

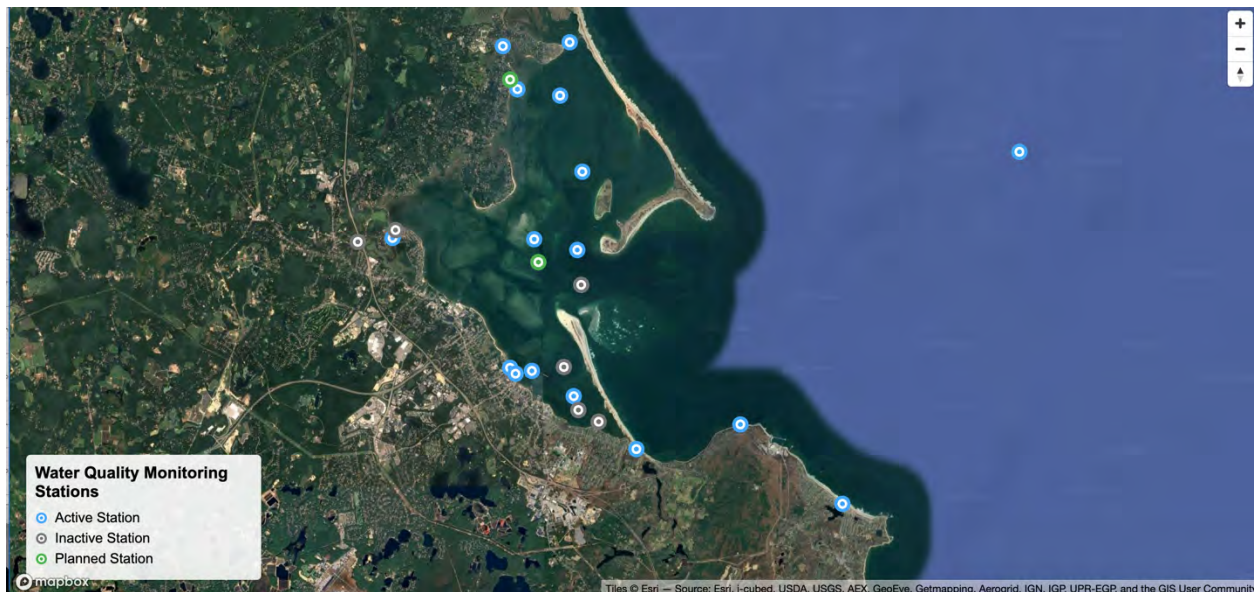
THE STATE OF DUXBURY BAY – 2025

October 10, 2025



Prepared by the Duxbury Bay Management Commission

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Executive Summary – State of the Bay – 2025

Overview

Duxbury Bay is an ecologically, economically and culturally important resource that supports extensive recreational activities, a thriving oyster aquaculture industry, and diverse habitats for fish and invertebrates. The bay's clean water underpins commercial shell fishing, recreation, and tourism, while sustaining valuable ecosystem services such as nutrient cycling, sediment stabilization, and biodiversity support.

Over twenty years of data has been analyzed and summarized in this report related to water quality and the health of Duxbury Bay. Key water quality indicators show that Duxbury Bay remains biologically productive with overall good water quality, but upper reaches of Duxbury Bay, (see light green areas in figure below from 2017 MA DEP) are increasingly stressed by nutrient enrichment and climate-related impacts.

MASSACHUSETTS ESTUARIES PROJECT

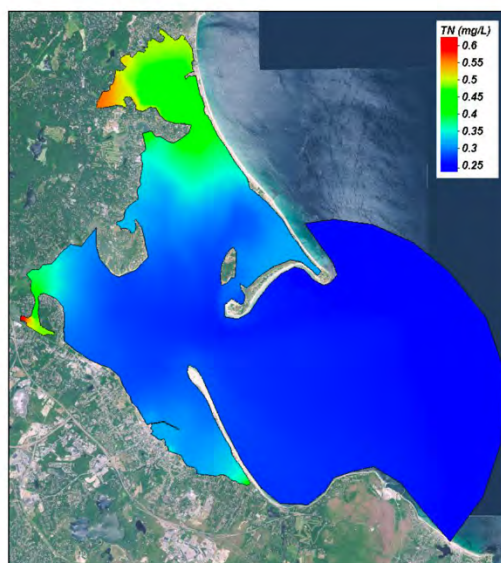


Figure VI-7. Contour plot of average total nitrogen concentrations from results of the present conditions loading scenario, for Plymouth Bay system.

Nutrient Enrichment and Algal Growth

Nitrogen concentrations are highest in the Bluefish River and have increased at Powder Point Bridge and Harbormaster Dock since 2006, often exceeding established ecological thresholds for good water quality. Excess nitrogen fuels phytoplankton blooms, leading to oxygen depletion and habitat degradation. Phosphorus, primarily from detergents and runoff, is present at lower levels but peaks seasonally in the upper bay. Both nutrients reflect watershed inputs from septic systems, fertilizer use, and stormwater.

Chlorophyll-a, a measure of phytoplankton biomass, has increased at multiple sites, particularly in the upper bay. Cyanobacteria blooms have been detected periodically, creating potential risks for shellfish aquaculture and ecosystem stability. These patterns indicate a need for targeted nutrient management in high-load sub-watersheds, along with continued monitoring to detect harmful algal blooms.

Massachusetts Department of Environmental Protection – MA Estuaries Project – 2017 Draft Report

The Massachusetts Estuaries Project (MEP), initiated in 2001 by MassDEP and UMass Dartmouth, aims to assess nitrogen impairment in coastal estuaries using a science-based framework aligned with the Clean Water Act. The project employs a comprehensive modeling approach—combining watershed analysis, hydrologic simulations, water quality monitoring, and scenario testing—to estimate Total Maximum Daily Loads (TMDLs) for nitrogen.

In Duxbury Bay, model projections indicate nitrogen concentrations exceeding the conservative threshold of 0.33 mg/L, primarily due to septic system contributions.

Although the bay shows only marginal signs of impairment, regulatory consequences may follow if TMDLs are not met, including restrictions on development and funding.

Dissolved Oxygen and Temperature Stress

There has been extensive reporting on overall warming trends of the water in Cape Cod Bay and the Gulf of Maine. However, from review of the past twenty years of data, there is not statistically significant evidence of average warming temperatures in Duxbury Bay.

However, over the last twenty years does indicate there is a significant increase in the number of (days), and duration (hours), when water temperature in Duxbury Bay exceeds 25 Deg. C (77 Deg F), considered a critical threshold temperature.

Overall, dissolved oxygen levels are generally above concern thresholds, but high-frequency monitoring reveals short-term low oxygen events—especially during warm, calm summer periods. These episodic low-oxygen conditions, which may not be captured by periodic sampling, can stress or kill aquatic life, including in particular eel grass, and juvenile fish.

Eelgrass Decline

Eelgrass (*Zostera marina*) meadows have declined by more than 60% in Duxbury Bay over the past 20 years. Eelgrass provides critical habitat for juvenile fish, enhances water clarity, and stabilizes sediments. Losses are driven by nutrient-driven turbidity, disease, physical disturbance from boating and aquaculture, and warming waters.

Water clarity remains generally favorable in much of the bay, but the Bluefish River shows persistently high turbidity, likely from organic matter and sediment resuspension in marshes.

Restoration success depends on improving water quality and protecting sensitive areas from disturbance.

Bacterial and Pathogen Monitoring

Bacterial water quality in Duxbury's coastal waters has been consistently good since 2009, with rare exceedances linked to stormwater runoff after extended dry periods. Weekly summer sampling of public beaches for *E. coli* and multiple annual inspections of shellfish beds by the Massachusetts Division of Marine Fisheries ensure compliance with public health standards.

Persistent problem areas remain closed to shell fishing due to contamination, but targeted infrastructure upgrades, septic improvements, and public education have reduced risk.

Shellfish Aquaculture and Water Quality

Commercial oyster aquaculture dominates Duxbury's shellfish industry, operating under strict local and state regulations. The Aquaculture Management Plan limits total lease area to 1.3% of the bay, mandates habitat protections, and requires ongoing environmental monitoring. Oysters provide measurable water quality benefits by removing nitrogen and improving clarity through filtration. However, the industry faces challenges from invasive species, fouling organisms, disease, and climate variability. Coordinating aquaculture policy with nutrient management strategies can maximize ecological benefits while sustaining economic viability.

Invasive Species Pressure

The bay is experiencing increased pressure from invasive marine species, notably European green crabs, tunicates (sea squirts), and bryozoans (moss animals). These species damage eelgrass beds, prey on juvenile shellfish, and foul aquaculture gear. Climate change and vessel traffic have facilitated their spread.

