence by type (plastic, metal, other) and then disposed of properly.

Over the years that this study has been conducted, there has been a 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 unit effort” or catch per trawl, calculated by dividing the total number of the organism caught in a period of time by the total number of trawls conducted during that same time period.

## Unified Water Study

The Unified Water Study (UWS) was started by Save the Sound in 2017 and has grown annually to include 48 embayments around Long Island Sound. The protocols followed are a part of an EPA-approved QAPP (Save the Sound, 2024). In 2025, Harbor Watch monitored seven stations in Norwalk Harbor and eight stations in Saugatuck Harbor (Figure M2). From May to October, each harbor was sampled twice a month within three hours of sunrise. Both harbors were monitored for dissolved oxygen, temperature, salinity, chlorophyll a, and turbidity (not included in analysis) using a YSI EXO2 multiparameter sonde. Measurements were taken at 0.5m from the surface and 0.5m from the bottom if the total depth of the site was between 1.5m – 10m. If it was less than 1.5m only a mid-depth reading was taken and if it was greater than 10m, readings were taken from 0.5m from the surface, mid-depth, and 0.5m from the bottom. For this project, qualitative (Saugatuck Harbor) and quantitative (Norwalk Harbor) data on nutrients were also collected in each harbor; however, that data is not included in this report. The entire suite of parameters is reported on biennially by Save the Sound in their Long Island Sound Report Card (Save the Sound, n.d.).

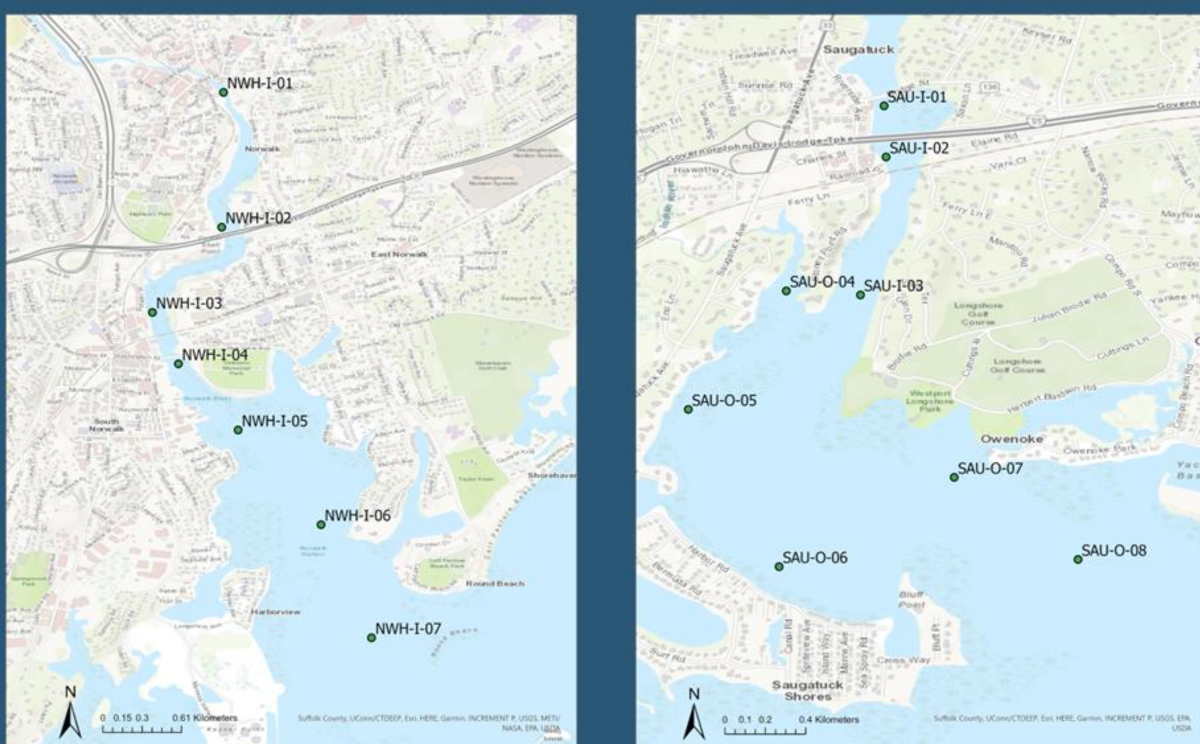



**Figure M2.** Location of UWS sampling sites in the Norwalk Harbor (left map) and the Saugatuck Harbor (right map).

# Norwalk Harbor Results and Discussion

Harbor Watch staff and volunteers conducted a total of 132 trawls from May to September 2025 in the Norwalk Harbor. A total of 614 individual fish from more than 22 different species and 11,784 individual crustaceans from over 14 different species were caught. The presence of over 30 different species of mollusks, worms, sponges, and other marine organisms were also noted. In total, 43% of all trawls had trash in them, with the most common type being plastic. Harbor Watch also collected over 900 data points on water quality parameters as part of UWS from May to October 2025.

614 individual fish from >22 different species

11,784 individual crustaceans from >14 different species

>30 different species of mollusks, worms, sponges, and other marine organisms

43% of all trawls had trash, most common type was plastic

>900 points of data on dissolved oxygen, temperature, salinity, turbidity, and chlorophyll

## Embayment Biological Study Analysis

### FISH

The three most abundant fish species caught in 2025 were weakfish (*Cynoscion regalis*), pipefish (*Syngnathus spp.*), and winter flounder (*Pseudopleuronectes americanus*), which accounted for about 62% of the total number of individuals caught (Figure N1). Fish were observed in all 20 trawling sampling areas or boxes (Figure N2). The three boxes with the greatest number of fish caught per trawl, or catch per unit effort (CPUE) were G, L, and J, in that order, making the middle harbor the section with the greatest fish CPUE (Figure N3 (a) & (b)). While sampling was typically conducted in the inner, middle, and outer harbor during each trawling trip, tidal cycles periodically impeded access to particularly shallow boxes.

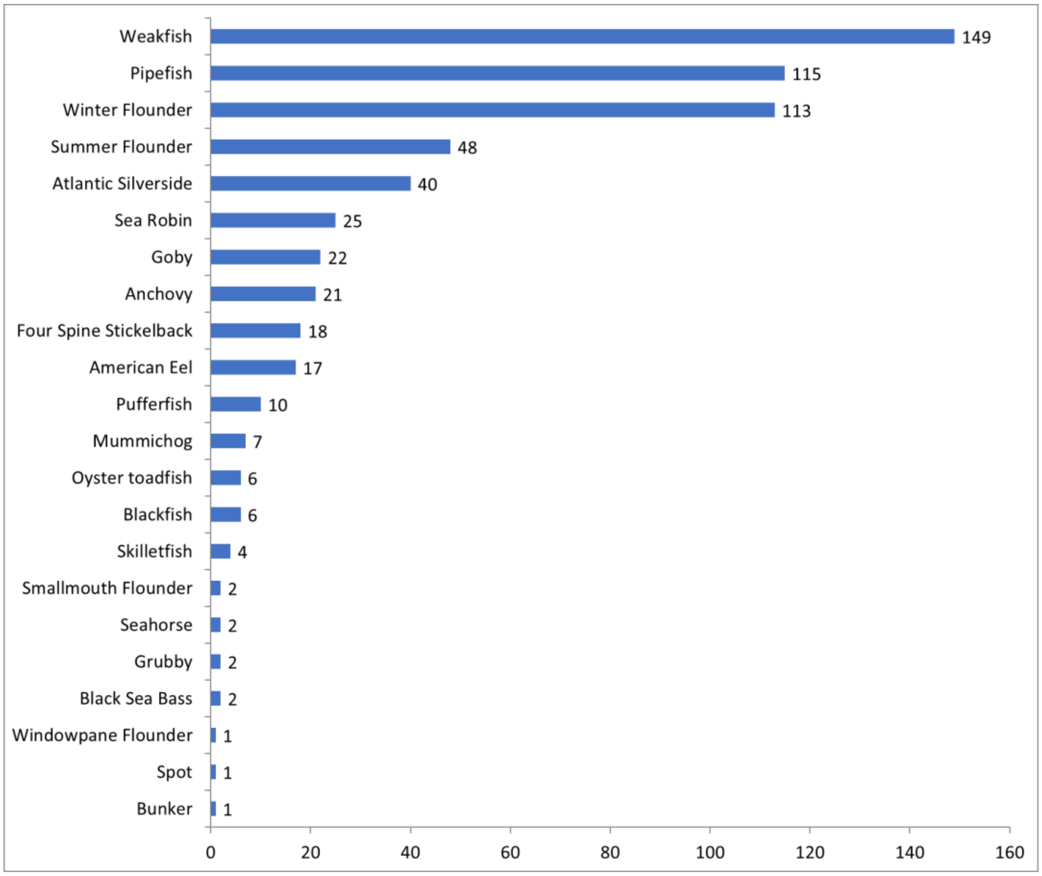



**Figure N1.** Total number of individuals caught for each fish species in Norwalk Harbor, May through September 2025. Two juvenile flatfish were also caught; however, due to their small size, Harbor Watch was unable to identify their species.

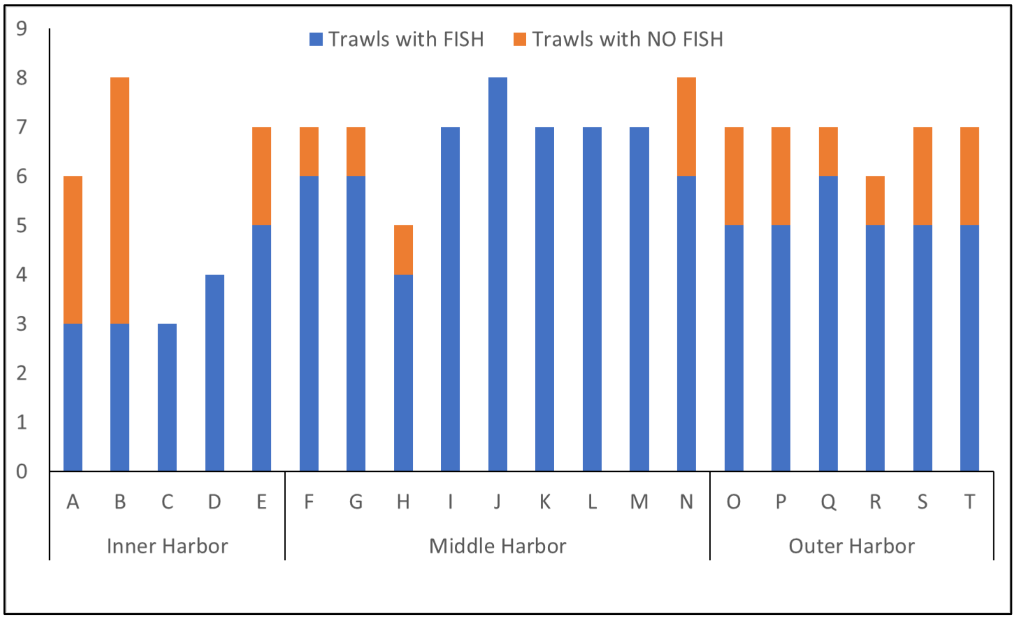
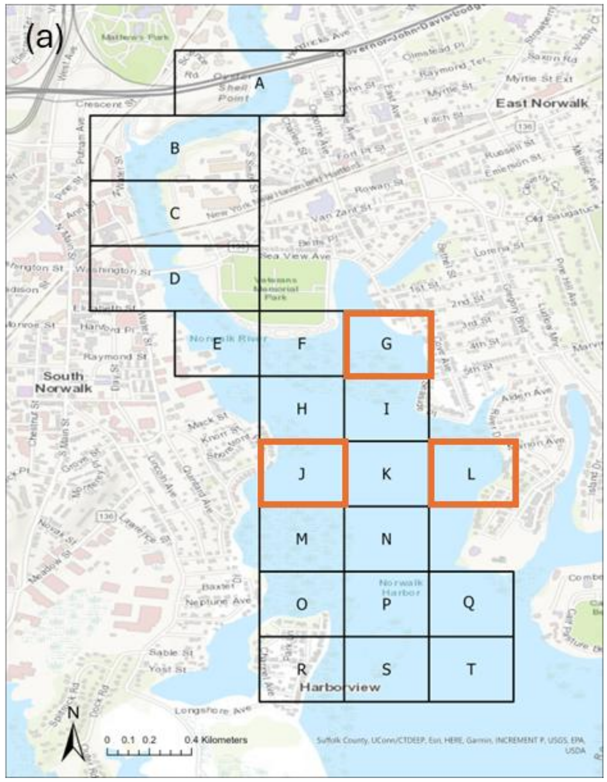



**Figure N2.** Number of trawls with and without fish in each box in Norwalk Harbor, May through September 2025.



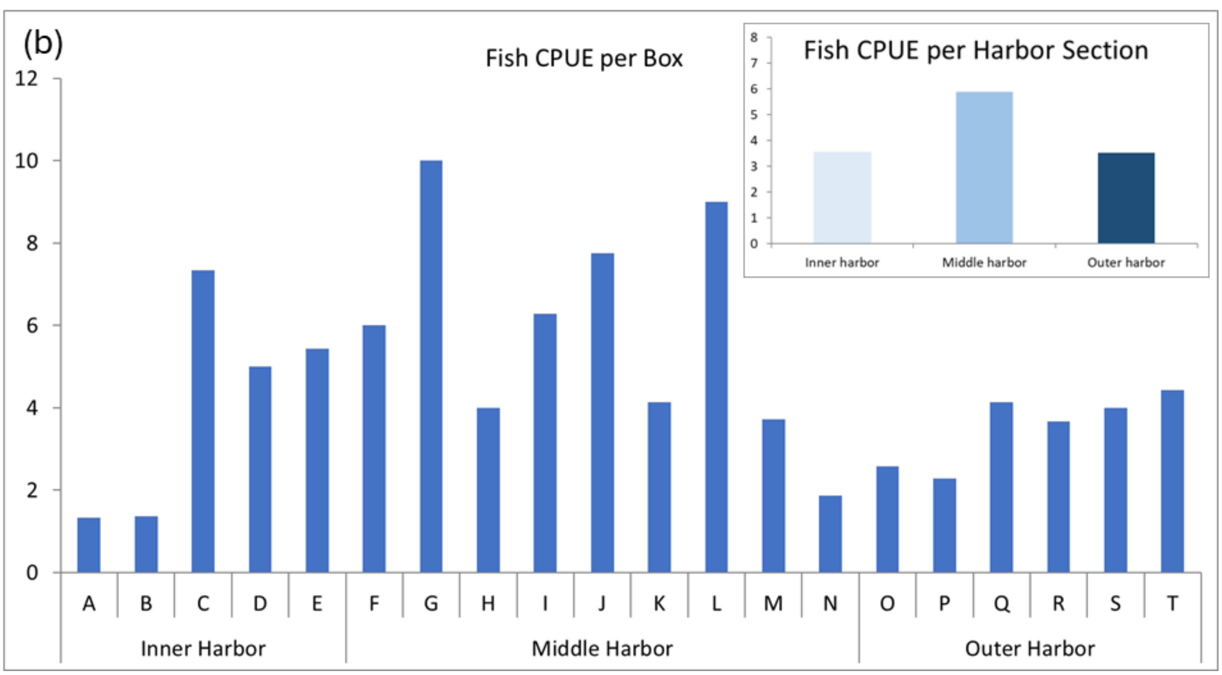




**Figure N3.** (a) Map of Norwalk Harbor showing boxes with the greatest fish CPUE (orange boxes), May through September 2025. (b) Fish caught per unit effort (CPUE) in each box of Norwalk Harbor, May through September 2025. The nested bar graph shows the fish CPUE by harbor section.