Early detection programs like Marine Invader Monitoring and Information Collaborative ("MIMIC"), combined with targeted removal, gear innovations, and biosecurity measures, are essential to limiting ecological and economic damage.

Recreational and Commercial Fisheries Context

Recreational fishing, lobstering, and nearby offshore species contribute to the local economy but are influenced by habitat condition and water quality. Striped bass, flounder, and other species are sensitive to nutrient-driven algal blooms, warming waters, and habitat loss. Habitat restoration—particularly eelgrass and salt marsh protection—supports fishery resilience.

Duxbury Beach, Climate and Sea Level Rise

Duxbury Beach serves a critical role in coastal protection as a barrier beach by absorbing wind and wave energy generated in Cape Cod Bay. In addition, wetlands lining the west side of the barrier create a healthy and well-maintained system that provides a natural buffer and safeguards the bay and the coastal community of Duxbury.

As a prominent coastal ecosystem in Massachusetts, Duxbury Beach supports a diverse range of wildlife, including 284 species of birds (ebird.org), 12 species of mammals, 89 species of invertebrates, and 206 species of plants (107 native, 90 non-native and 13 invasive). The entirety of Duxbury Beach is mapped by NHESP as Priority Habitat of Rare Species and Estimated Habitat of Rare Wildlife.

Sea level along the Massachusetts coast is projected to rise 10–14 inches by 2050, increasing flooding frequency – and poses ongoing challenges and increasing costs to preserve Duxbury Beach. Higher water levels, combined with storms, can mobilize sediments, alter salinity, and exacerbate nutrient loading from upland areas. Protecting and restoring wetlands, dunes, and marshes provides natural water filtration and buffers flood impacts, indirectly improving water quality.

Conclusion and Recommendations

With coordinated management, community engagement, and sustained investment in monitoring and restoration, Duxbury Bay can remain both a productive ecosystem and a resilient economic asset in the face of environmental change.

1. Nutrient Reduction & Water Quality Improvement

- **Target high-load sub-watersheds** (Bluefish River, Back River, Island Creek, Kingston/Duxbury Bay) for nitrogen reduction.
- **Address primary nutrient sources** by upgrading septic systems, reducing fertilizer use, and maintaining effective stormwater Best Management Practices (BMPs).

2. Monitoring, Research & Data Integration

- **Expand high-frequency water quality monitoring** for nutrients, dissolved oxygen, temperature, and algal blooms using sondes and continuous sensors.
- **Maintain long-term habitat mapping** (eelgrass, salt marsh) via aerial, drone, and sonar surveys.
- **Integrate monitoring results** into adaptive management decisions, aquaculture licensing, and habitat restoration planning.

3. Habitat Protection & Restoration

- **Protect and restore eelgrass** in historically vegetated, high-clarity areas using proven replanting methods and anchoring/dredging restrictions.

- **Implement coastal habitat safeguards** for bayside mudflats, marshes, and dunes through restoration projects and targeted protections.
- **Leverage nature-based solutions** (living shorelines, wetland restoration, oyster reefs, quahog aquaculture) to remove nutrients, buffer flooding, improve water filtration, and stabilize sediments.

4. Invasive Species & Aquaculture Resilience

- **Control priority invasives** (green crabs, tunicates) through targeted removal and trapping.
- **Support resilient aquaculture** by developing gear and farming practices that minimize fouling, withstand climate variability, and maximize nitrogen bio extraction.

2. Water Quality



Figure VI-1. Estuarine water quality monitoring station locations in the Plymouth Bay estuary system. Station labels correspond to those provided in Table VI-1.

2.1 Introduction

Duxbury Bay, located along the Massachusetts coast, supports a diverse array of ecological habitats and provides valuable services to the surrounding community, including shellfish aquaculture, boating, and recreation. Like many estuarine systems, the bay is sensitive to nutrient enrichment, warming temperatures, and changing land use patterns in its watershed. Regular monitoring of environmental indicators is essential to track these changes and guide effective stewardship.

This report presents a synthesis of available water quality data to evaluate the current state of Duxbury Bay and assess trends in ecological condition. The analysis focuses on five core environmental indicators: nutrients, phytoplankton, dissolved oxygen, turbidity, and water temperature. These indicators were selected based on their relevance to estuarine health, data availability, and their use in regional coastal assessments.

Data Sources and Scope of Analysis

The findings in this report are based on data collected by three monitoring programs: the Center for Coastal Studies (CCS), the Cape Cod Cooperative Extension (CCCE), and the Massachusetts Bays National Estuary Partnership (MassBays). Together, these programs have compiled over two decades of monitoring data within Duxbury Bay and its tributaries. However, only the CCS and CCCE datasets met the quality standards for inclusion in this report. These data were selected for their consistency, methodological rigor, and temporal coverage.

The CCS dataset spans from 2006 to 2023 and includes monthly measurements of nutrients, chlorophyll-a, dissolved oxygen, and turbidity from three long-term stations in Duxbury Bay: Harbormaster Dock, Power Point Bridge, and Bluefish River Bridge. Additional CCS monitoring stations are in Kingston Bay (Jones River Estuary), Plymouth Harbor, and adjacent Cape Cod Bay locations (see Appendix X for summary information from these stations). The CCCE data supplement this with high-frequency measurements of water temperature and dissolved oxygen recorded at 15-minute intervals during the growing season (May–October) over the last decade.

MassBays data from 2023 and 2024 were reviewed but excluded from this version of the report due to the monitoring locations and period of record. While these data may prove useful in future assessments, they were not deemed appropriate for trend analysis or condition evaluation at this time.

Although the Massachusetts Estuaries Project (MEP) did not provide raw monitoring data for use in this report, it remains a foundational source. The MEP conducted a comprehensive assessment of nitrogen loading and ecological health in the Plymouth-

Kingston-Duxbury (PKD) embayment system, including modeled watershed nitrogen inputs, analysis of eelgrass habitat loss, benthic community condition, and development of nitrogen thresholds to protect estuarine habitat. These thresholds (e.g., 0.331–0.335 mg/L for total nitrogen to protect eelgrass) serve as important reference points throughout this report and are cited where appropriate in discussions of nutrient trends and management implications.

Parameter	CCS (2006–2023)	CCCE (2006–2023)	MassBays (2023–2024)	Used in Report?
Total Nitrogen	✓	✓	✓	✓
Ammonium	✓	✓	✓	✓
Nitrate + Nitrite	✓	✓	✓	✓
Total Phosphorus	✓	X	✓	✓
Orthophosphate (PO ₄)	✓	X	✓	✓
Chlorophyll-a	✓	✓	✓	✓
Dissolved Oxygen	✓	✓	✓	✓
Turbidity	✓	✓	✓	✓
Water Temperature	✓	✓	✓	✓
Quality Rating	High	High	Moderate/Variable	—
Used in This Report	✓	✓	X	—

Table 2. Water Quality Monitoring Data Used in This Report

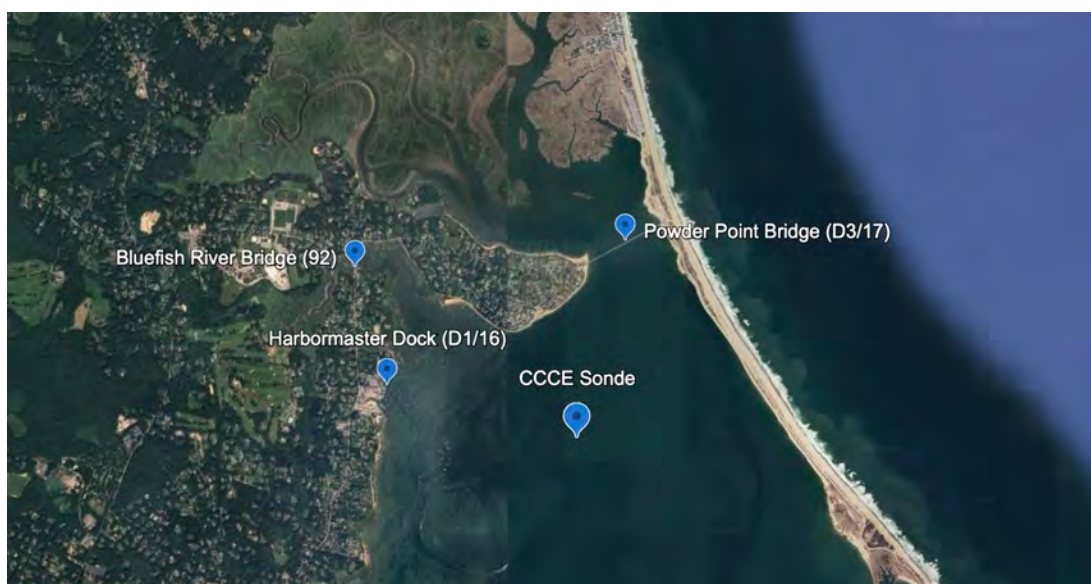


Figure 1. Locations of long-term water quality monitoring stations in Duxbury Bay. The Center for Coastal Studies (CCS) maintains stations at Bluefish River Bridge (Station 92), Harbormaster Dock (D1/16), and Powder Point Bridge (D3/17). The Cape Cod Cooperative Extension (CCCE) operates a high-frequency monitoring sonde at a mid-bay location.

Station Name	Station ID	Latitude	Longitude
Bluefish Creek	92	42.050	-70.670
Powder Point	71	41.965	-70.670
Harbormaster Dock	16 (D1)	42.040	-70.670
CCCE Sonde	—	42.035	-70.652

Table 3. Geographic coordinates of the four primary water quality monitoring stations evaluated in this report, including three Center for Coastal Studies (CCS) stations (Bluefish Creek, Powder Point, and Harbormaster Dock) and the CCCE continuous monitoring sonde location in central Duxbury Bay.

Understanding the condition of Duxbury Bay requires a consistent and long-term assessment of the environmental factors that influence water quality, habitat health, and biological productivity. This section summarizes trends and patterns for six key indicators: nutrients, phytoplankton (as measured by chlorophyll-a), blue-green algae (BGA), dissolved oxygen, turbidity, and water temperature. These indicators were selected based on their ecological importance, their role in estuarine function, and the availability of high-quality data across multiple monitoring programs.

For each indicator, we assess both spatial and temporal patterns using data collected by the Center for Coastal Studies (CCS) and Cape Cod Cooperative Extension (CCCE). Analyses include median value ranges, statistically significant trends over time, and exceedances of scientifically recognized thresholds. Each subsection integrates figures and tables to support interpretation and identify areas of concern, particularly during the growing season (May through October), when biological activity is highest and estuarine systems are most vulnerable to stress.

Taken together, these indicators provide a foundation for understanding the ecological health of Duxbury Bay. They also help identify where management actions may be needed to protect or restore critical habitats, reduce nutrient loads, and improve resilience to climate change.

2.2 Nutrients

Why We Track This Indicator

Nitrogen and phosphorus are essential nutrients that support primary production in estuarine systems. However, when present in excess—often due to human activities—these nutrients fuel algal blooms, deplete dissolved oxygen, and degrade sensitive habitats like eelgrass beds.

Tracking nutrient concentrations provides a direct measure of the amount of biologically available nutrients in the water column at the time of sampling. These measurements complement estimates of nutrient loading by showing how inputs translate to actual environmental conditions that affect estuarine organisms.

2.2.1 Total Nitrogen (TN)

Why We Track This Indicator

Nitrogen is a critical nutrient for primary production in estuarine ecosystems, but when present in excess, it can contribute to eutrophication—fueling algal blooms, reducing water clarity, and accelerating oxygen depletion. Total Nitrogen (TN) is a composite measure that includes both *inorganic forms* (nitrate, nitrite, and ammonium) and *organic forms* (dissolved and particulate organic nitrogen). This comprehensive measure is used to evaluate overall nutrient loading and its potential to drive ecological change.

Although Duxbury Bay is relatively well-flushed compared to many other New England estuaries, the upper reaches, particularly near the Bluefish River and inner embayment, experience longer residence times that allow for nutrient accumulation and biological response. Monitoring TN concentrations helps assess the cumulative impact of watershed inputs—such as wastewater, septic systems, stormwater, and agricultural runoff—on water quality.

Tracking this indicator is vital for understanding long-term trends, evaluating ecological thresholds such as those defined by the Massachusetts Estuaries Project (MEP), and supporting nutrient management strategies. It also helps identify areas at risk of organic enrichment, eelgrass loss, and hypoxia, especially under changing climate and land use conditions.

Monitoring Results

Historical Monitoring (2003–2007: MEP)

The Massachusetts Estuaries Project (MEP) identified moderate impairment in the upper reaches of Duxbury Bay due to nitrogen enrichment and oxygen stress. Elevated nutrient levels in the Bluefish River were linked to organic matter accumulation and eelgrass loss.

Recent Monitoring (2006–2023: Center for Coastal Studies)

Total nitrogen (TN) concentrations have been monitored in Duxbury Bay since 2006 by the Center for Coastal Studies (CCS) at three long-term locations: Harbormaster Dock, Powder Point Bridge, and Bluefish River Bridge. Earlier studies by the Massachusetts Estuaries Project (MEP) from 2003 to 2007 established a nitrogen threshold of 0.331–0.335 mg/L (23.6–23.9 μM) to support healthy eelgrass habitat. This threshold remains a valuable benchmark for assessing nitrogen-related stress in the estuary.

Spatial and Temporal Trends

The Bluefish River Bridge station consistently reports the highest TN concentrations, with annual median values ranging from 56.5 to 71.6 μM , well above the MEP threshold. This area is also characterized by a lack of eelgrass and some degree of benthic community degradation, indicating nutrient-related impacts. It should be noted that this site is adjacent to a saltmarsh and mudflat environment and these typically do have elevated TN signatures compared to well-mixed open bays.

At Powder Point Bridge and Harbormaster Dock, TN concentrations have shown statistically significant increasing trends over the monitoring period (2007–2023), with median values ranging from 16.5 to 40.4 μM . These concentrations generally fall within the moderate concern range according to the U.S. EPA National Coastal Condition Assessment, with some years reaching into the high range (above 0.48 mg/L or $\sim 34 \mu\text{M}$).

Ecological Significance

Elevated TN fuels phytoplankton growth and organic matter accumulation, which can lead to hypoxia and habitat degradation through enhanced microbial respiration. The consistently high concentrations in the upper estuary—especially at Bluefish River—suggest localized nutrient loading and poor flushing conditions. Increasing trends at the other stations indicate a widening footprint of eutrophication stress, reinforcing the need for watershed-based nutrient management strategies.

Source	TN Threshold (mg/L)	TN Threshold (μM)	Ecological Interpretation
MEP (Duxbury Bay Target)	0.331–0.335	23.6–23.9	Supports eelgrass growth; exceeds threshold may impair habitat
NCCA (EPA) – Low	<0.34	<24.3	Considered healthy
NCCA (EPA) – Moderate	0.34–0.48	24.3–34.3	Increasing risk of eutrophication
NCCA (EPA) – High	>0.48	>34.3	Often associated with eutrophic conditions

Table 4. Ecological threshold ranges for total nitrogen (TN) concentrations in estuarine waters based on guidance from the Massachusetts Estuaries Project (MEP) and the U.S. EPA National Coastal Condition Assessment (NCCA). Thresholds represent concentrations above which negative impacts on eelgrass, benthic fauna, and water quality are likely to occur.

Continued exceedance of the MEP threshold and upward trends at multiple locations suggest that total nitrogen reductions are warranted, particularly in tributary inputs to the upper bay, to support long-term eelgrass restoration and estuarine health.

Location	Monitoring Period	Significant Change	Range of Median Values
Harbormaster Dock	2007–2023	Yes (↑)	9.6–24.0 μM
Power Point Bridge	2007–2023	Yes (↑)	16.5–40.4 μM
Bluefish River Bridge	2016–2023	No	56.5–71.6 μM

Table 5. Summary of annual median total nitrogen (TN) concentrations at three long-term monitoring stations in Duxbury Bay. The table shows the monitoring period, presence of statistically significant trends, and the range of annual median values (in micromolar, μM) at each site. Notably, TN concentrations are highest and most persistent at the Bluefish River Bridge, while significant increasing trends were observed at the Harbormaster Dock and Power Point Bridge.