The month with the greatest fish CPUE was July. As can be seen in Figure N4, the greatest abundance of each species is observed during different times throughout the season. At the start of the season, American eels (dark blue in the graph) were most abundant. Winter flounder (light blue in the graph) abundance peaked in June, dwindling afterwards. Weakfish (light grey in the graph) and pipefish (periwinkle in the graph) were most abundant in July. Most Atlantic silversides (dark grey in the graph) were caught in August and most gobies (orange in the graph) were caught in September. The fluctuations in population density and temporal abundance correspond with the life cycles of each species. For example, spawning for winter flounder occurs from late winter to early spring with juveniles completing metamorphosis just a few weeks after hatching (Chesapeake Bay Program, n.d.-a). In this study, all winter flounder caught were in their juvenile stage and a majority were observed in June and July, right after spawning likely occurred. The temperature of the water also plays a role in their movement; because winter flounder prefer colder water, they typically migrate to deeper water or offshore locations during the later summer months (to learn more about the temperature observed this year, see the Norwalk Harbor “Temperature and Salinity” section).

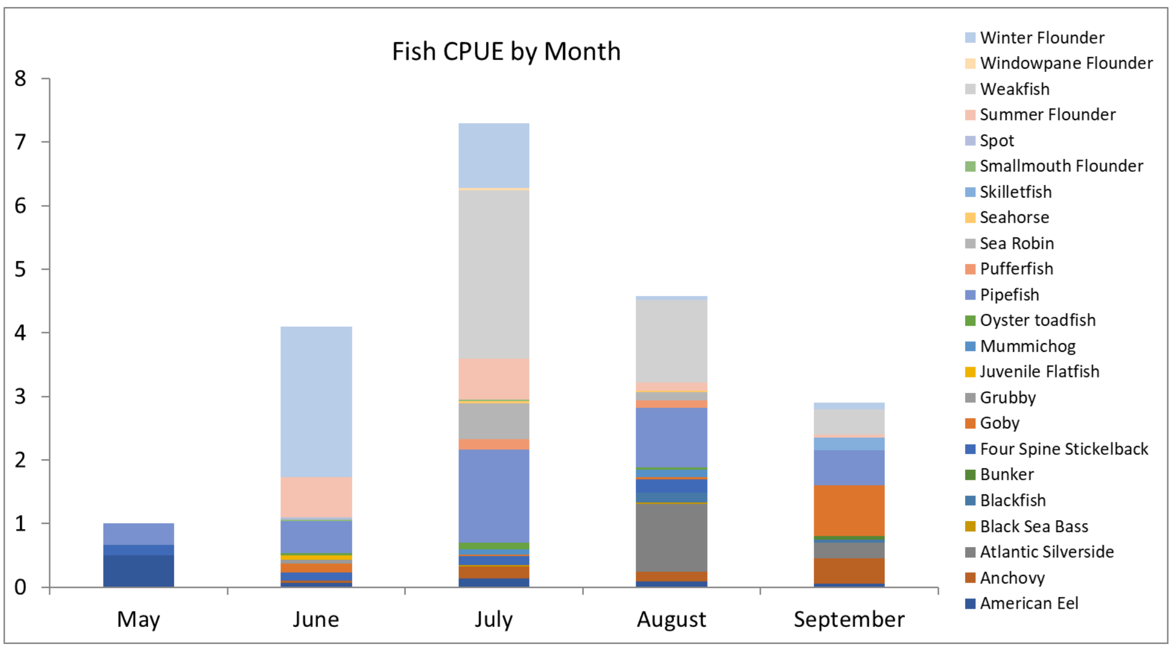



**Figure N4.** Fish CPUE across all sampling months in Norwalk Harbor, 2025.

# Over the Years

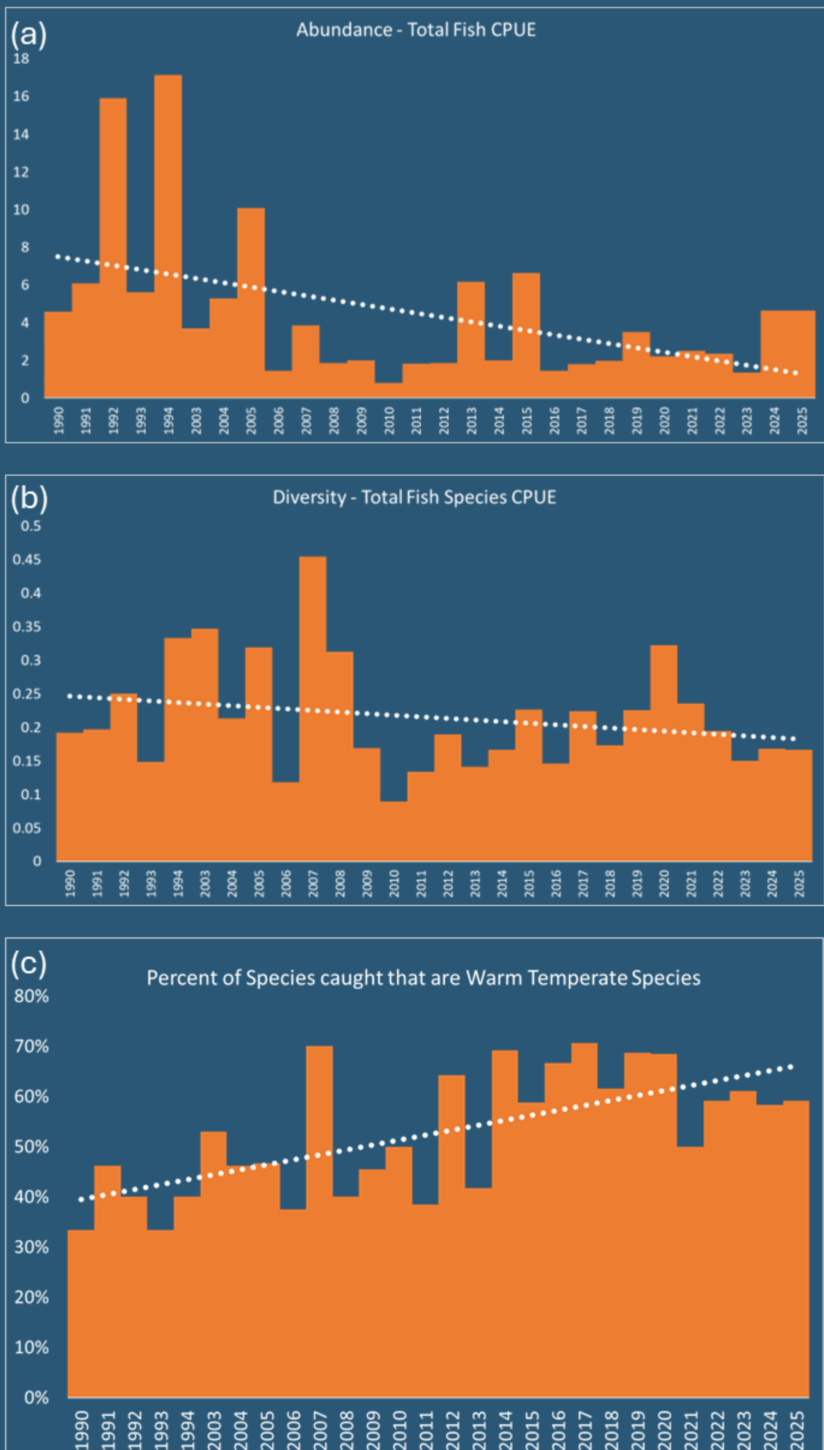



**Figure N5.** (a) Total fish abundance CPUE over time in Norwalk Harbor (b) total fish species CPUE over time in Norwalk Harbor (c) percent of all species caught over time that are warm temperate in Norwalk Harbor

When looking at the total fish CPUE over the entire length of the study, there is a significant decrease in total abundance over time ($R^2$ = 0.31, p = 0.0021; Figure N5 (a))[1]. Many factors can contribute to this trend including poor water quality, habitat destruction, and overfishing. Although not statistically significant, there is also a downward trend in fish diversity in Norwalk Harbor, meaning less species are caught (Figure N5 (b)). Perhaps this trend isn't significant because there is a shift in the species caught. Over time, there has been a significant increase in the percent of species caught that are warmer temperate ($R^2$ = 0.46, p = 6.5E-05; Figure N5 (c); list of species can be found in the appendix). These warm temperate species are found more abundantly south of New York, spawn at the higher end of their temperature tolerances, and prefer water temperatures around 11-22°C (CT DEEP, n.d.). Over time, Norwalk Harbor has become an estuary that these species prefer.

[1]There was a break in this study between 1994-2003. There is data from 2002 but due to the low number of trawls it was excluded from analysis. It should also be noted that the inner harbor was dredged in 2006 and the outer harbor was dredged in 2010 which may have impacted the study. Also, 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.

## CRUSTACEANS

In 2025, the three most abundant crustaceans caught were sand shrimp (*Crangon septemspinosa*), shore shrimp (*Palaemon spp.*), and long-wristed hermit crabs (*Pagurus longicarpus*), which account for 91% of the total number of crustaceans counted (Figure N6). The three most abundant shrimp caught, making up 99% of the total number of shrimp caught, were sand shrimp (*Crangon septemspinosa*), shore shrimp (*Palaemon spp.*), and chameleon shrimp (*Hippolyte zostericola*). Certain individual shrimp were too small to confidently identify and therefore were documented as “Juvenile Shrimp” and recorded as a presence instead of a count. The three most abundant crabs were long-wristed hermit crabs (*Pagurus longicarpus*), mud crabs (various species), and blue crabs (*Callinectes sapidus*), accounting for 96% of the total number of crabs caught. Individual speciation for mud crabs and spider crabs was not conducted. The “Mud Crab” identification represents potentially four species (*Panopeus herbstii, Hexapanopeus angustifrons, Dyspanopeus sayi, and Eurypanopeus depresssus)* but was likely dominated by black-fingered mud crab (*Panopeus herbstii*). The “Spider Crab” identification represents potentially 2 species (*Libinia emarginata* and *Libinia dubia*) but was likely dominated by the nine-spined spider crab (*Libinia emarginata*). The Asian shrimp (*Palaemon macrodactylus*) was the only crustacean caught that is non-native and so it was documented and shared with CT DEEP for identification confirmation and to be used in assessing the impacts of this species on the native populations.

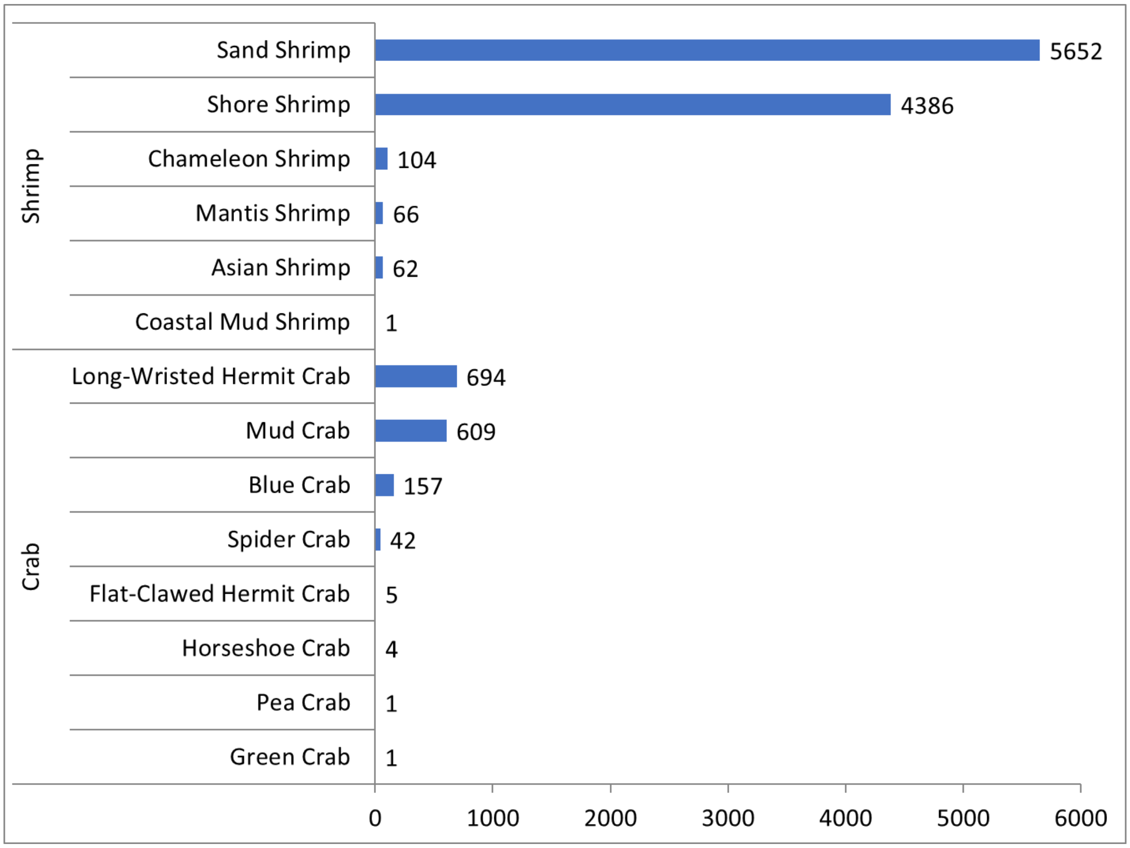



**Figure N6**. Total number of crustaceans counted in Norwalk Harbor, May through September 2025.

## CRUSTACEANS: *SHRIMP*

In 2025, sand and shore shrimp dominated the trawl catch. Overall, the majority of shrimp were caught in the outer harbor (Figure N7). The majority of mantis shrimp and Asian shrimp were found in the middle harbor while the majority of chameleon shrimp were found in the inner and outer harbors. The chameleon shrimp are much smaller than the mantis and Asian shrimp, therefore, the inverse abundance between the larger and smaller shrimp may be related to competition. Differences in habitat preferences can also be a contributing factor.