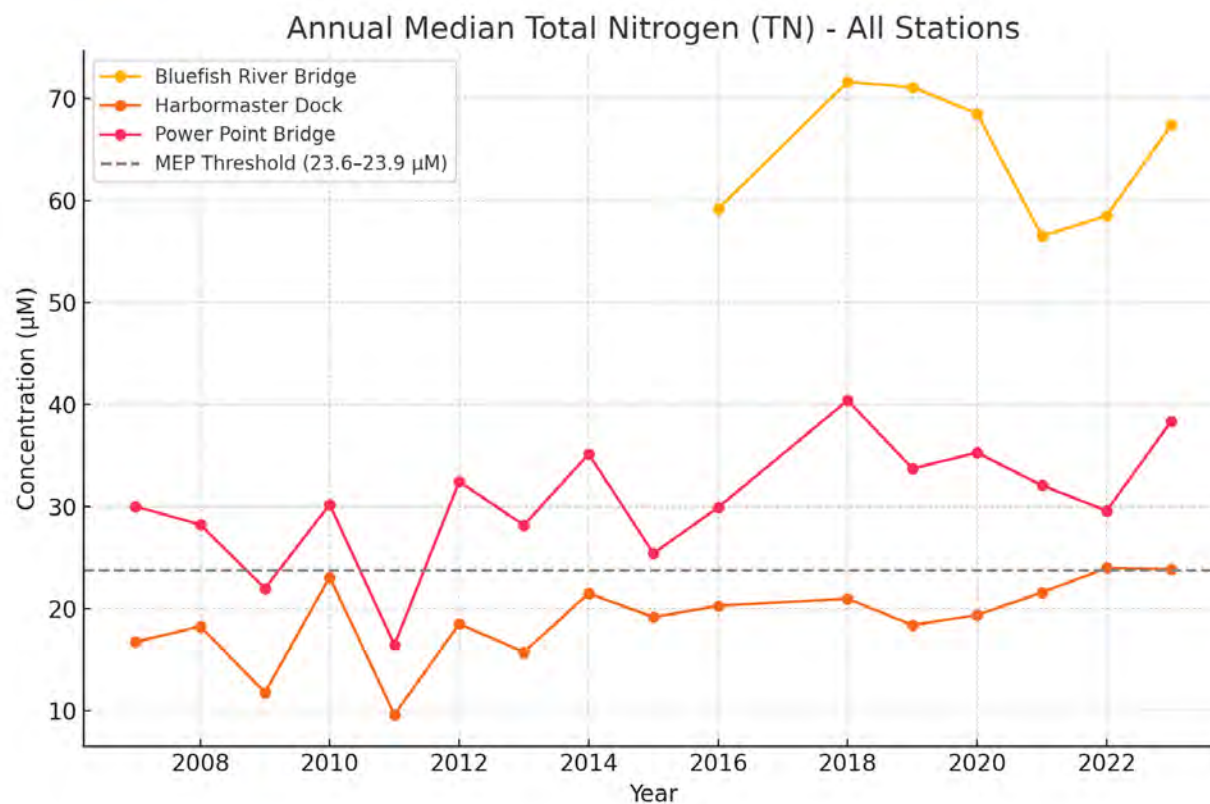


Figure 1: Annual Median Total Nitrogen (TN) at All Monitoring Stations (2007–2023).

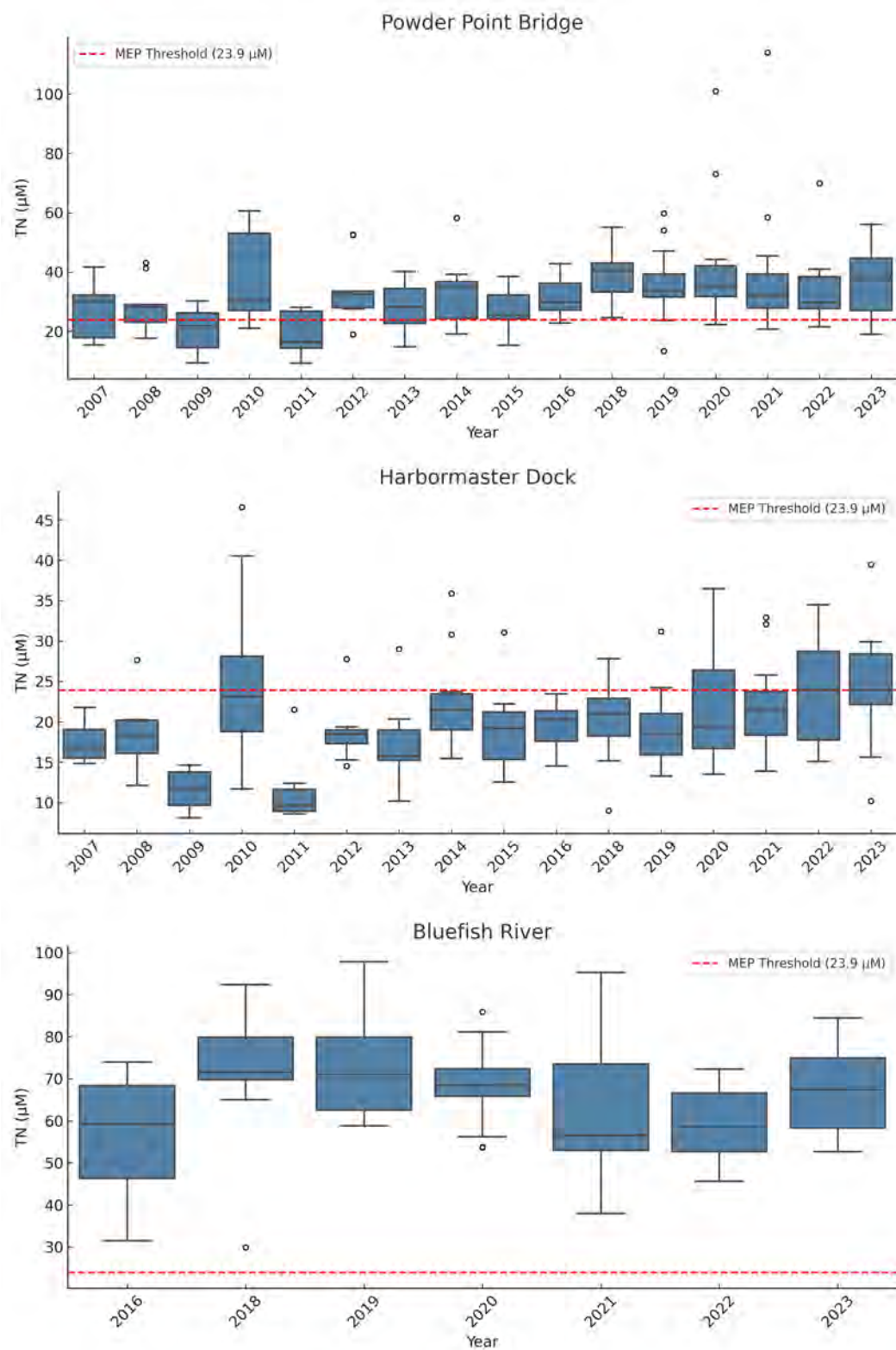


Figure 2. Annual box plots of total nitrogen (TN) concentrations. In each box plot, the horizontal line indicates the median; the box represents the interquartile range (IQR); the whiskers extend to 1.5 times the IQR; and individual points beyond this range are plotted as outliers.

2.2.2 Dissolved Inorganic Nitrogen (DIN)

Why We Track This Indicator

Dissolved Inorganic Nitrogen (DIN)—composed of nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+)—is a highly bioavailable form of nitrogen that directly fuels phytoplankton growth in estuarine systems. Unlike total nitrogen, which includes both organic and inorganic fractions, DIN reflects the immediate nutrient pool available for primary production. This makes it a sensitive and timely indicator of eutrophication potential, especially during the growing season when nutrient uptake by algae is most intense.

Monitoring DIN is critical because its concentrations fluctuate more rapidly than total nitrogen in response to changes in watershed inputs, sediment fluxes, and biological uptake. High DIN levels, particularly when coupled with warm, stratified conditions, can trigger algal blooms, promote hypoxia through microbial respiration, and destabilize benthic habitats. Tracking seasonal and spatial patterns of DIN helps identify areas of nutrient enrichment, assess the effectiveness of management actions, and inform future efforts to reduce nitrogen loads in Duxbury Bay—a relatively well-flushed estuary that is nonetheless vulnerable to eutrophication in its upper reaches.

Monitoring Results

Historical Monitoring (2003–2007: MEP)

The Massachusetts Estuaries Project (MEP) report for the Plymouth-Duxbury-Kingston (PDK) embayment system does not specifically reference Dissolved Inorganic Nitrogen (DIN) concentrations—i.e., the combined concentrations of nitrate, nitrite, and ammonium—as a primary focus of its analysis.

Instead, the MEP emphasizes Total Nitrogen (TN) concentrations and nitrogen loading rates (in kg/day) to the estuary from watershed sources. Their analysis centers on watershed-based nitrogen inputs, in situ total nitrogen levels in water column samples, sediment regeneration, and habitat thresholds (particularly for eelgrass). While ammonium is sometimes measured in sediment flux studies, there is no consistent presentation of DIN in the water column, either in terms of spatial distribution or concentration ranges.

“The MEP report focused on total nitrogen concentrations and loading rates as key indicators of nutrient impairment in Duxbury Bay. While dissolved inorganic nitrogen (DIN) concentrations were not explicitly reported, sediment flux studies included measurements

of ammonium release, suggesting a role for regenerated DIN in sustaining algal productivity during the summer season.” (p. 216-217)

Recent Monitoring (2006–2023: Center for Coastal Studies)

Dissolved Inorganic Nitrogen (DIN), composed of nitrate, nitrite, and ammonium, is the key group of nutrients influencing phytoplankton growth and estuarine productivity. The Center for Coastal Studies (CCS) has monitored DIN at Harbormaster Dock, Powder Point Bridge, and Bluefish River Bridge from 2006 to 2023. DIN provides a consistent indicator of biologically available nitrogen from watershed sources and internal recycling of organic matter.

Spatial and Temporal Trends

DIN concentrations vary by location and year, reflecting differences in nutrient loading, water circulation, and the recycling of organic matter (via decomposition). The Bluefish River Bridge consistently exhibits the highest DIN concentrations, with annual medians between 24.0 and 39.8 μM . These elevated values align with observed eutrophic conditions and impaired eelgrass habitat in this part of the estuary.

DIN levels at the Harbormaster Dock and Powder Point Bridge are substantially lower, with medians ranging from 0.5 to 7.1 μM . Despite previous findings of increasing nitrate concentrations at these sites, no statistically significant trend in total DIN was detected at any of the three stations, likely due to variability in ammonium concentrations over time.

Ecological Significance

DIN serves as a critical source of nitrogen for phytoplankton, macroalgae, eelgrass, and saltmarsh vegetation. Elevated concentrations, particularly in the upper estuary, can promote algal blooms, increase organic loading, and contribute to oxygen depletion through microbial respiration. The consistently high DIN at Bluefish River indicates persistent nutrient enrichment. Meanwhile, the lack of trends at other sites, despite increasing nitrate, suggests that changes in ammonium dynamics play a moderating role.

Management efforts should continue to target nutrient reductions in the upper estuary and improve understanding of the sources and seasonal behavior of ammonium, which may mask or offset overall changes in DIN trends.

Location	Monitoring Period	Significant Change	Range of Median Values
Harbormaster Dock	2009–2023	No	0.5–4.0 μM
Power Point Bridge	2009–2023	No	0.5–7.1 μM
Bluefish River Bridge	2016–2023	No	24.0–39.8 μM

Table 6. Summary of Dissolved Inorganic Nitrogen (DIN) Concentrations at Long-Term Monitoring Stations in Duxbury Bay. Median annual DIN concentrations from three stations between 2009 and 2023 indicate generally low levels at Harbormaster Dock and Power Point Bridge, with no statistically significant trends detected. In contrast, Bluefish River Bridge consistently exhibits elevated DIN concentrations, reflecting localized nutrient inputs in the upper estuary. Median ranges are based on monthly samples collected during the May–October monitoring season.

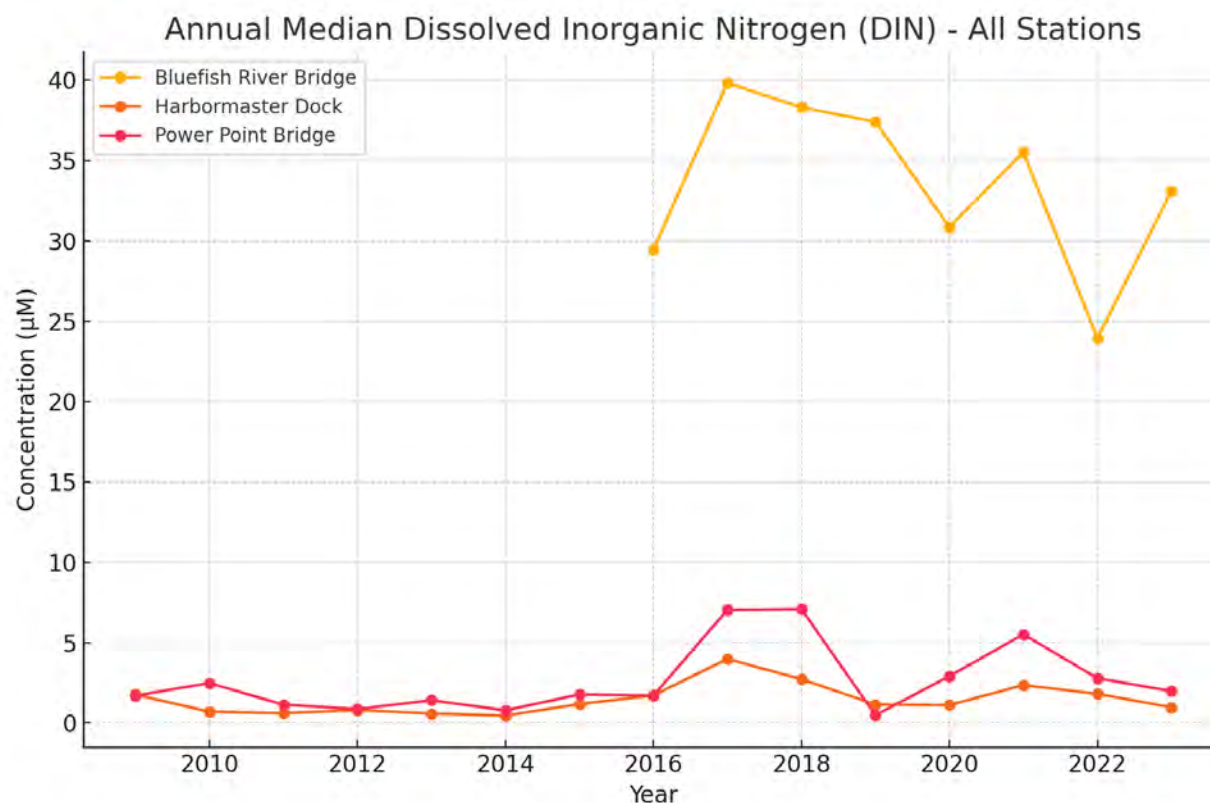


Figure 3. Annual median concentrations of dissolved inorganic nitrogen (DIN) at three long-term monitoring stations in Duxbury Bay from 2009 to 2023. DIN concentrations remain low at Harbormaster Dock and Power Point Bridge, with no statistically significant trends. In contrast, Bluefish River Bridge exhibits persistently elevated DIN levels, with annual medians ranging from 24 to nearly 40 µM, suggesting localized nutrient enrichment in the upper estuary.

2.2.3 Phosphorus

Why We Track This Indicator

While nitrogen is generally the limiting nutrient in most temperate estuarine and coastal systems, including Duxbury Bay, phosphorus remains an important indicator of eutrophication risk and nutrient imbalance. Total phosphorus (TP) includes all forms of phosphorus—both organic and inorganic, particulate and dissolved—while orthophosphate (PO_4^{3-}) represents the immediately bioavailable fraction that phytoplankton can readily assimilate. Elevated phosphorus levels, especially when paired

with high nitrogen concentrations, can exacerbate algal blooms, shift phytoplankton community structure, and contribute to oxygen depletion in bottom waters.

Tracking TP and orthophosphate provides insight into watershed sources such as agricultural runoff, stormwater inputs, and septic leachate. These indicators also reflect internal loading from sediment release, particularly under low-oxygen conditions when phosphorus can be regenerated from organic-rich sediments. Although Duxbury Bay is relatively well-flushed and not phosphorus-limited under most conditions, localized phosphorus enrichment may still affect ecological processes, especially in upper estuarine zones with reduced mixing and longer residence times. Continued monitoring of phosphorus alongside nitrogen supports a more complete understanding of nutrient dynamics and potential shifts in limiting conditions under climate change or altered land use.

Monitoring Results

Historical Monitoring (2003–2007: MEP)

From the MEP report: “The MEP did not report estuarine phosphorus concentrations or establish phosphorus thresholds for Duxbury Bay. While phosphorus was considered in watershed loading models, the study emphasized nitrogen as the limiting nutrient driving eutrophication in the embayment system. As a result, phosphorus was not a focal point of the water quality monitoring or habitat assessment efforts.”

Recent Monitoring (2006–2023: Center for Coastal Studies)

The Center for Coastal Studies (CCS) has monitored both total phosphorus (TP) and orthophosphate concentrations in Duxbury Bay since 2006 at three long-term stations: Harbormaster Dock, Powder Point Bridge, and Bluefish River Bridge. Total phosphorus includes all forms of phosphorus—dissolved and particulate—while orthophosphate represents the immediately bioavailable form. These metrics are essential for understanding nutrient dynamics that drive phytoplankton productivity and eutrophication risk in estuarine waters.

Spatial and Temporal Trends

The highest TP and orthophosphate concentrations were consistently observed at Bluefish River Bridge, with annual median TP ranging from 2.22 to 3.60 μM and orthophosphate from 1.12 to 1.99 μM . These elevated values reflect greater nutrient loading and lower flushing in the upper estuary. Powder Point Bridge exhibited intermediate concentrations, while Harbormaster Dock had the lowest phosphorus levels.