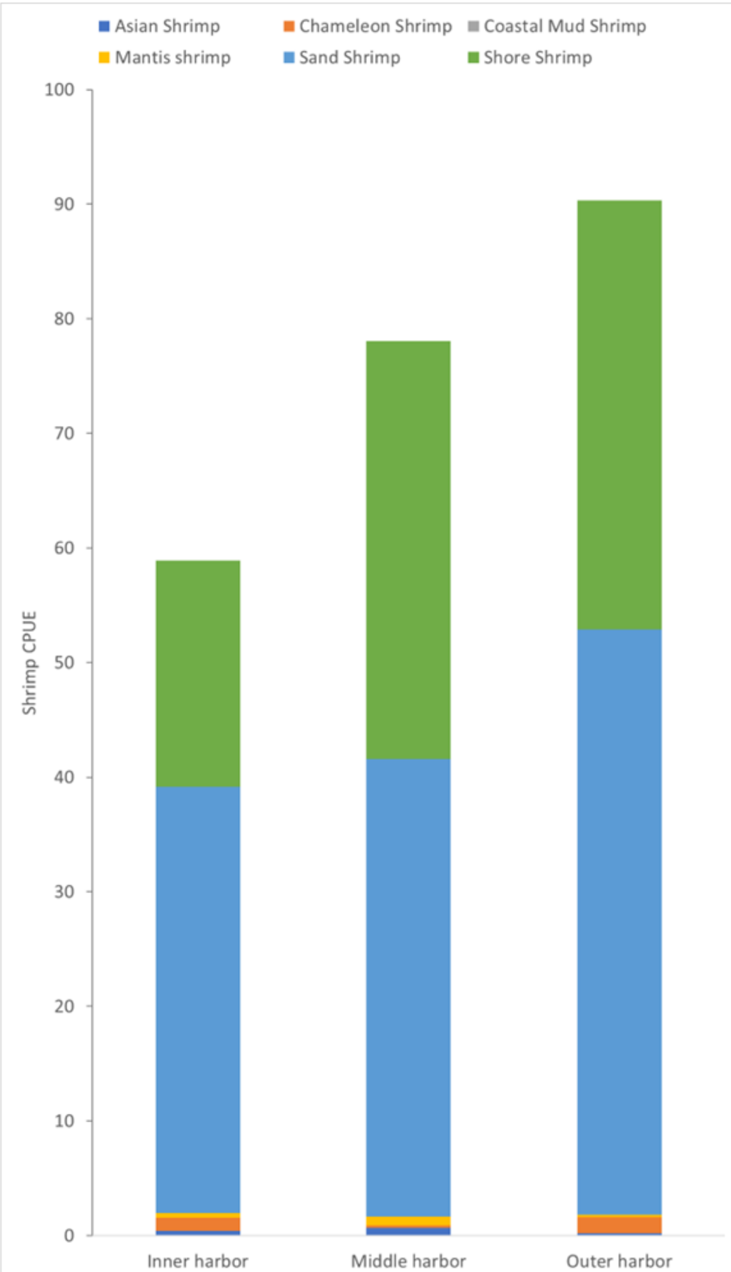



**Figure N7.** Total shrimp CPUE in each section of Norwalk Harbor, May through September 2025

When comparing shrimp CPUE between each sampling month, sand shrimp peak in May and June, while the other species peak in July (mantis shrimp), August (shore and chameleon shrimp), and September (Asian shrimp) (Figure N8). These peaks correlate with many of their spawning periods. For example, sand shrimp have two periods of spawning, one in early spring and the other in late fall, so their peak in May could represent the first spawning period (Modlin, 1980). The greatest percentage of trawls with juvenile shrimp present was in June, which provides further support for this hypothesis.

Not much is known about the spawning timing for Asian shrimp in the western Atlantic Ocean, however their spawning period in their native range in Japan is from mid-April to early October and in California, egg-bearing females are found mainly from May to August (Ashelby et al., 2013). This data may suggest that their spawning in the northwestern Atlantic Ocean peak around September, however, more research is needed to confirm this.

Not much is known about the spawning period of chameleon shrimp in this area either. They are more prevalent in warmer areas (SeaLifeBase, n.d.) and tend to have continuous spawning in their more southern ranges (Romero-RodrÍguez & Román-Contreras, 2013). Perhaps their peak in August in the Norwalk Harbor more closely resembles environmental conditions in those southern ranges.

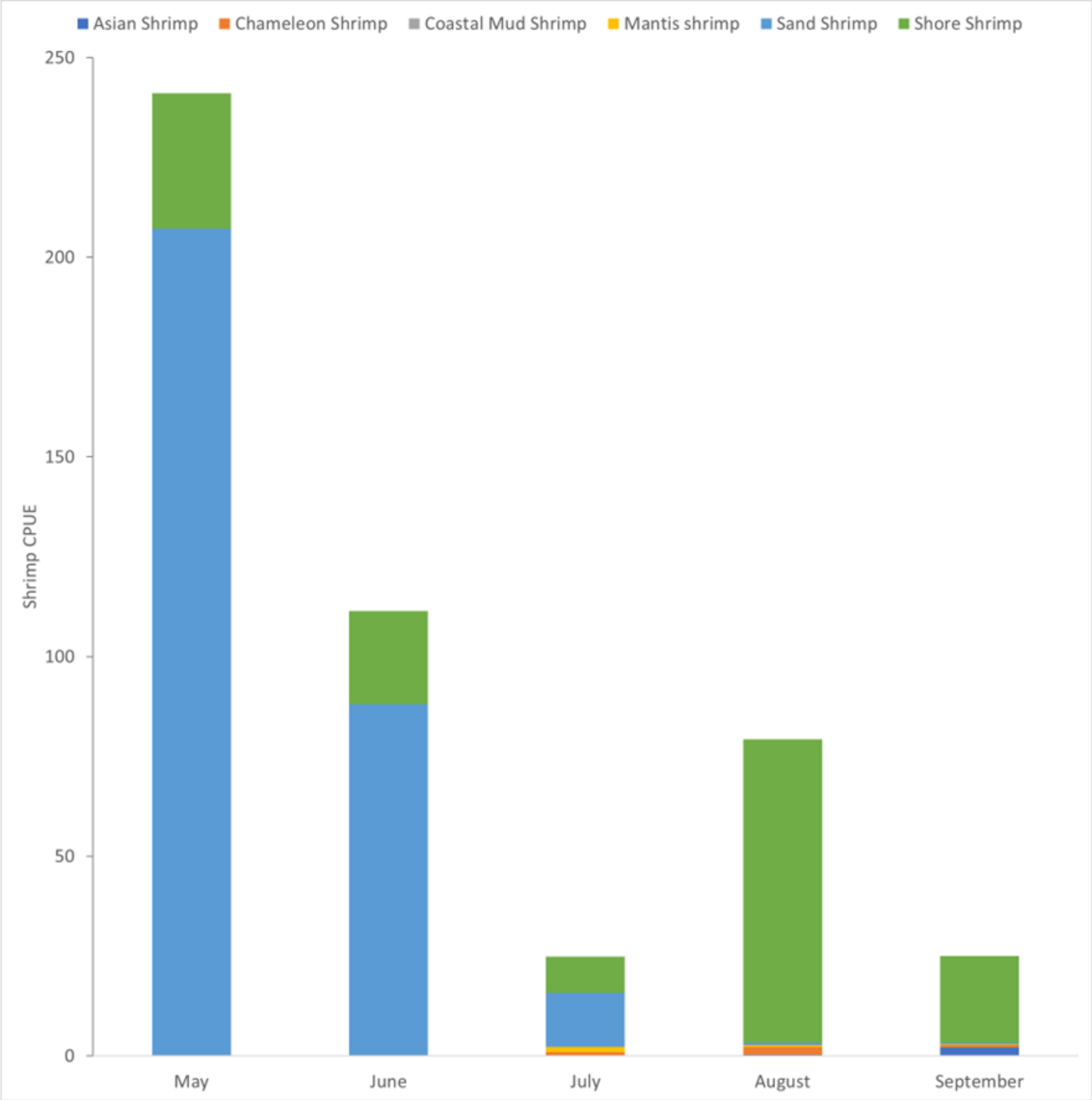



**Figure N8.** Total shrimp CPUE for each month of the sampling season in Norwalk Harbor, 2025.

In terms of distribution in Norwalk Harbor, the three boxes with the greatest overall shrimp CPUE in order were J, L, and R (orange boxes in Figure N9). The greatest CPUE for shore shrimp was in box J, sand shrimp was in box L, and chameleon shrimp was in box R. These boxes in the harbor are very shallow areas not accessible at low tide by boat. The sediment is also very fine, silty mud. These factors may contribute to the higher presence of shrimp.

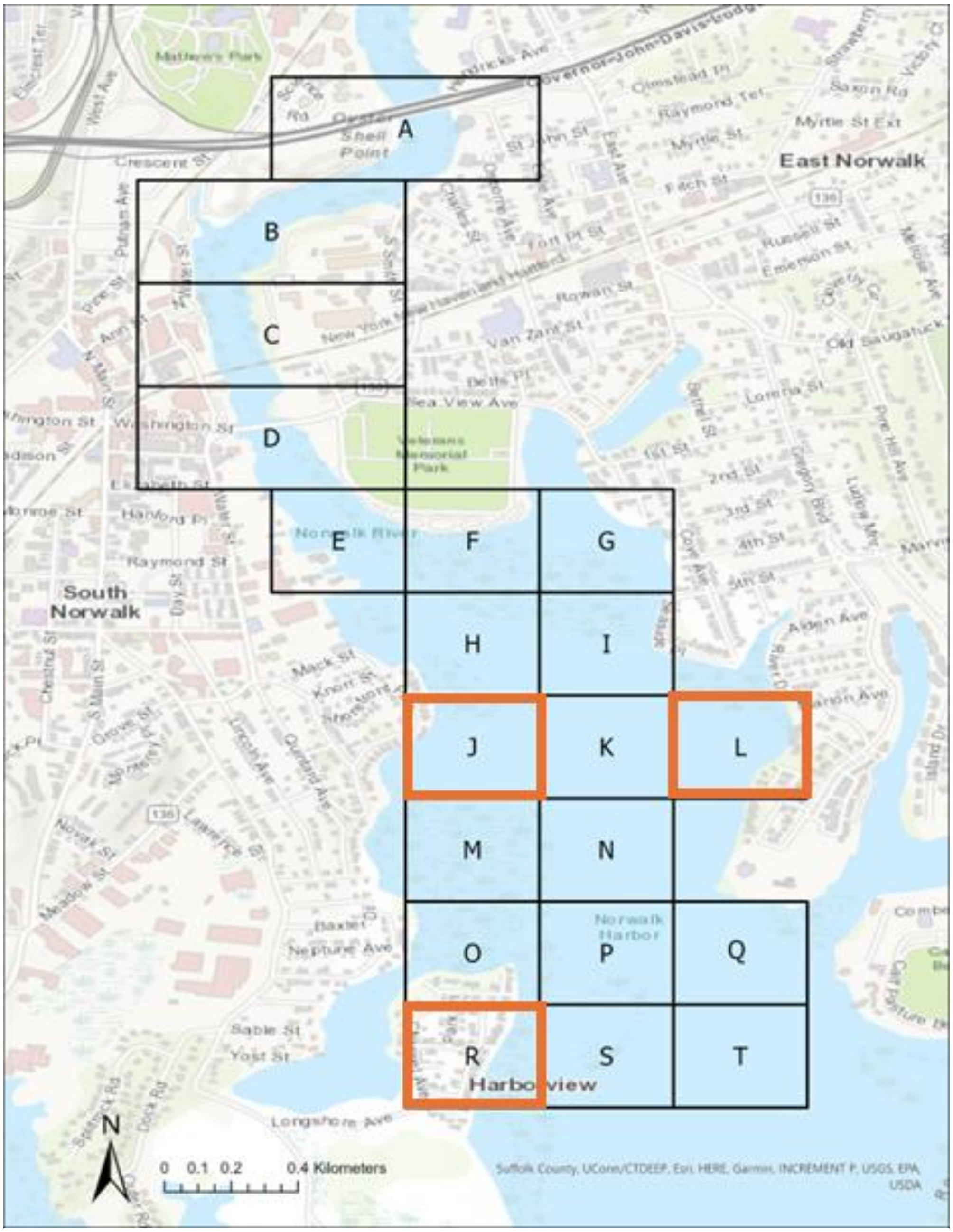



**Figure N9.** Map of the boxes with the greatest shrimp CPUE (orange boxes) in Norwalk Harbor, May through September 2025.

## CRUSTACEANS: *CRABS*

Most crabs caught in the Norwalk Harbor in 2025 were in the outer portion of the harbor (Figure N10). Long-wristed hermit crabs and mud crabs dominated the catch, both of which were more prevalent in the outer harbor. Blue crabs were the third most caught crab, and they were mostly found in the inner harbor. The inner harbor is closer to the mouth of the Norwalk River, which is the freshwater input of the harbor. Male blue crabs inhabit fresher water areas while female blue crabs tend to be found in higher salinity areas (Chesapeake Bay Program, n.d.-b). This may explain why so many were caught in this part of the harbor, though we cannot say for sure because the sex of the individual crabs was not recorded. Spider crabs make up a large portion of the catch, concentrating in the outer harbor. Flat-clawed hermit crabs are also more prevalent in the outer harbor because they prefer deeper water (Chesapeake Bay Program, n.d.-c).

The month with the most crabs caught was May (Figure N11), which is typically one of the months with the best water quality for aquatic organisms during the sampling season, characterized by higher dissolved oxygen levels and lower temperatures (see UWS: Water Quality Analysis section). Long-wristed hermit crabs had the greatest CPUE in May, blue crab in June and August, and mud crabs in September. The peak CPUE of horseshoe crabs in June correlates with their spawning period, which is typically during full and new moons in May and June (Chesapeake Bay Program, n.d.-d).

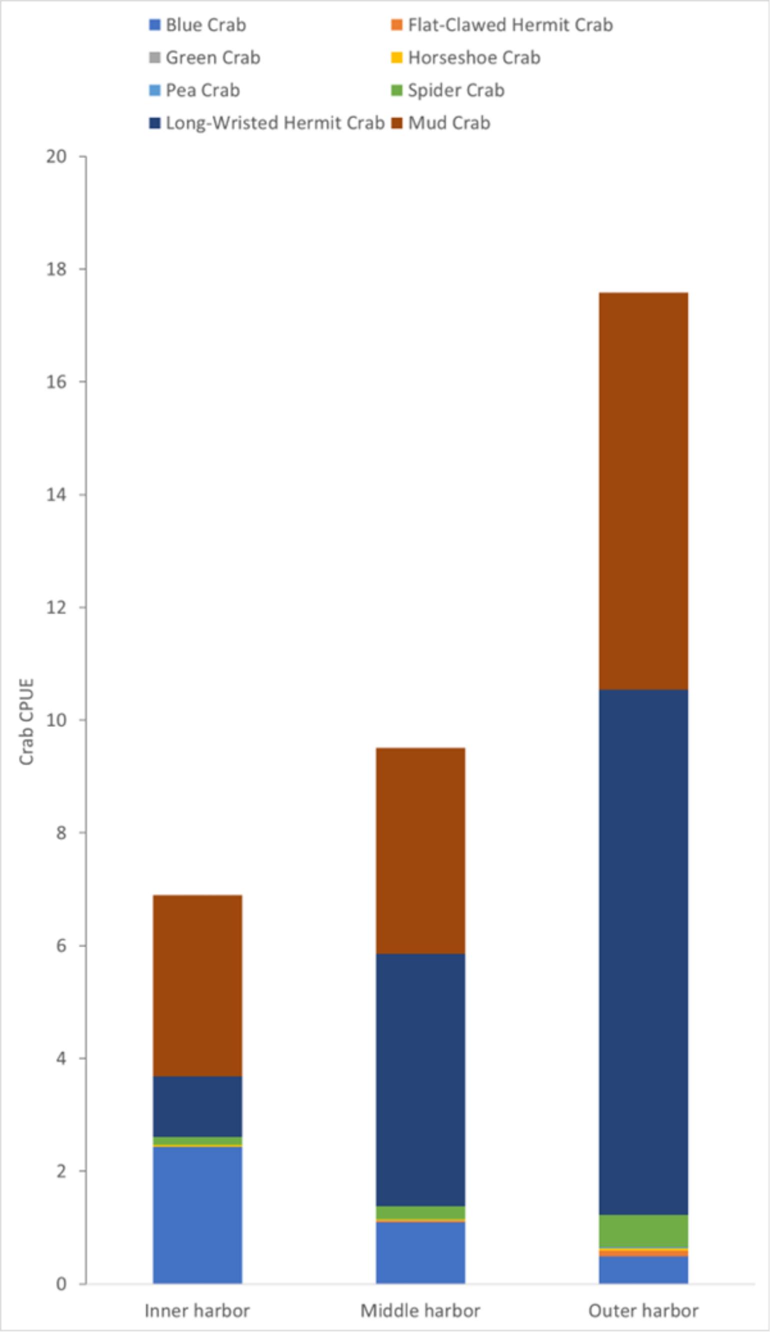



**Figure N10.** Total crab CPUE in each section of Norwalk Harbor, May through September 2025.

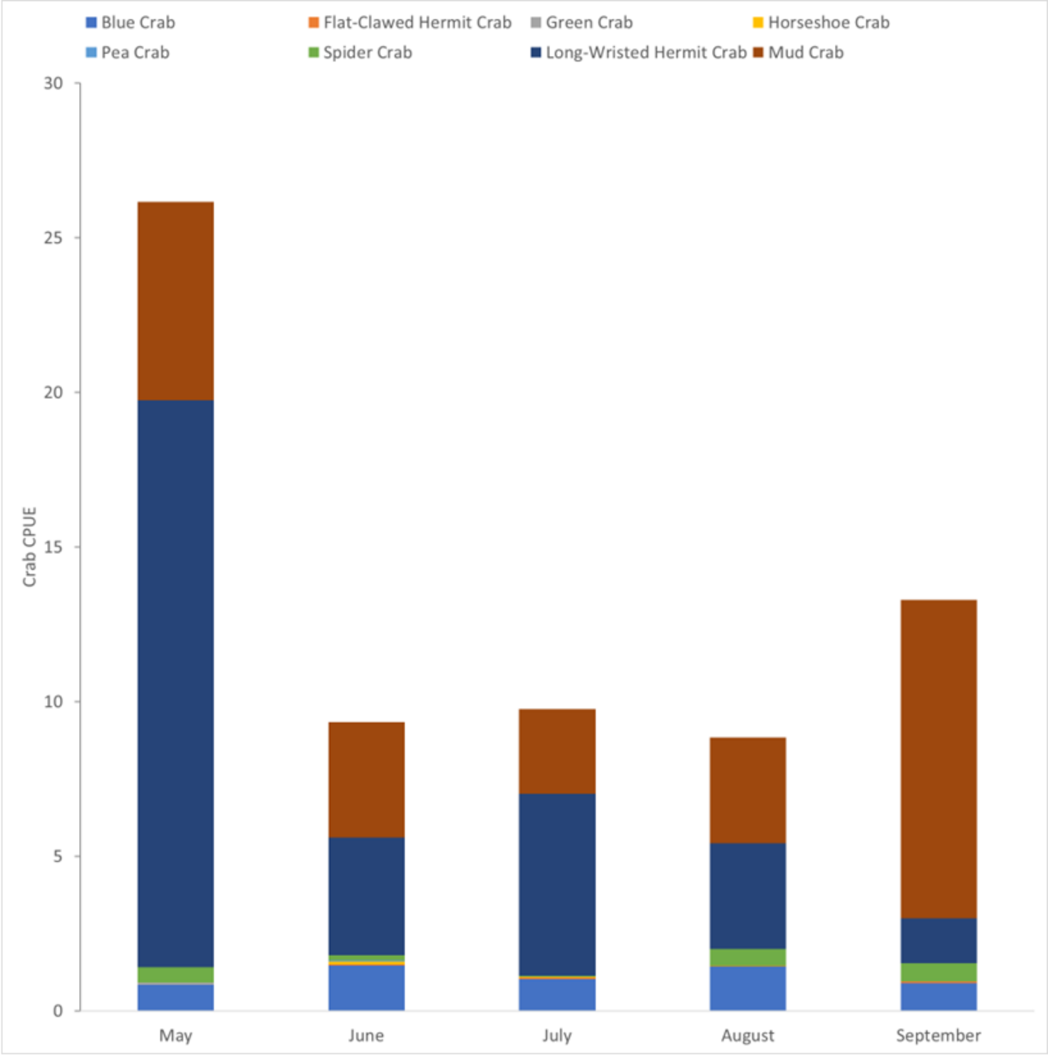



**Figure N11.** Total crab CPUE in each month of the sampling season in Norwalk Harbor, 2025.

The areas of the harbor with the greatest CPUE across all crabs in order were boxes R, L, and S (orange boxes in Figure N12). The greatest CPUE for mud crabs was in box R and for long-wristed hermit crabs was box L. These boxes are in the lower-middle to outer boxes of the harbor, which tend to have better water quality and higher salinity.

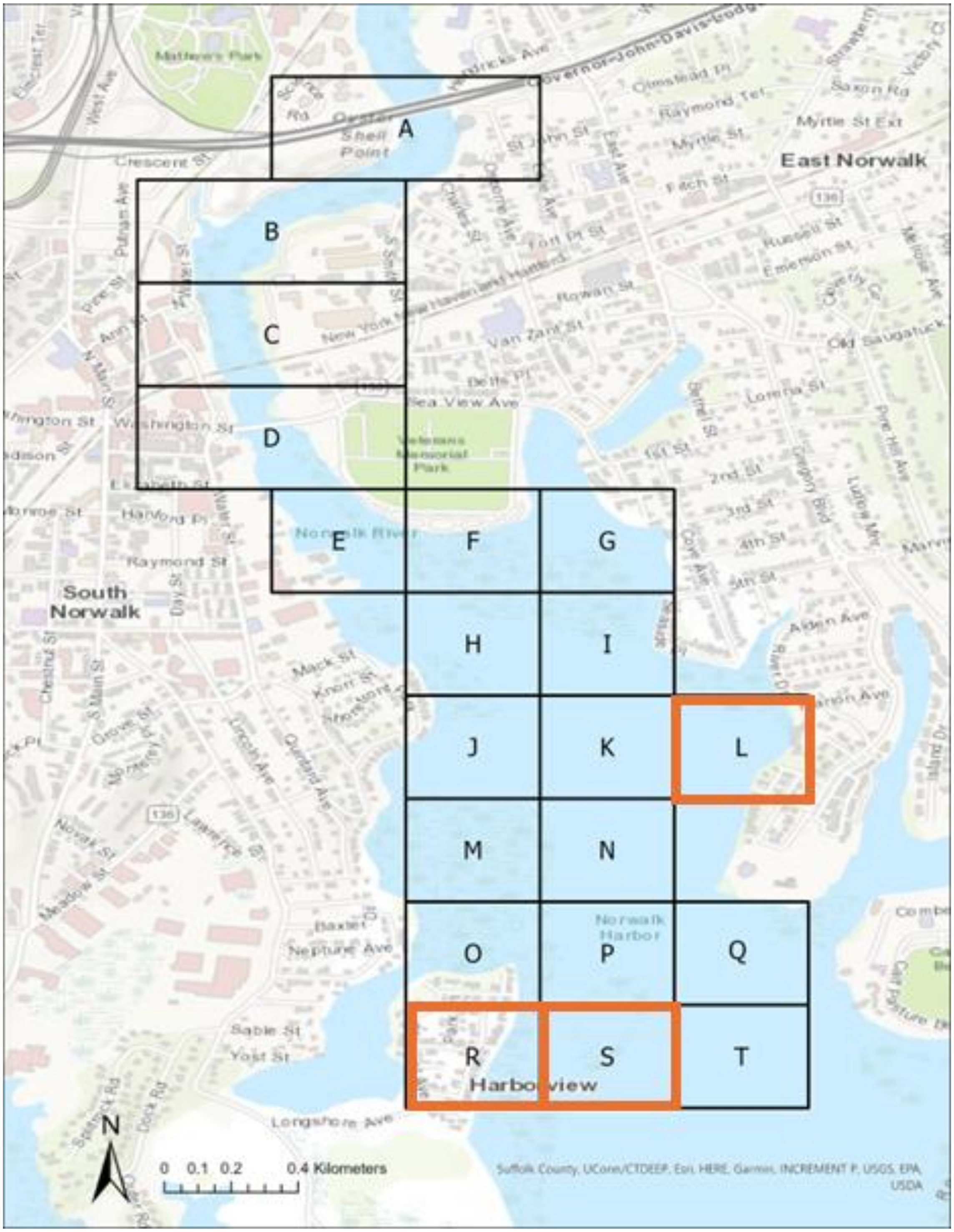



**Figure N12.** Map of Norwalk Harbor showing the boxes with the greatest crab CPUE (orange boxes), May through September, 2025

## OTHER SPECIES

Harbor Watch also documented the presence of many different species of mollusks, sponges, worms and other groups of organisms in Norwalk Harbor in at least one trawl during the 2025. Due to their commonality and general abundance, individual numbers of each were not recorded. The three most commonly caught organisms were mud snails (in 75% of trawls), comb jellies (in 70% of trawls), and amphipods (in 53% of trawls). June was the month with the largest presence of organisms in the trawls. Two interesting catches during the 2025 season were the common sea star and the diamondback terrapin, both of which are rare occurrences in the Harbor Watch records.


**Crustaceans**
- ✓ Barnacle
- ✓ Juvenile Crab
- ✓ Juvenile Shrimp

**Worms**
- ✓ Flatworm
- ✓ Ribbon Worm
- ✓ Segmented Worm

**Sponges**
- ✓ Boring Sponge
- ✓ Red Beard Sponge
- ✓ Yellow Sun Sponge

**Mollusks**
- ✓ Channeled Whelk
- ✓ Clam
- ✓ Gemma Gemma
- ✓ Glassy Bubble Snail
- ✓ Jingle Shell
- ✓ Mud Snail
- ✓ New England Dog Whelk
- ✓ Oyster
- ✓ Atlantic Oyster Drill
- ✓ Thick-Lipped Oyster Drill
- ✓ Sea Slug
- ✓ Slipper Shell
- ✓ Yoldia

**Other**
- ✓ Amphipods
- ✓ Anemone
- ✓ Bryozoan
- ✓ Common Sea Star
- ✓ Diamondback Terrapin
- ✓ Isopod
- ✓ Sea Spider
- ✓ Sea Squirt
- ✓ Comb Jelly

## MARINE DEBRIS

Trash was observed in 79 trawls, 43% of the total effort, in Norwalk Harbor from May through September 2025. Plastic was the most common type of trash found (Figure N13). The “Other” category was the second most common type of trash found, which includes items like rubber, rope, fabric, and pottery. The metal category mainly consists of drink cans. Spatially, the three boxes where trash was most likely to be found when trawling were C, B, and I in that order. Boxes B and C are the closest to the mouth of the Norwalk River, which means trash flowing downstream most likely settled in these northernmost boxes (Figure N14). The three boxes that had no trash were H, M, O, and R. All of these boxes are on the western part of the harbor so perhaps the movement of the water throughout the harbor impacts the settlement of the trash.

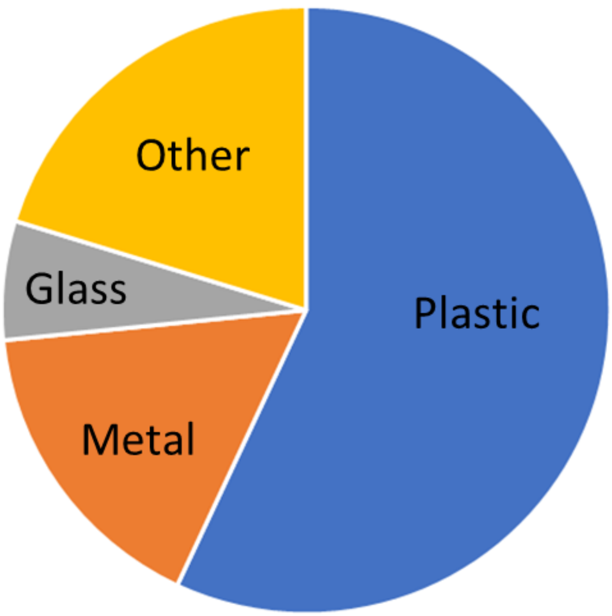



**Figure N13**. Proportion of each type of trash found in trawls in Norwalk Harbor, May through September 2025.

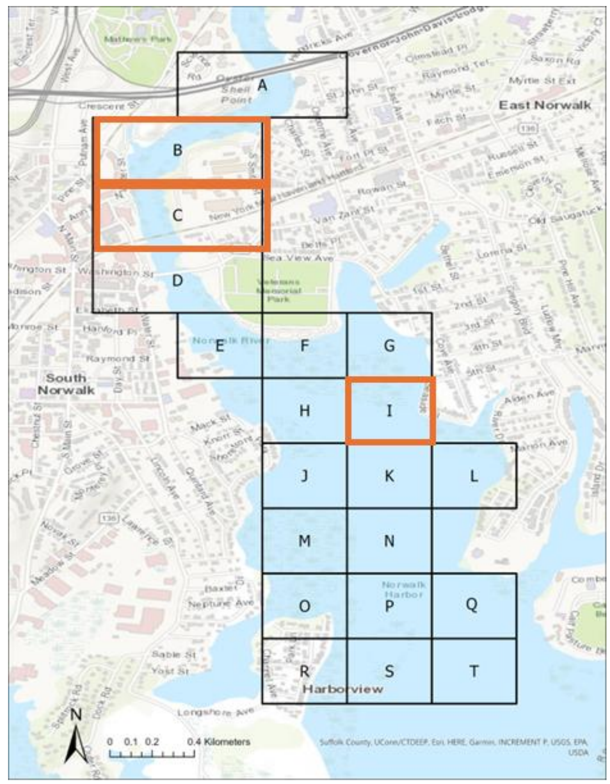



**Figure N14**. Map of Norwalk Harbor showing the boxes where trash was most likely to be found when trawling (orange boxes), May through September 2025.

# Unified Water Study Analysis

## DISSOLVED OXYGEN

The minimum dissolved oxygen (DO) levels established by CT DEEP in saltwater water is 3 mg/L, acutely (CT DEEP, 2015). Under this level, water is considered hypoxic or lacking oxygen, which is harmful for aquatic organisms. Three sites in Norwalk Harbor experienced hypoxia in 2025: NWH-I-01, NWH-I-02, and NWH-I-05 (Figure N15). All of these low DO observations were at the bottom of the harbor, except for site NWH-I-01 in September, which experienced low DO at both the surface and at the bottom on two sampling days. This part of the harbor has very little mixing due to its morphology and is also the part closest to the freshwater source (Norwalk River), which causes stratification. The denser saltwater falls to the bottom, pushing northward with the tide, while the freshwater flows above it.