Despite spatial differences in concentration, no statistically significant trends were detected in TP or orthophosphate over the monitoring period at any of the three stations.

This suggests that phosphorus inputs have remained relatively stable over the past decade, even as nitrogen trends increased at some locations.

Ecological Significance

Phosphorus, along with nitrogen, fuels primary production in estuarine systems. When present in excess, it can promote harmful algal blooms and decrease water clarity, which in turn impacts eelgrass health and benthic habitats. Although no long-term changes in phosphorus levels have been detected, the persistently high concentrations in the upper estuary—particularly at Bluefish River Bridge—indicate localized sources that may warrant targeted management attention, particularly in areas with ongoing ecological impairment.

Location	Monitoring Period	Significant Change	Range of Median Values
Harbormaster Dock	2007–2023	No	0.9–1.95 μM
Power Point Bridge	2007–2023	No	1.7–3.38 μM
Bluefish River Bridge	2016–2023	No	2.22–3.6 μM

Table 7. Summary of total phosphorus concentrations (μM) at three Center for Coastal Studies monitoring locations in Duxbury Bay. The table includes the monitoring period, whether a statistically significant long-term trend was detected, and the observed range of annual median values at each site.

Location	Monitoring Period	Significant Change	Range of Median Values
Harbormaster Dock	2007–2023	No	0.24–0.74 μM
Power Point Bridge	2007–2023	No	0.24–1.52 μM
Bluefish River Bridge	2016–2023	No	0.64–1.2 μM

Table 8. Summary of orthophosphate concentrations (μM) at three Center for Coastal Studies monitoring locations in Duxbury Bay. The table presents the monitoring period, whether a statistically significant long-term trend was detected, and the observed range of annual median values at each site.

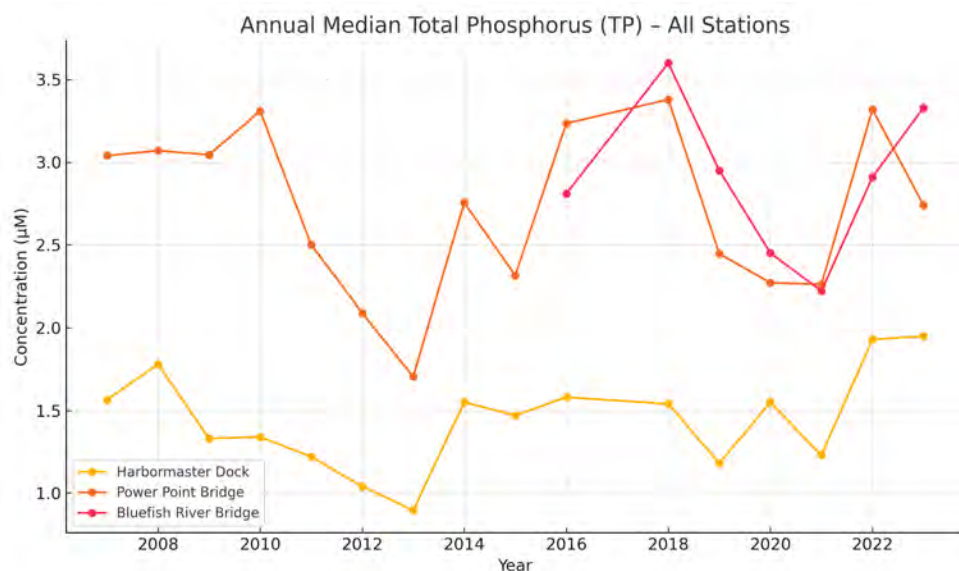


Figure 4. Annual median concentrations of total phosphorus (TP) at three long-term monitoring stations in Duxbury Bay from 2007 to 2023. TP concentrations remain relatively low at Harbormaster Dock and Power Point Bridge, while Bluefish River Bridge exhibits persistently elevated levels. These patterns suggest localized phosphorus enrichment in the upper estuary. Data represent growing season (May–October) samples collected by the Center for Coastal Studies (CCS).

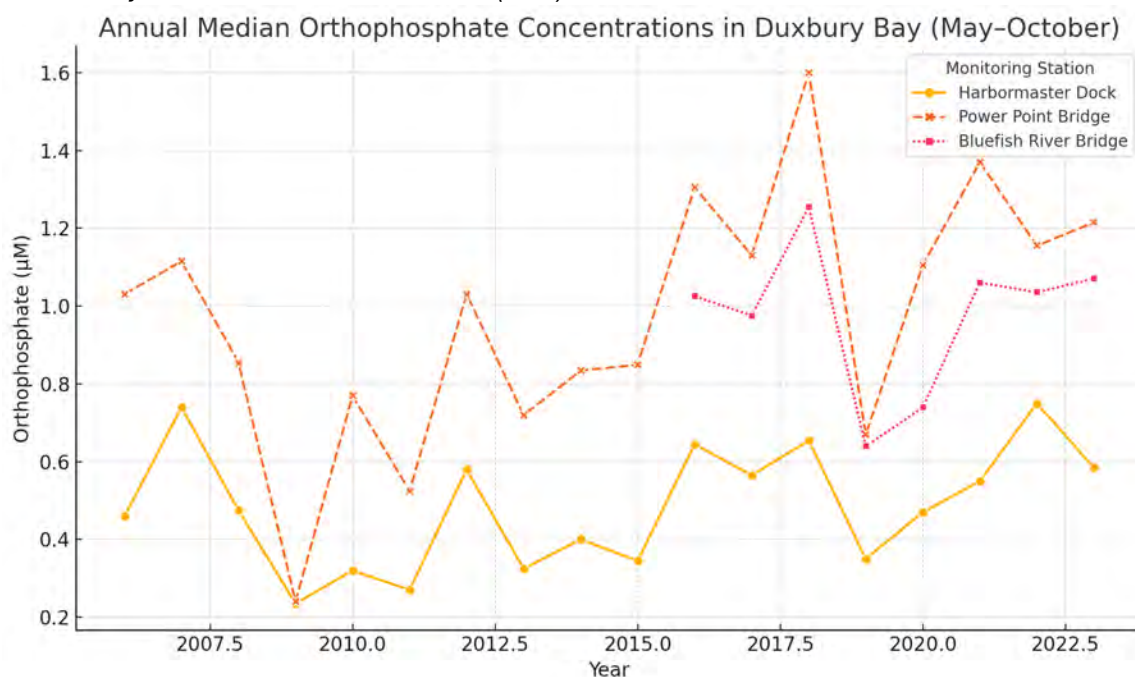


Figure 5. Annual median orthophosphate (PO_4^{3-}) concentrations (µM) during the growing season (May–October) at three long-term monitoring stations in Duxbury Bay from 2006 to 2023. Values are based on monthly grab samples collected by the Center for Coastal Studies. This indicator represents the bioavailable fraction of total phosphorus and is important for assessing potential contributions to algal productivity. Variation among sites and years reflects differences in watershed inputs, estuarine flushing, and internal nutrient cycling.

Parameter	Low (Background)	Moderate	High (Ecologically Concerning)	Bluefish River Bridge Median
Total Phosphorus (TP)	< 0.5 µM	0.5–1.6 µM	> 1.6 µM	2.22–3.60 µM
Orthophosphate (PO ₄)	< 0.3 µM	0.3–0.5 µM	> 0.5–1.0+ µM	0.64–1.20 µM

Table 9. Summary of ecological thresholds for total phosphorus and orthophosphate in estuarine waters, based on EPA guidance and literature benchmarks. Values observed at Bluefish River Bridge fall within the high/ecologically concerning range for both parameters.

2.2.4 Phytoplankton

Why We Track This Indicator

Phytoplankton are the foundational primary producers in estuarine ecosystems, forming the base of the aquatic food web and supporting a wide array of consumers, from zooplankton to commercially important shellfish and finfish. The abundance, composition, and seasonal dynamics of phytoplankton communities influence food availability, energy transfer efficiency, and overall ecosystem productivity. Shifts in phytoplankton biomass or species dominance can cascade through the food chain, altering trophic interactions and impacting ecosystem services such as fisheries yield and water quality.

In nutrient-enriched systems, excessive phytoplankton growth can lead to harmful algal blooms (HABs), reduced water clarity, and hypoxic conditions—especially when bloom decay depletes oxygen in bottom waters. These stressors threaten eelgrass beds, benthic invertebrate communities, and the resilience of estuarine habitats to climate change.