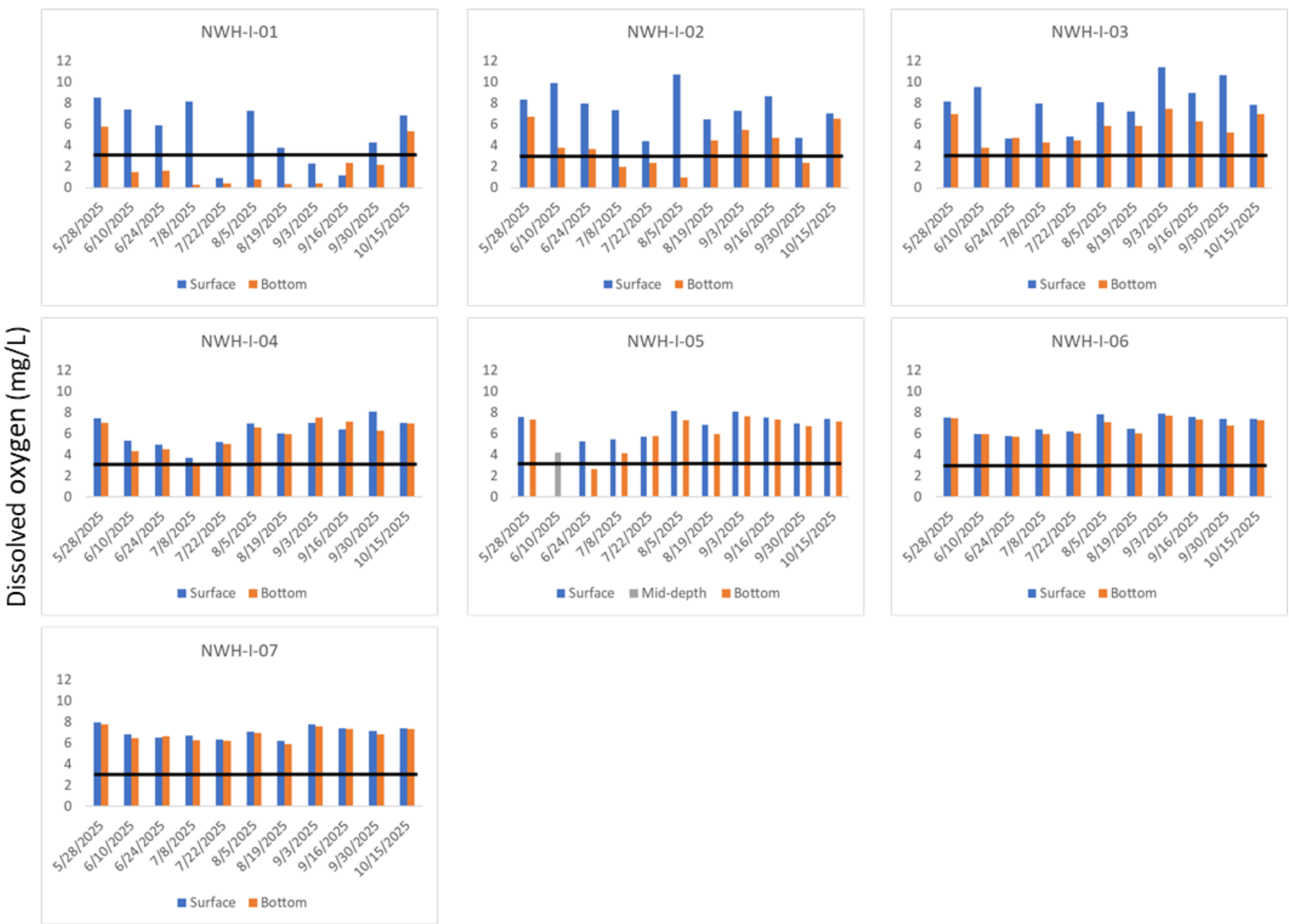



**Figure N15.** Dissolved oxygen readings at the surface and bottom of each UWS site on each sampling date in Norwalk Harbor, May to October 2025. Site NWH-I-05 has only a mid-depth reading on 6/10/25 because the total depth at the site was less than 1.5m. Black line represents the state criteria for dissolved oxygen, which is 3 mg/L.

## CHLOROPHYLL-*A*

When an excess of nutrients enters a waterway from runoff of fertilized lawns or agricultural fields, microalgae in the water consume it and experience a boom in population. This results in the water turning shades of red, brown, or green. Once these organisms die, they sink to the bottom where bacteria break them down, a process that uses up lots of oxygen. Therefore, algal blooms can negatively impact water quality in the areas they overpopulate. The microalgae photosynthesize and the main pigment used in this process is chlorophyll-*a*, which can be and was measured at each site at the surface and the bottom. What becomes evident is that NWH-I-01 experienced much higher levels of chlorophyll-*a* than any of the other sites measured, especially in late-July and early-August (Figure N16, note scale of graphs). This may be another explanation for the low average DO values at this site.


**Figure N16.** Chlorophyll-a readings (µg/L) at each site on each sampling date in Norwalk Harbor, 2025. Note differences in scales for each graph.

## TEMPERATURE AND SALINITY

Average water temperatures were very similar along the length of the harbor. The average monthly temperature across all sites ranged from a minimum of 15.6°C at the bottom in May to a maximum of 24.7°C at the bottom in August (Figure N17 (a)). Average bottom salinity was similar across sites. A small increase was observed over the course of the monitoring season, with the highest average salinity, 28.02 ppt, being observed in October. Average monthly surface salinity was much more variable at each site (Figure N17 (b)). This is a result of the freshwater input of the Norwalk River at the north end of the harbor and the resulting salt wedge formed as the less dense freshwater sat on top of the denser saltwater. As the sites moved seaward and mixing of the water layers became more prominent, the surface salinity became more consistent. The sharp increase in salinity at NWH-I-01 between June and July could be a result of the drought conditions that impacted the watershed by reducing flow and therefore input of freshwater to the harbor.

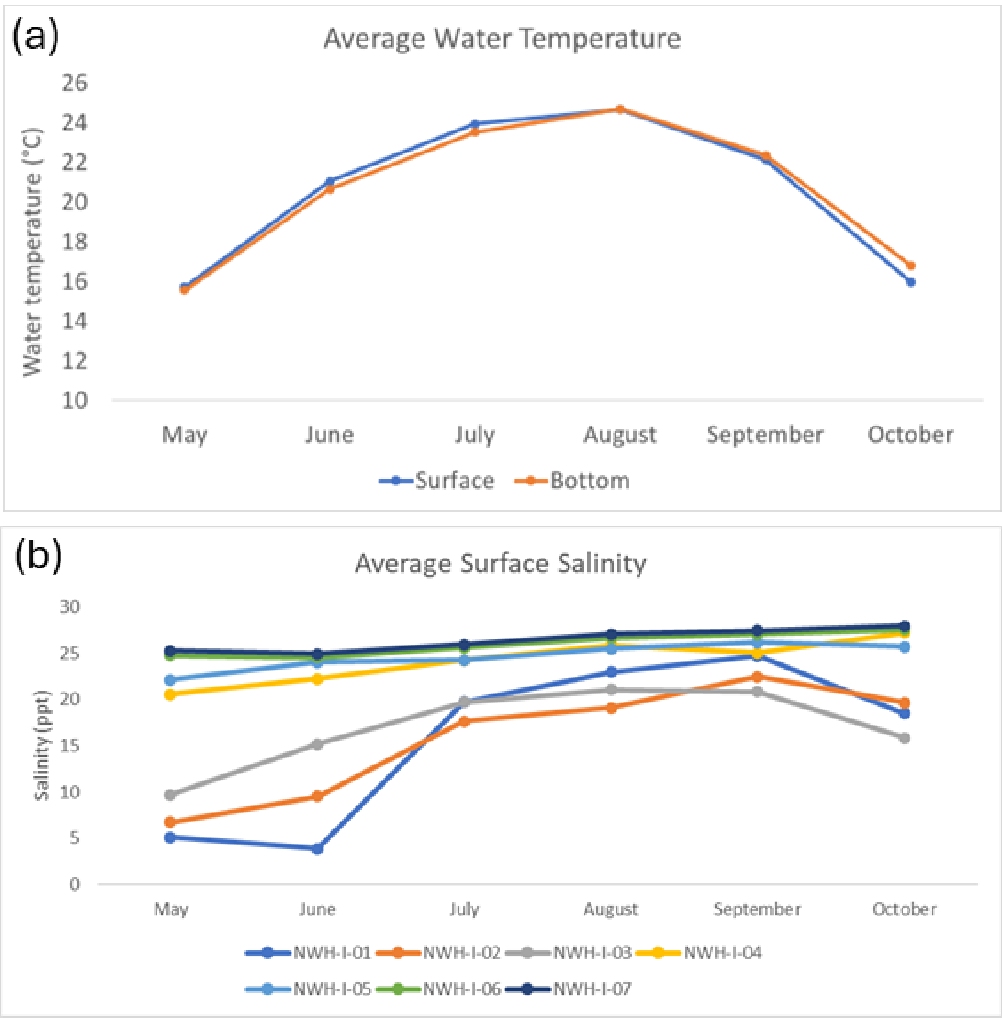



**Figure N17.** (a) Average monthly water temperature across all sampling sites at the surface and bottom of Norwalk Harbor, May to October 2025. Note range of y-axis. (b) Average monthly surface salinity at each site in Norwalk Harbor, May to October 2025.

# Saugatuck Harbor Results and Discussion

Harbor Watch staff and interns conducted a total of 66 trawls from June to October 2025 in Saugatuck Harbor. A total of 132 individual fish from more than 12 different species and 3,465 individual crustaceans from over 12 different species were caught. The presence of over 28 different species of mollusks, sponges, and other marine organisms were also noted. In total, 38% of all trawls had trash in them, with the most common type being plastic. Harbor Watch also collected over 1,000 data points on water quality parameters as part of UWS from May to October 2025.

132 individual fish from >12 different species

3,465 individual crustaceans from >12 different species

>30 different species of mollusks, sponges, and other marine organisms

38% of all trawls had trash, most common type was plastic

>1,000 points of data on dissolved oxygen, temperature, salinity, turbidity, and chlorophyll

## Embayment Biological Study Analysis

### FISH

The three most abundant fish species caught in 2025 were pipefish (*Syngnathus spp.*), goby (*Gobiosoma spp.*) and grubby (*Myoxocephalus aenaeus*), which accounted for about 73% of the total number of individuals caught (Figure S1). Fish were observed in 23 of the 24 trawling sampling areas or boxes (Figure S2). The three boxes with the greatest number of fish caught per trawl or catch per unit effort (CPUE) were E, J, and N, in that order (Figure S3 (a)). Despite each of the top boxes being in a different section of the harbor, the greatest fish CPUE overall was the inner harbor (Figure S3 (b)). While sampling was typically conducted in the inner, middle, and outer harbor during each trawling trip, tidal cycles periodically impeded access to particularly shallow boxes. Boxes A and B were only trawled once each during the season because they are difficult to access due to the tide.

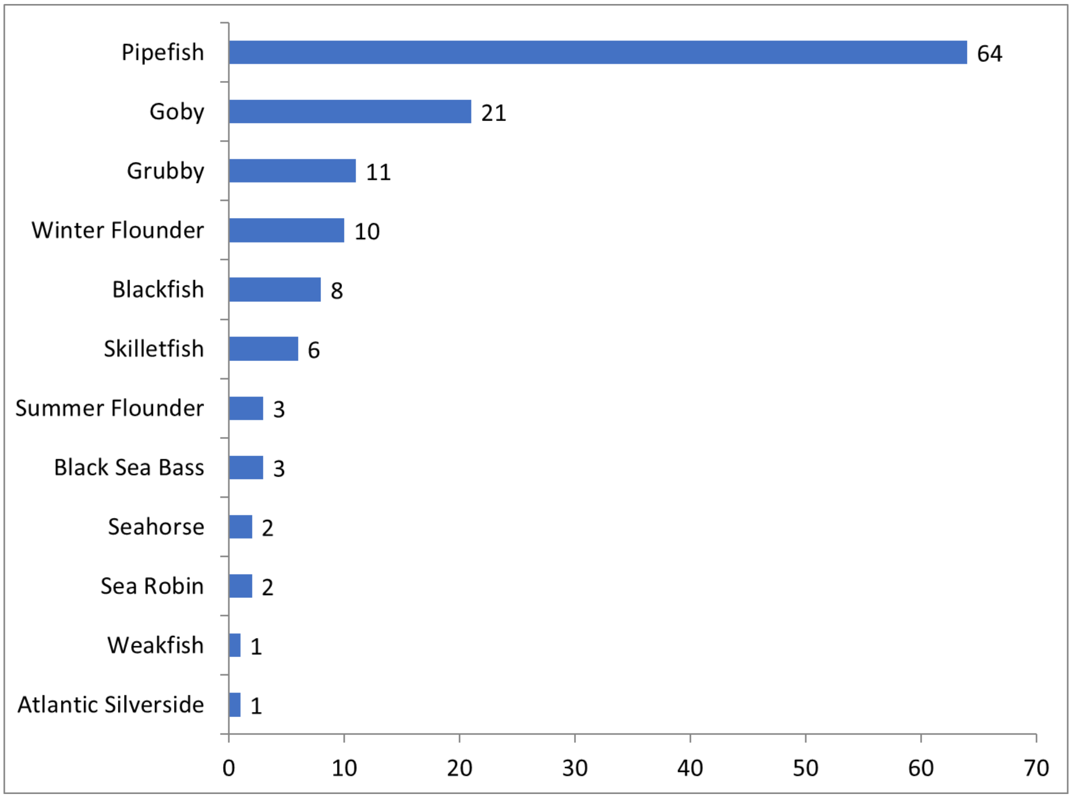



**Figure S1.** Total number of individuals caught for each fish species in Saugatuck Harbor, June through October 2025.

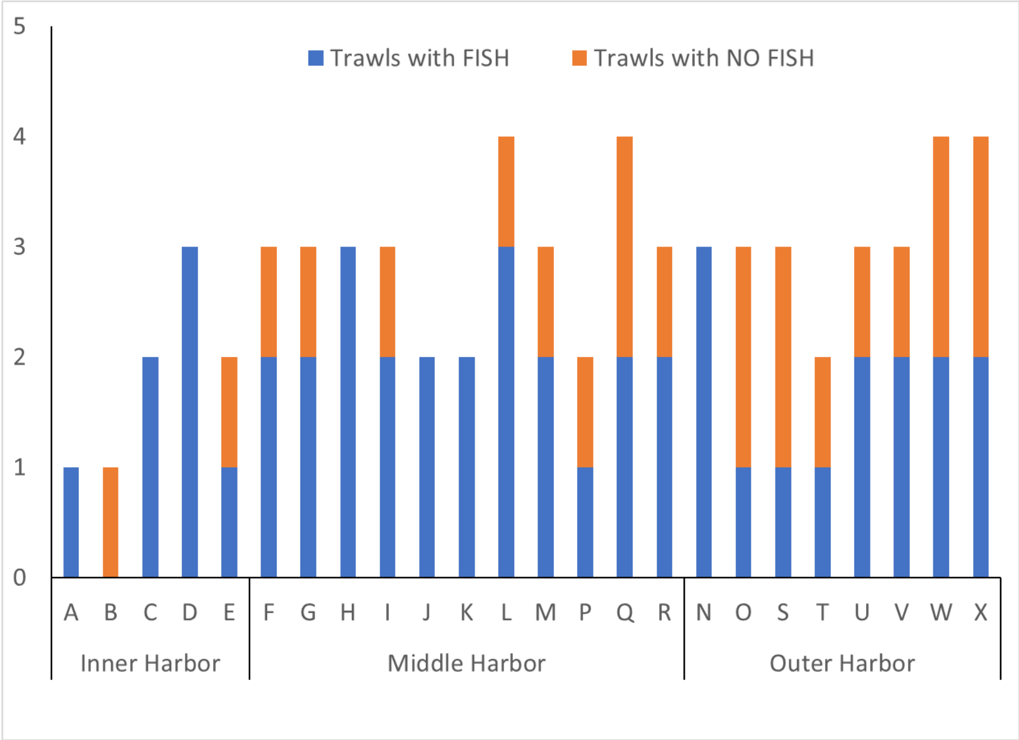



**Figure S2.** Number of trawls with and without fish in each box in Saugatuck Harbor, June to October 2025.

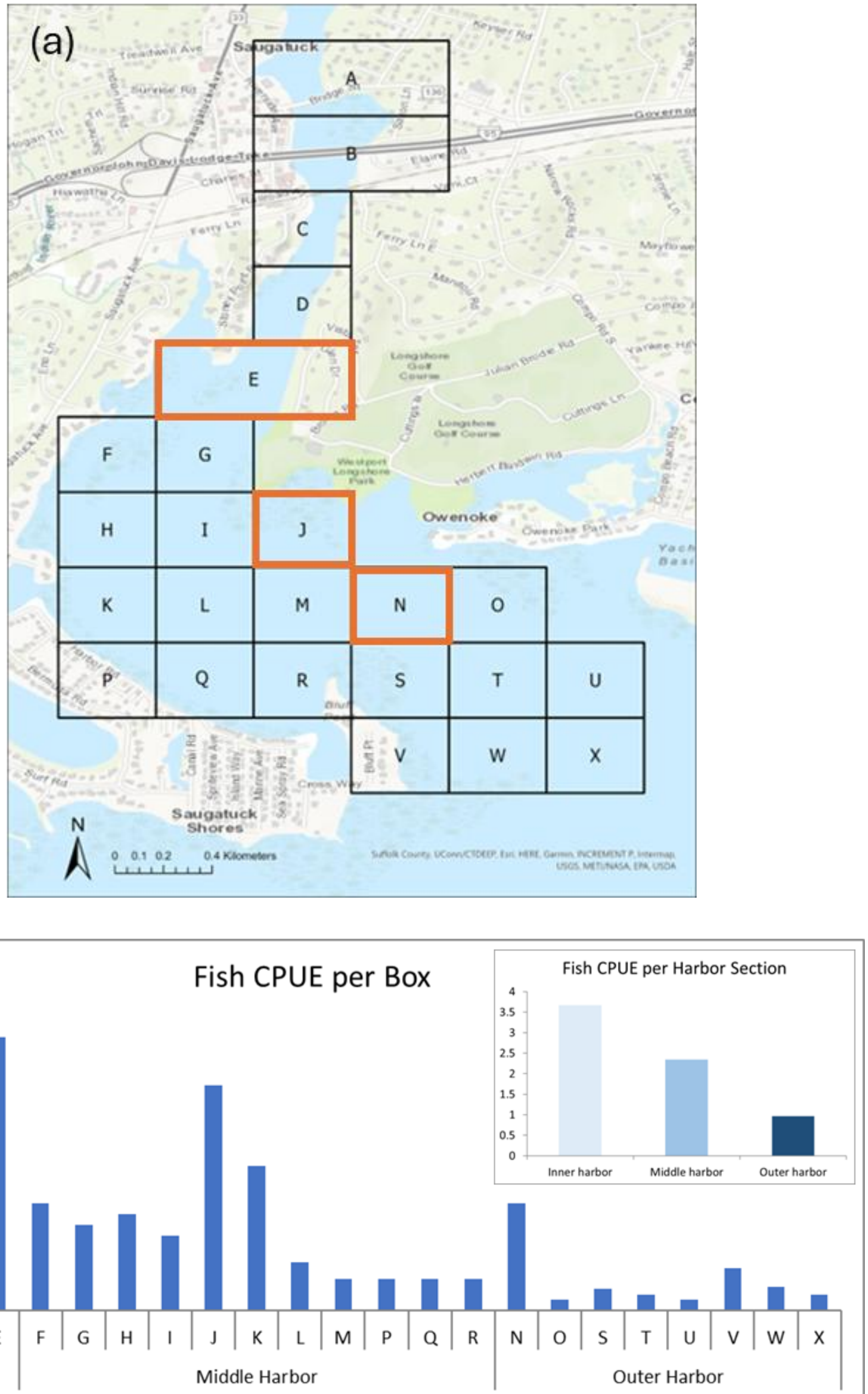



**Figure S3.** (a) Map of Saugatuck Harbor showing boxes with the greatest fish CPUE (orange boxes), June to October 2025. (b) Fish caught per unit effort (CPUE) in each box of Saugatuck Harbor, June to October 2025. The nested bar graph shows the fish CPUE by harbor section.

The month with the greatest fish CPUE was August. The greatest abundance of each species was observed at slightly different times throughout the season (Figure S4). Near the start of the season, grubbies (light blue bars) were most abundant. Winter flounder (dark green bars) abundance peaked in July, dwindling afterwards. Pipefish (light green bars) and blackfish (light grey bars) were most abundant in July, and gobies (yellow bars) were most common in September. In October, skilletfish (dark grey bars) and summer flounder (copper bars) hit their highest CPUE. The fluctuations in population density and temporal abundance correspond with the life cycles of each species. For example, spawning for winter flounder occurs from late winter to early spring with juveniles completing metamorphosis just a few weeks after hatching (Chesapeake Bay Program, n.d.-a). In this study, all winter flounder caught were in their juvenile stage and a majority were observed in June and July, right after spawning likely occurred. The temperature of the water also plays a role in their movement. Winter flounder prefer colder water and thus move to deeper water or migrate offshore during the later summer months.

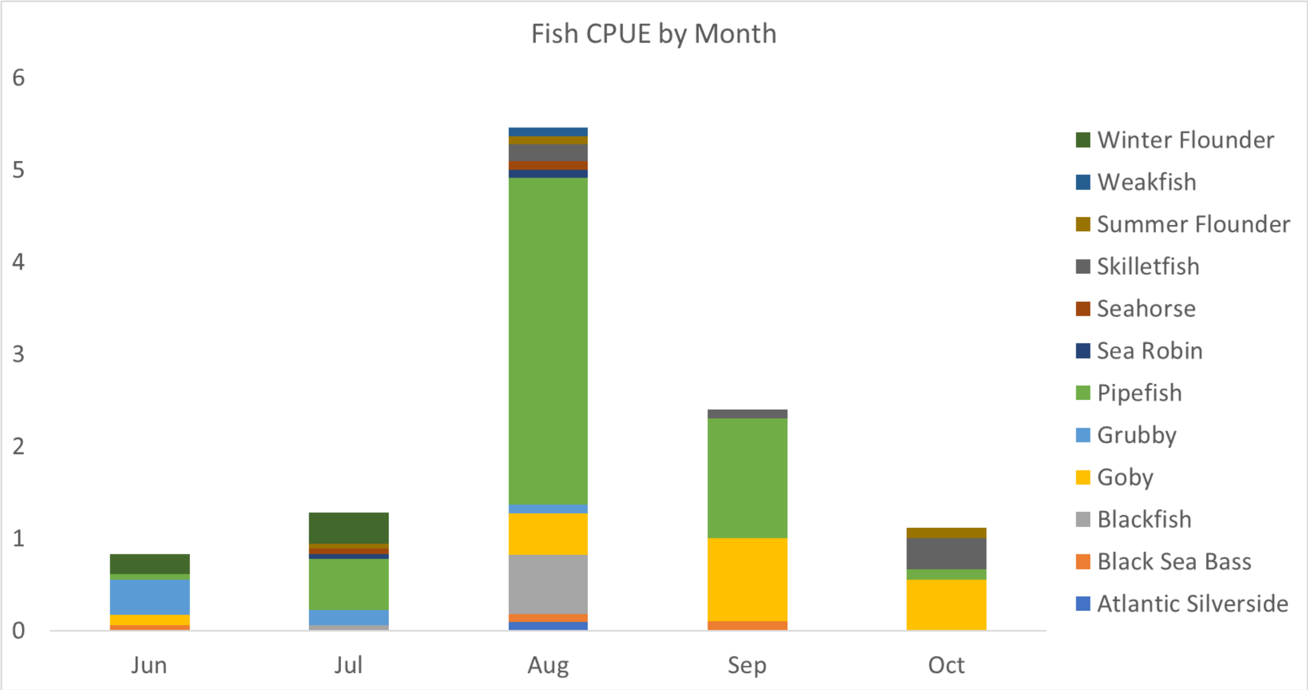


**Figure S4.** Fish CPUE across all sampling months in Saugatuck Harbor, 2025.

## CRUSTACEANS

In 2025, the three most abundant crustaceans caught in Saugatuck Harbor were shore shrimp (*Palaemon spp.*), long-wristed hermit crabs (*Pagurus longicarpus*), and sand shrimp (*Crangon septemspinosa*), which account for 74% of the total number of crustaceans counted (Figure S6). The three most abundant shrimp caught, making up 98% of the total number of shrimp caught, were shore shrimp (*Palaemon spp.*), sand shrimp (*Crangon septemspinosa*), and chameleon shrimp (*Hippolyte zostericola*). Certain individual shrimp were too small to confidently identify and therefore were documented as "Juvenile Shrimp" and recorded as a presence instead of a count. The three most abundant crabs were long-wristed hermit crabs (*Pagurus longicarpus*), mud crabs (various species), and spider crabs (*Libinia spp.*), accounting for 97% of the total number of crabs caught. Individual speciation for mud crabs and spider crabs was not conducted. The "Mud Crab" identification represents potentially four species (*Panopeus herbstii, Hexapanopeus angustifrons, Dyspanopeus sayi, and Eurypanopeus depresssus)* but was likely dominated by black-fingered mud crab (*Panopeus herbstii*). The "Spider Crab" identification represents potentially 2 species (*Libinia emarginata* and *Libinia dubia*) but was likely dominated by the nine-spined spider crab (*Libinia emarginata*). The Asian shrimp (*Palaemon macrodactylus*) was the only crustacean caught that is non-native and so it was documented and shared with CT DEEP for identification confirmation and to be used in assessing the impacts of this species on the native populations.

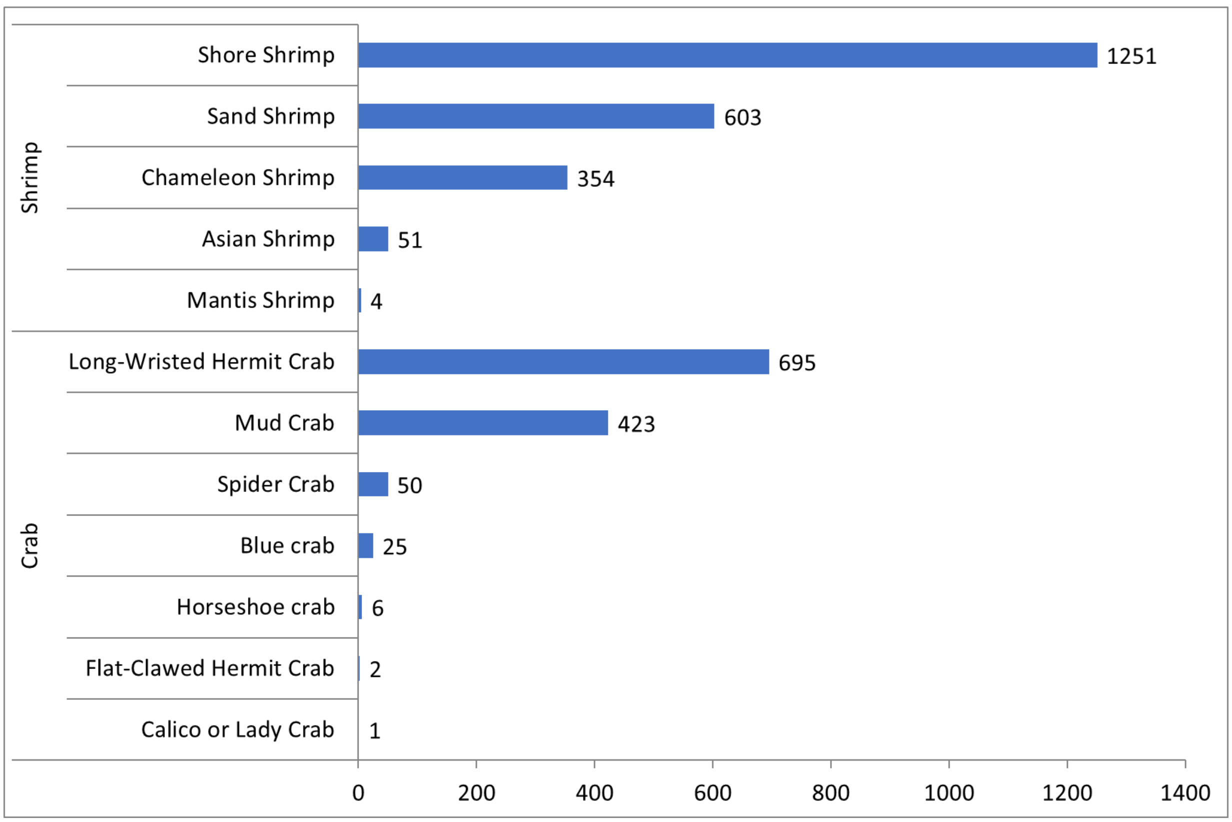



**Figure S6**. Total number of crustaceans counted in Saugatuck Harbor, June to October 2025

## CRUSTACEANS: *SHRIMP*

Sand shrimp and shore shrimp dominated the trawl catch in 2025. Overall, the majority of shrimp were caught in the inner harbor (Figure S7). The majority of shore shrimp were found in the inner harbor, and the majority of sand shrimp were found in the middle harbor. As for chameleon shrimp, most were found in the middle harbor while most of Asian and mantis shrimp were found in the inner harbors. The chameleon shrimp are much smaller than the mantis and Asian shrimp, therefore, the inverse abundance between the larger and smaller shrimp may be related to competition. Differences in habitat preferences can also be a contributing factor. When comparing shrimp CPUE between each sampling month, sand shrimp peaked in June, while all other species peaked in August (shore, mantis, and Asian shrimp) and September (chameleon shrimp) (Figure S8). These peaks could potentially correlate with the spawning periods of the shrimp. Not much is known about the spawning timing for Asian shrimp in the western Atlantic, however their spawning period in their native range in Japan is from mid-April to early October and in California, egg-bearing females are found mainly from May to August (Ashelby et al., 2013). This data may suggest that their spawning in the northwestern Atlantic peak around August-September, however, more research is needed to confirm this. Not much is known about the spawning period of chameleon shrimp in this area either. They are more prevalent in warmer areas (SeaLifeBase, n.d.) and tend to have continuous spawning in their more southern ranges (Romero-Rodríguez & Román-Contreras, 2013). Perhaps their peak in September in Saugatuck Harbor more closely resembles environmental conditions in those southern ranges.