Because phytoplankton are microscopic and taxonomically complex, long-term trend detection typically relies on the measurement of chlorophyll-a, a light-harvesting pigment common to all photosynthetic algae. Chlorophyll-a is widely used as a proxy for phytoplankton biomass and offers an efficient, cost-effective way to assess trends in productivity and eutrophication. While chlorophyll-a measurements do not reveal species composition or bloom toxicity, they remain a core environmental indicator in estuarine monitoring due to their consistency, ease of interpretation, and linkage to broader ecological processes.

In Duxbury Bay, tracking chlorophyll-a concentrations allows managers to detect productivity changes over time, identify potential eutrophication hotspots, and evaluate the effectiveness of nutrient management strategies. Continued monitoring of this indicator is essential for understanding phytoplankton dynamics and maintaining estuarine health.

Monitoring Results

Historical Monitoring (2003–2007: MEP)

The Massachusetts Estuaries Project (MEP) did not directly monitor phytoplankton community composition in Duxbury Bay. Instead, the MEP assessed estuarine productivity and eutrophication risk using chlorophyll-a concentrations as a proxy for algal biomass. These measurements, alongside dissolved oxygen profiles and sediment nutrient flux studies, provided evidence of elevated biological activity in the upper bay and estuarine tributaries. The MEP identified the Bluefish River area as exhibiting signs of organic enrichment and declining habitat quality, likely linked to high nutrient loads fueling phytoplankton growth. While taxonomic or toxin-related assessments were not included, the MEP results support the interpretation that nutrient-fueled phytoplankton production contributes to ecological stress in the upper estuary.

Recent Monitoring (2006–2023: Center for Coastal Studies)

Long-term chlorophyll-a data collected by the Center for Coastal Studies from 2006 to 2023 show spatial and temporal variability in phytoplankton biomass across Duxbury Bay. Power Point Bridge frequently exhibits the highest peak chlorophyll-a concentrations among the three sites, with annual median values reaching up to 12.9 µg/L, occasionally exceeding thresholds of ecological concern during the growing season. Harbormaster Dock exhibits more moderate chlorophyll-a levels, with annual medians ranging from 3.3 to 8.5 µg/L, while Bluefish River Bridge shows a slightly narrower range of 4.8 to 8.0 µg/L.

These concentrations generally fall within the moderate concern range for estuarine waters, indicating elevated but not extreme levels of primary productivity. Spatial gradients are evident, with Power Point Bridge representing a transition zone between the more nutrient-influenced upper estuary and the better-flushed lower estuary.

A statistically significant upward trend in chlorophyll-a concentrations was observed only at Harbormaster Dock, suggesting a possible increase in phytoplankton biomass over time in this mid-bay region. No consistent long-term trend was detected at either Power Point Bridge or Bluefish River Bridge, though both experienced episodic high values, particularly during late summer. These patterns may reflect localized variation in nutrient inputs, circulation, and temperature, underscoring the need for site-specific monitoring to detect and manage emerging eutrophication risks.

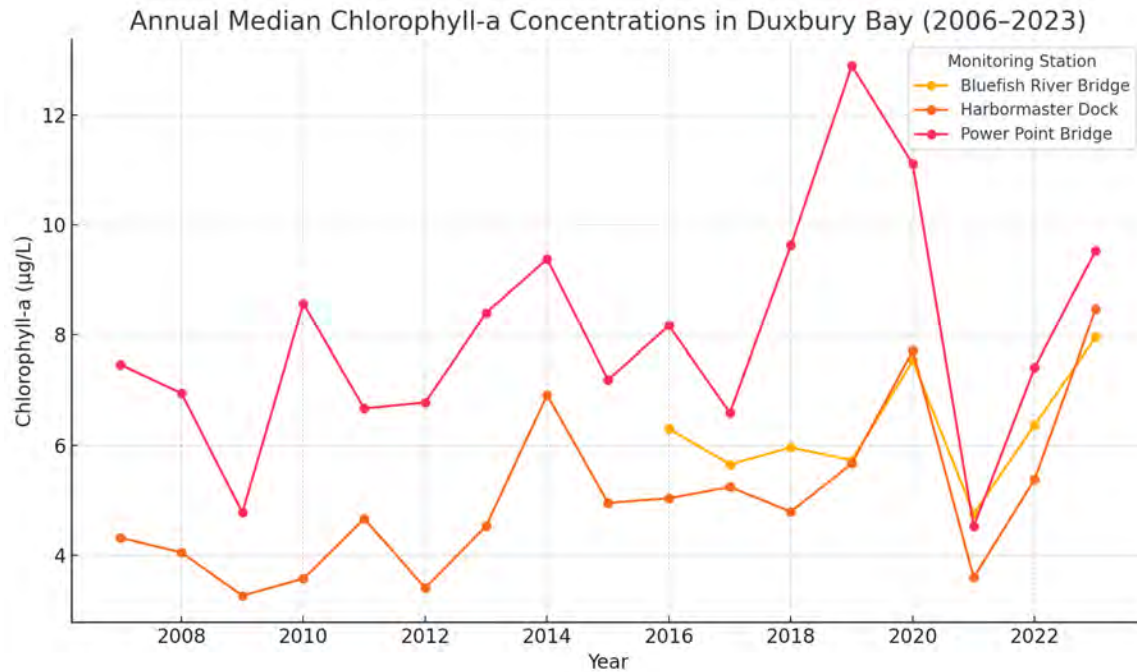


Figure 6. Annual median chlorophyll-a concentrations at three long-term monitoring stations in Duxbury Bay from 2006 to 2023. Chlorophyll-a serves as a proxy for phytoplankton biomass. Variability among stations reflects spatial differences in productivity, nutrient inputs, and hydrodynamic conditions.

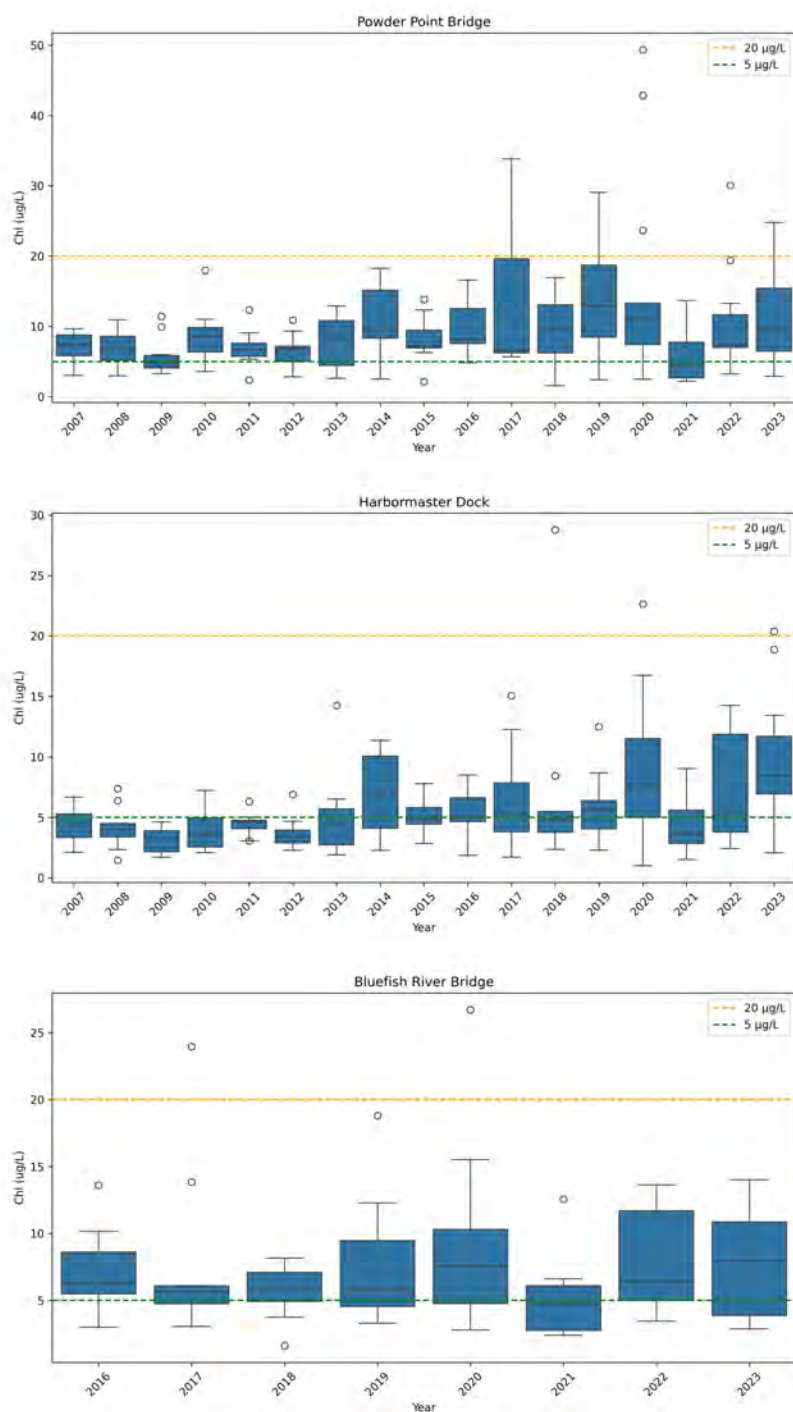


Figure 7. Annual box plots of chlorophyll-a concentrations showing upper and lower thresholds. In each box plot, the horizontal line indicates the median; the box represents the interquartile range (IQR); the whiskers extend to 1.5 times the IQR; and individual points beyond this range are plotted as outliers.