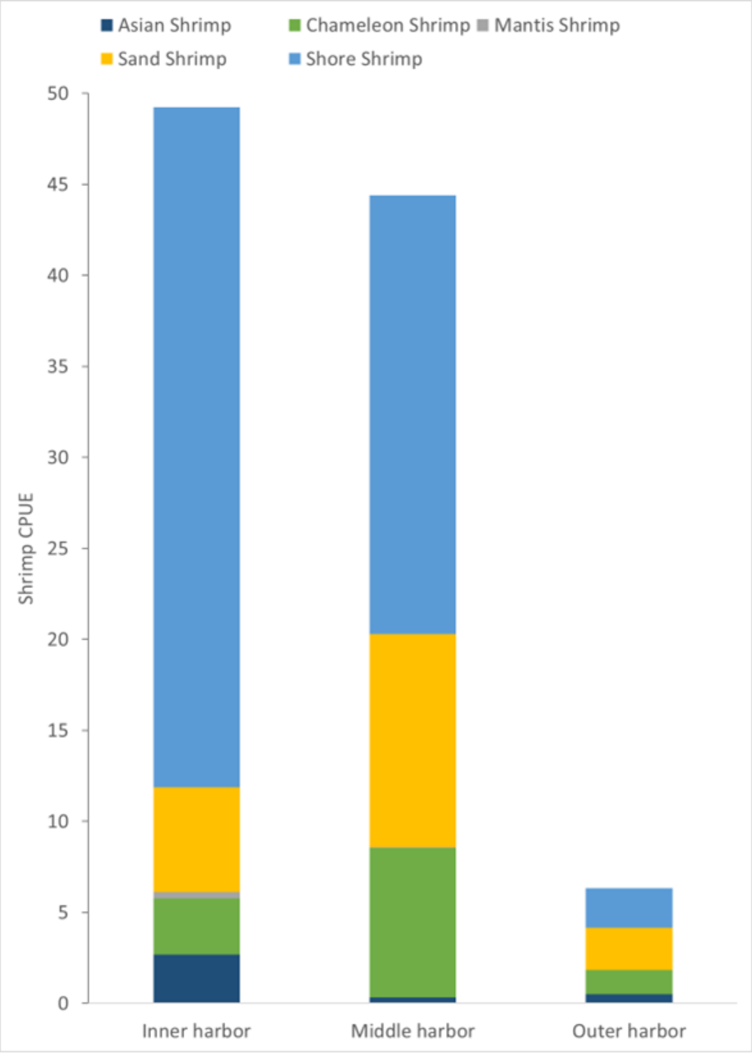



**Figure S7.** Total shrimp CPUE in each section of Saugatuck Harbor, June to October 2025.

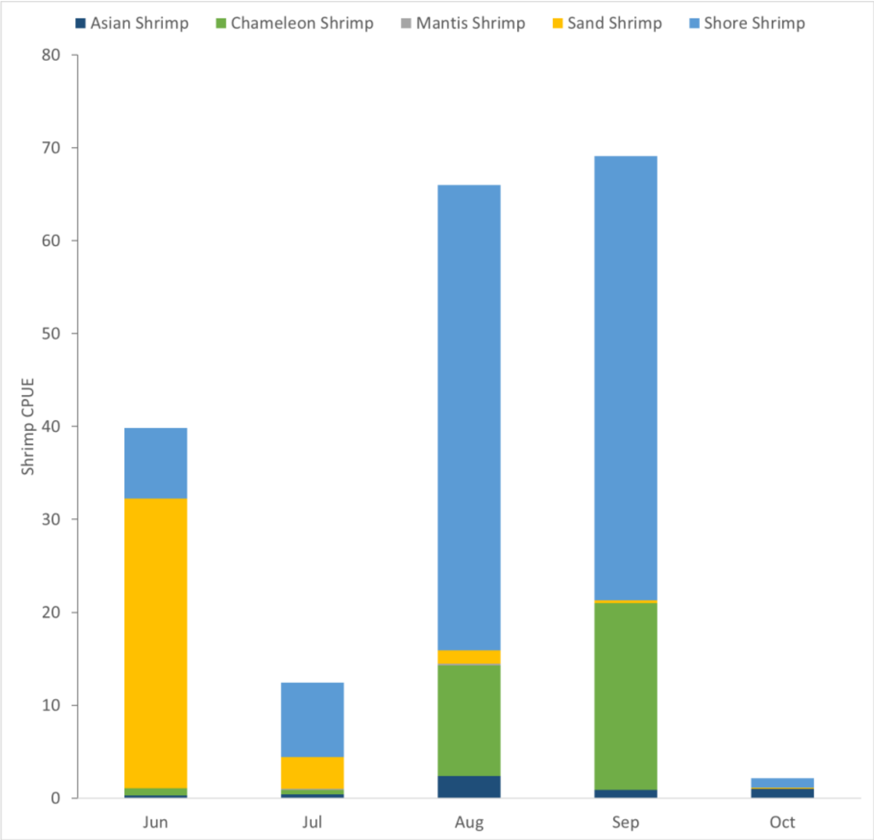



**Figure S8.** Total shrimp CPUE for each month of the sampling season in Saugatuck Harbor, 2025.

In terms of distribution in Saugatuck Harbor, the three boxes with the highest overall shrimp CPUE in order were J, E, and G (orange boxes in Figure S9). The box with the greatest CPUE of sand, shore, and chameleon shrimp was J. These boxes are closest to areas with the greatest amount of marsh grasses in the areas trawled which could be a potential contributing factor to the higher presence of shrimp.

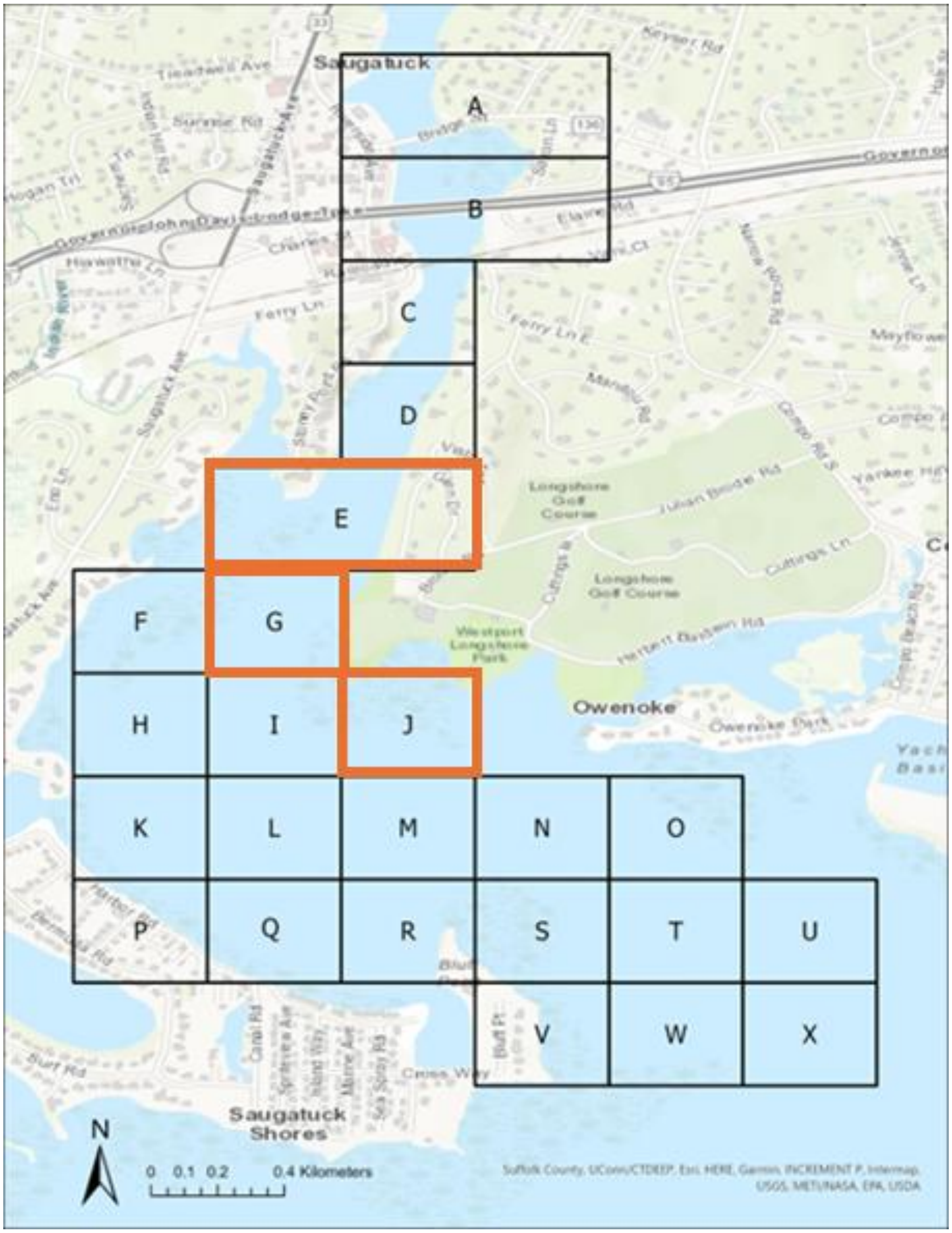



**Figure S9.** Map of the boxes with the greatest shrimp CPUE (orange boxes) in Saugatuck Harbor, June to October 2025.

## CRUSTACEANS: *CRABS*

Most crabs caught in the Saugatuck Harbor in 2025 were in the outer portion of the harbor (Figure S10). Long-wristed hermit crabs and mud crabs dominated the catch, with mud crabs being more prevalent in the inner harbor and the long-wristed hermit crabs being more prevalent in the outer harbor. Spider crabs and blue crabs were mostly found in the inner harbor. The inner harbor is closer to the mouth of the Saugatuck River, which is the main freshwater input of the harbor. Male blue crabs inhabit fresher water areas while female blue crabs tend to be found in higher salinity areas (Chesapeake Bay Program, n.d.-b). This may explain why so many were caught in this part of the harbor, though we cannot say for sure because the sex of the individual crabs was not recorded. Spider crabs have more of a range, inhabiting shallower water and deeper waters (Chesapeake Bay Program, n.d.-e).

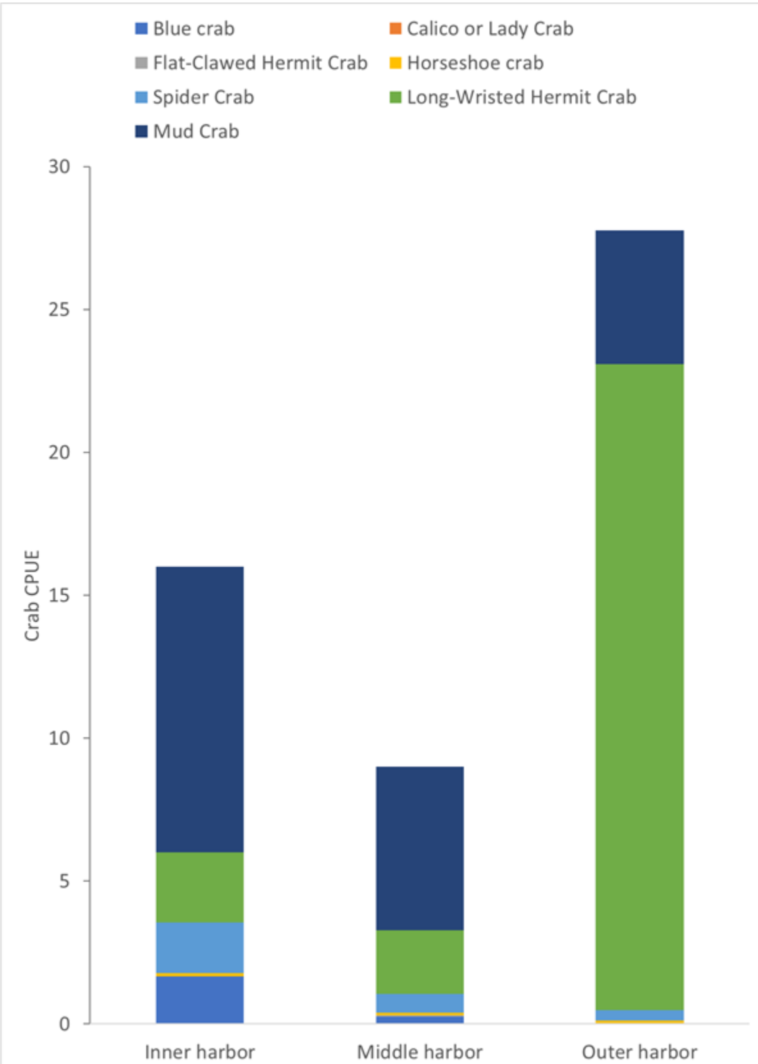



**Figure S10.** Total crab CPUE in each section of Saugatuck Harbor, June to October 2025.

The month with the most crabs caught was July (Figure S11). When long-wristed crabs and mud crabs are removed from the graph, the CPUE per month is more variable, showing blue crab populations peaking in June, horseshoe crabs peaking in July, and spider crabs peaking in August.

The areas of the harbor with the highest CPUE across all crabs in order were boxes O, E, and J (orange boxes in Figure S12). The box with the greatest CPUE for long-wristed hermit crabs was O, and for mud crabs and spider crabs was E. These areas are similar to the areas with the greatest fish and shrimp CPUE, which could be an indicator of better water quality and/or better habitat for these organisms.

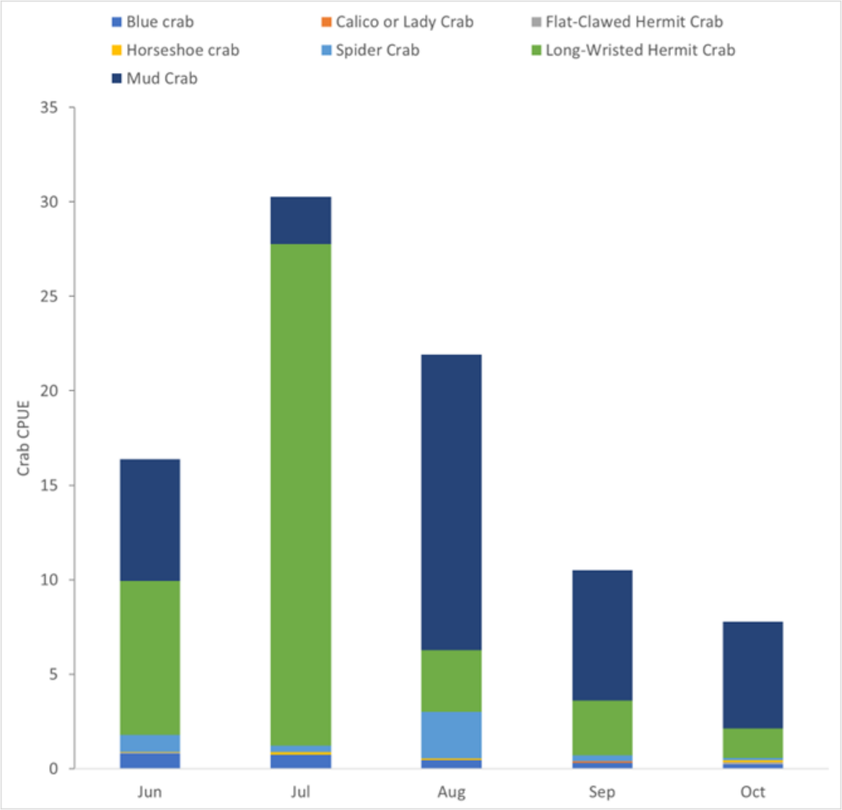



**Figure S11.** Total crab CPUE in each month of the sampling season in Saugatuck Harbor, 2025.

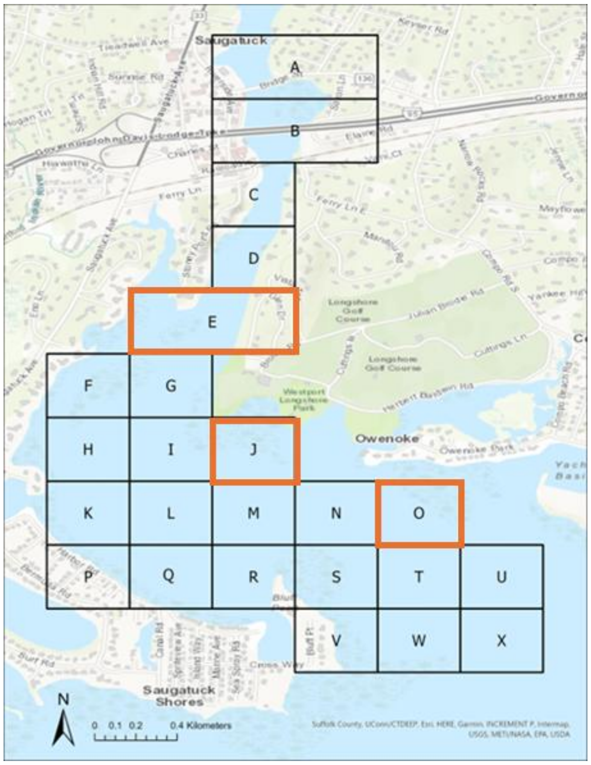



**Figure S12.** Map of Saugatuck Harbor showing the boxes with the greatest crab CPUE (orange boxes), June to October 2025.

## OTHER SPECIES

Harbor Watch documented the presence of many different species of mollusks, sponges, crustaceans and other groups of organisms in Saugatuck Harbor in 2025. The three most commonly caught organisms were slipper shells (in 71% of trawls), amphipods (in 58% of trawls), and mud snails (in 56% of trawls). June was the month with the largest presence of organisms in the trawls. Two notable catches in 2025 were northern star coral and a bay scallop. Scallop shells are found often, but not a live scallop.

**Mollusks**
- ✓ Arc Clam
- ✓ Bay Scallop
- ✓ Channeled Whelk
- ✓ Clam
- ✓ Glassy Bubble Snail
- ✓ Jingle Shell
- ✓ Mud Snail
- ✓ New England Dog Whelk
- ✓ Oyster
- ✓ Atlantic Oyster Drill
- ✓ Thick-Lipped Oyster Drill
- ✓ Sea Slug
- ✓ Seila adamsii
- ✓ Slipper Shell

**Sponges**
- ✓ Boring Sponge
- ✓ Red Beard Sponge
- ✓ Sea Sponge

**Crustaceans**
- ✓ Barnacle
- ✓ Juvenile Shrimp

**Worms**
- ✓ Segmented Worm

**Other**
- ✓ Amphipods
- ✓ Anemone
- ✓ Bryozoan
- ✓ Common Sea Star
- ✓ Diamondback Terrapin
- ✓ Isopod
- ✓ Sea Spider
- ✓ Sea Squirt
- ✓ Comb Jelly

## MARINE DEBRIS

In total, 25 trawls or 38% of all trawls from June to October 2025 in Saugatuck Harbor had some type of trash in it. Plastic was the most common type of trash found (Figure S13). The "Other" category was the second most common type of trash found, which includes items like rubber, fabric, and golf balls. The metal category mainly consists of drink cans. Spatially, the four boxes where trash was most likely to be found in the trawls were D, G, H and E in that order (G and H had the same probability, Figure S14). These boxes are in the lower-inner and upper-middle harbor boxes and, interestingly, all the outer harbor boxes had no trash. This could potentially be a result of the hook-shape of the harbor and the hydrology of the harbor. The boxes with the greatest number of trawls with trash are in the part of the hook right before it turns, which could potentially be a settling area for it.

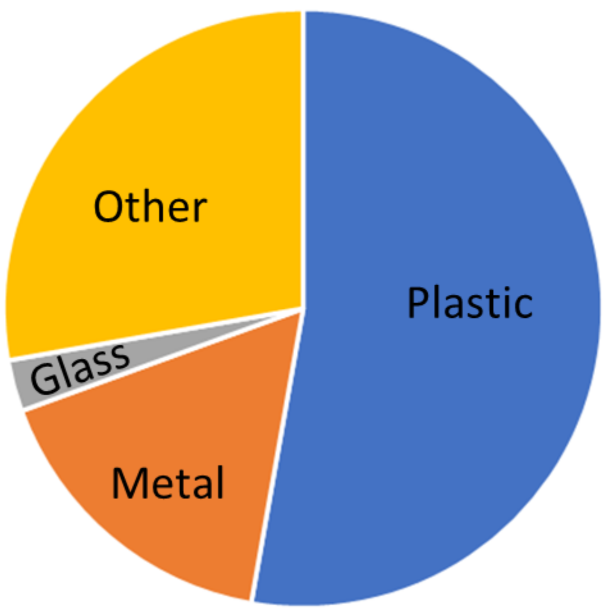



**Figure S13.** Proportion of each type of trash found in trawls in Saugatuck Harbor, June to October 2025.

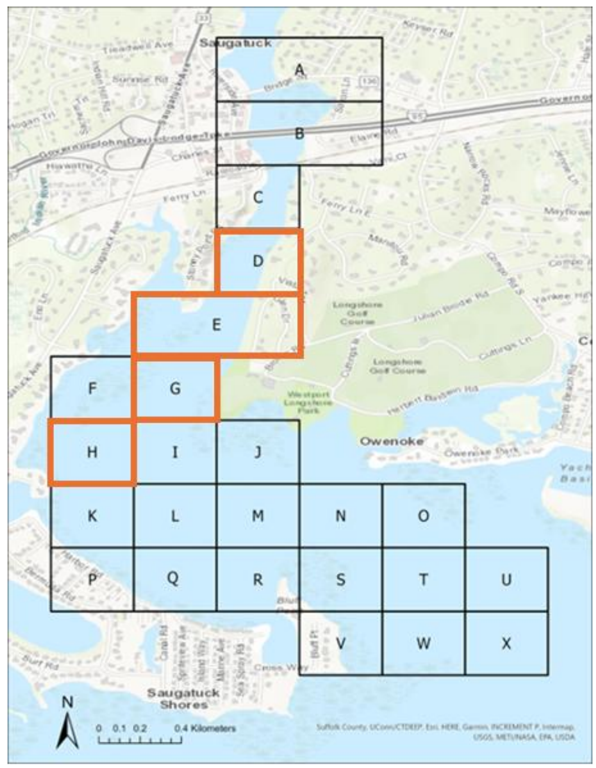



**Figure S14**. Map of Saugatuck Harbor showing the boxes where trash was most likely to be found when trawling (orange boxes), June to October 2025.

# Unified Water Study Analysis

## DISSOLVED OXYGEN

The minimum dissolved oxygen (DO) established by CT DEEP in saltwater is 3 mg/L, acutely (CT DEEP, 2015). Under this level, water is considered hypoxic or lacking oxygen, which is harmful for aquatic organisms. No individual DO readings in Saugatuck Harbor were observed below 3mg/L. Throughout May to October 2025, the lowest DO recorded in Saugatuck Harbor was 4.85 mg/L at the bottom of site SAU-I-01 on 7/15 (Figure S15). All sites follow the same trend with higher DO observed at the start and end of the sampling season and lower DO in the middle. This is because as water temperatures increase through the summer, dissolved oxygen decreases and then as water temperatures cool off as fall begins, dissolved oxygen begins to increase.


**Figure S15.** Dissolved oxygen readings at the surface and bottom of each UWS site on each sampling date in Saugatuck Harbor, May to October 2025. Sites SAU-I-02 and SAU-I-04 only have mid-depth readings on certain dates because the total depth at the site was less than 1.5m. Black line represents the state criteria for dissolved oxygen, which is 3 mg/L.

## CHLOROPHYLL-*A*

When an excess of nutrients enters a waterway from runoff of fertilized lawns or agricultural fields, microalgae in the water consume it and experience a boom in population. This results in the water turning shades of red, brown, or green. Once these organisms die, they sink to the bottom where bacteria break them down, a process that uses up lots of oxygen. Therefore, algal blooms can negatively impact water quality in the areas they overpopulate. The microalgae photosynthesize and the main pigment used in this process is chlorophyll-*a*, which can be and was measured at each site at the surface and the bottom. For most sites, the highest concentrations of chlorophyll are during July and August (Figure S16, note scale in graphs). The sites closest to the mouth of the Saugatuck River also have the highest concentration of chlorophyll. Note different scales in graphs below.


**Figure S16.** Chlorophyll-a readings (µg/L) at each site on each sampling date in Saugatuck Harbor, 2025. Note differences in scales for each graph.

## TEMPERATURE AND SALINITY

Average water temperatures were very similar along the length of the harbor. The average monthly temperature across all sites ranged from a minimum of 13.6°C at the bottom in May to a maximum of 24.5°C at the surface in July (Figure S17 (a)). The average monthly surface and bottom salinity were more variable between sites (Figure S17 (b) & (c)). This is a result of the freshwater input of the Saugatuck River at the north end of the harbor and the resulting salt wedge formed as the less dense freshwater sat on top of the denser saltwater. As the sites moved seaward and mixing of the water layers became more prominent, the surface salinity became more consistent.

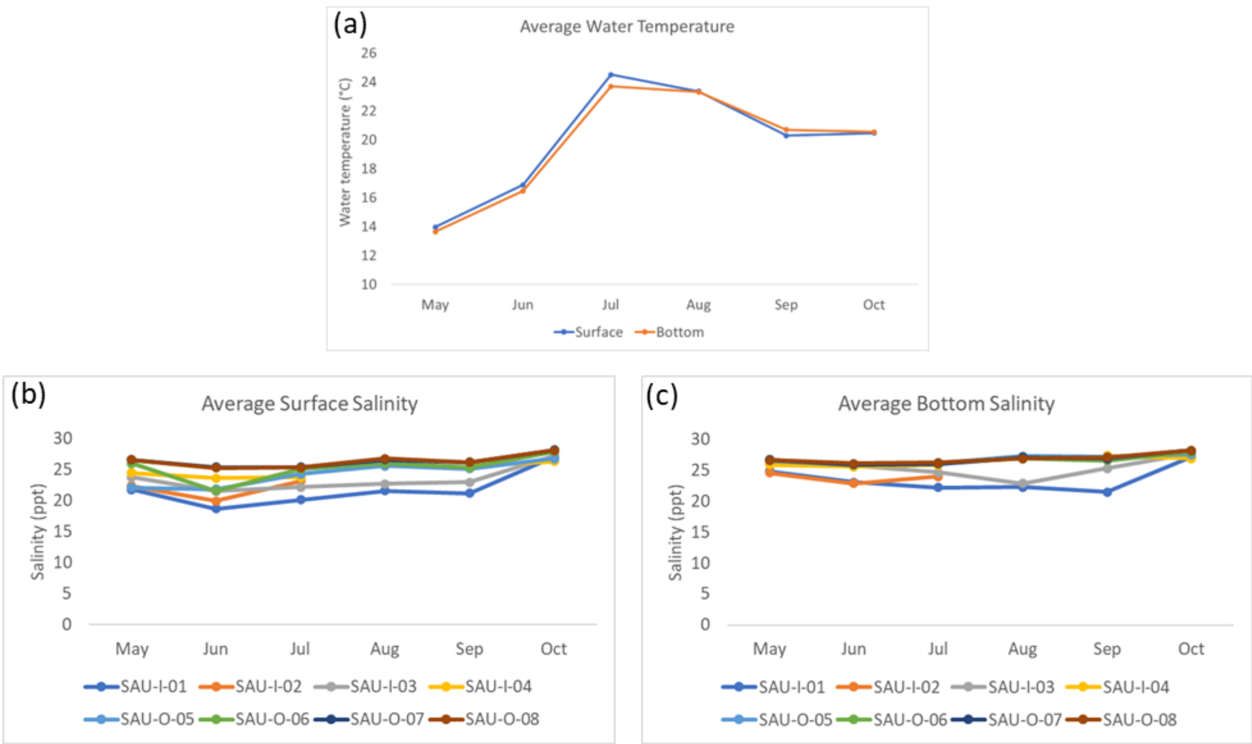



**Figure S17.** (a) Average monthly water temperature across all sampling sites at the surface and bottom of Saugatuck Harbor, May to October 2025. Note range of y-axis, (b) Average monthly surface salinity at each site in Saugatuck Harbor, May to October 2025, (c) Average monthly bottom salinity at each site in Saugatuck Harbor, May to October 2025.

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# QAPP Deviation Summary

**Quality Assurance Project Plan (QAPP) Report (11/14/25)**
This report includes any deviations from the approved QAPP (QA Tracking #25002). These deviations are listed by the section of the QAPP where the deviation occurred. Any notes from this report that would result in a process change will be updated in future QAPP submissions.

**Project Name:** Embayment Biological Study in Fairfield County Harbors

**Monitoring Organization:** Harbor Watch, a program of Earthplace, Inc.
10 Woodside Lane, Westport, CT 06880

**Approved for:** Monitoring Season 2025-2029

**2.1 Sampling Design**
- In Norwalk Harbor, a majority of the boxes were trawled between 6-7 times, with box H only being trawled 5 times.
- In Saugatuck Harbor, a majority of the boxes were trawled between 2-4 times, with boxes A and B only being trawled 1 time each.

**2.5 Quality Control Requirements**
- There was only 1 species identification discrepancy on the second trawl species QC ID, which was discussed as a team and will be added to the guide to avoid issues in the future.

**Appendix 1: Sample Data Sheet**
- A new data sheet was designed and updated in the following ways:
- Modified how species (other than fish, shrimp, and crabs) were recorded from exact numbers to presence/absence

# Appendix

Table of warm temperate fish species that were caught in Norwalk Harbor and Saugatuck Harbor collectively. List is gathered from a larger list detailed in the CT DEEP Marine finfish survey from 2023 (see citation CT DEEP (n.d.) for more information). These species are found more abundantly south of New York, spawn at the higher end of their temperature tolerances and prefer water temperatures around 11-22°C.

| Warm Temperate Species | |
|---|---|
| Common Name | Scientific Name |
| American eel | *Anguilla rostrata* |
| Atlantic croaker | *Micropogonias undulatus* |
| Bunker | *Brevoortia tyrannus* |
| Black sea bass | *Centropristis striata* |
| Bluefish | *Pomatomus saltatrix* |
| Butterfish | *Peprilus triacanthus* |
| Clearnose skate | *Raja eglanteria* |
| Feather blenny | *Hypsoblennius hentz* |
| Hogchoker | *Trinectes maculatus* |
| Lined seahorse | *Hippocampus erectus* |
| Goby | *Gobiosoma spp.* |
| Northern kingfish | *Menticirrhus saxatilis* |
| Northern puffer | *Sphoeroides maculatus* |
| Sea Robin | *Prionotus spp.* |
| Oyster toadfish | *Opsanus tau* |
| Scup | *Stenotomus chrysops* |
| Summer flounder | *Paralichthys dentatus* |
| Weakfish | *Cynoscion regalis* |
| Blackfish | *Tautoga onitis* |
| Spot | *Leiostomus xanthurus* |
| Smallmouth flounder | *Etropus microstomus* |
| White perch | *Morone americana* |