Ecological Significance

Elevated chlorophyll-a concentrations are indicative of increased phytoplankton biomass and can initiate a series of ecological responses that impair estuarine health. One of the primary consequences is reduced light penetration through the water column, which can limit photosynthesis and hinder the growth and survival of submerged aquatic vegetation such as eelgrass. Eelgrass beds are foundational habitats in shallow estuaries, supporting biodiversity and stabilizing sediments; thus, their decline can have far-reaching ecosystem impacts.

Another consequence of excessive phytoplankton is the accumulation of organic matter in the water and sediments, which fuels microbial respiration during decomposition. This process consumes dissolved oxygen, particularly at night or during periods of water column stratification and can lead to hypoxic conditions that stress or exclude oxygen-sensitive species such as benthic invertebrates and juvenile fish.

Additionally, high nutrient availability combined with elevated chlorophyll-a concentrations can create favorable conditions for harmful or nuisance algal blooms, including cyanobacteria. These blooms can outcompete more beneficial phytoplankton species, reduce water quality, and in some cases, release toxins harmful to aquatic life and human health.

The chlorophyll-a data presented in this report suggest that the mid- to upper reaches of the estuary—particularly at the Harbormaster Dock and Power Point Bridge stations—are experiencing heightened eutrophication stress. These areas show both higher concentrations and upward trends over time, reinforcing the need for continued nutrient monitoring, targeted source reduction efforts, and adaptive management strategies to protect water quality and ecosystem function.

Chlorophyll-a (µg/L)	Condition
< 5	Low – Oligotrophic
5 – 20	Moderate – Mesotrophic
> 20	High – Eutrophic

Table 10. General classification thresholds for chlorophyll-a concentrations in estuarine waters. These thresholds reflect trophic status and potential eutrophication risk, with higher concentrations indicating increased algal biomass and productivity.

Station	Median Chlorophyll-a Range (µg/L)
Harbormaster Dock (16)	3.3–8.5
Power Point Bridge (17)	4.5–12.9
Bluefish River Bridge (92)	4.8–8.0

Table 11. Range of annual median chlorophyll-a concentrations (2006–2023) at three long-term monitoring stations in Duxbury Bay. These values reflect spatial variability in phytoplankton biomass, with the highest concentrations consistently observed at Power Point Bridge.

2.2.5 Harmful Algal Blooms (HABs)

Why We Track This Indicator

Phytoplankton are microscopic algae that form the foundation of the estuarine food web. While most species are ecologically beneficial, some—particularly blue-green algae (BGA), or cyanobacteria—can form harmful algal blooms (HABs) under favorable environmental conditions. These blooms may reduce light availability, lower dissolved oxygen levels, and produce toxins that impair the growth and reproduction of filter-feeding shellfish such as oysters. In estuarine environments, HABs are commonly linked to excess nutrient inputs, elevated water temperatures, poor flushing, and reduced water clarity.

Monitoring Results (2014–2024: CCCE)

Since 2014, the Cape Cod Cooperative Extension (CCCE) has conducted high-frequency monitoring of BGA in Duxbury Bay using in situ sondes deployed at one fixed location. Continuous data were recorded between April and November each year, but data from May through October were analyzed for the purpose of consistency (there were different start and end dates each year). These 15-minute interval data capture peak biological activity and bloom development windows.

BGA concentrations consistently increase in late summer, coinciding with warm, stratified, and low-oxygen conditions. Elevated BGA levels have been detected most frequently at the Harbormaster Dock and Bluefish River Bridge during August and September. Sustained elevated concentrations during some years have raised concern about the presence of potentially toxin-producing genera such as *Microcystis* and *Anabaena*.

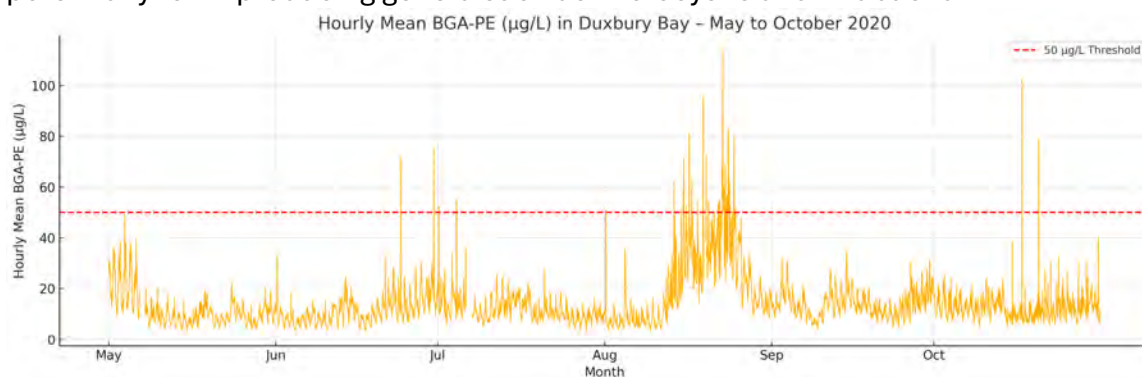


Figure 8. Hourly mean concentrations of phycocyanin-based blue-green algae (BGA-PE) in Duxbury Bay from May to October 2020. A red dashed line marks the 50 µg/L threshold for elevated BGA-PE levels, indicating periods of potential concern for water quality and harmful algal blooms.

Number of BGA-PE Bloom Events > 50 µg/L Lasting ≥ 1 Hour (May-October)

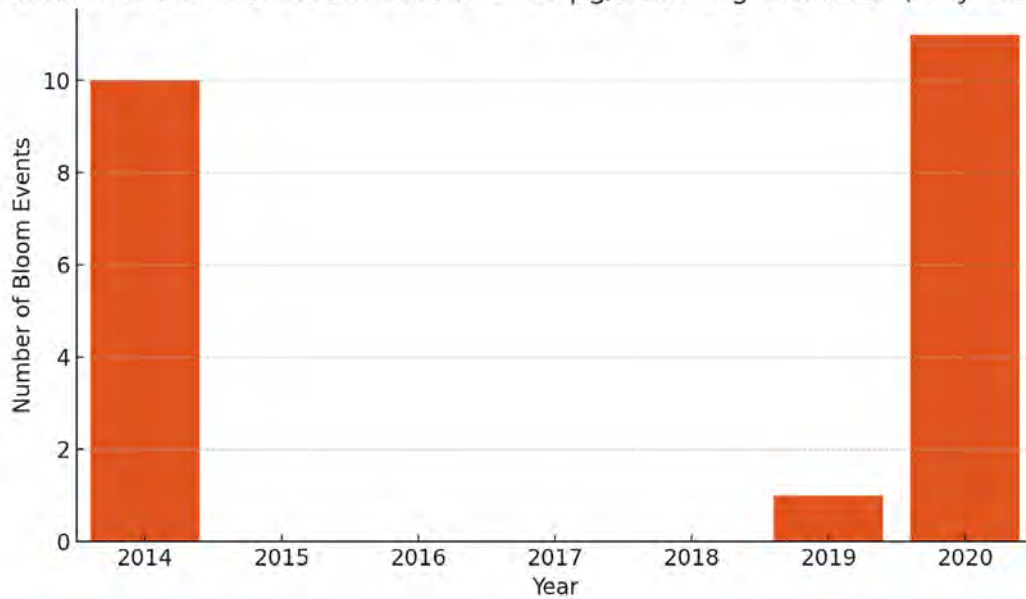


Figure 9. Number of blue-green algae (BGA-PE) bloom events in Duxbury Bay exceeding 50 µg/L and lasting at least one hour, based on CCCE high-frequency sonde monitoring from May through October. Notable bloom activity occurred in 2014 and 2020, with smaller events recorded in 2019. No qualifying bloom events were observed in other years.

Number of BGA-PE Bloom Events > 25 µg/L Lasting ≥ 1 Hour (May-October)

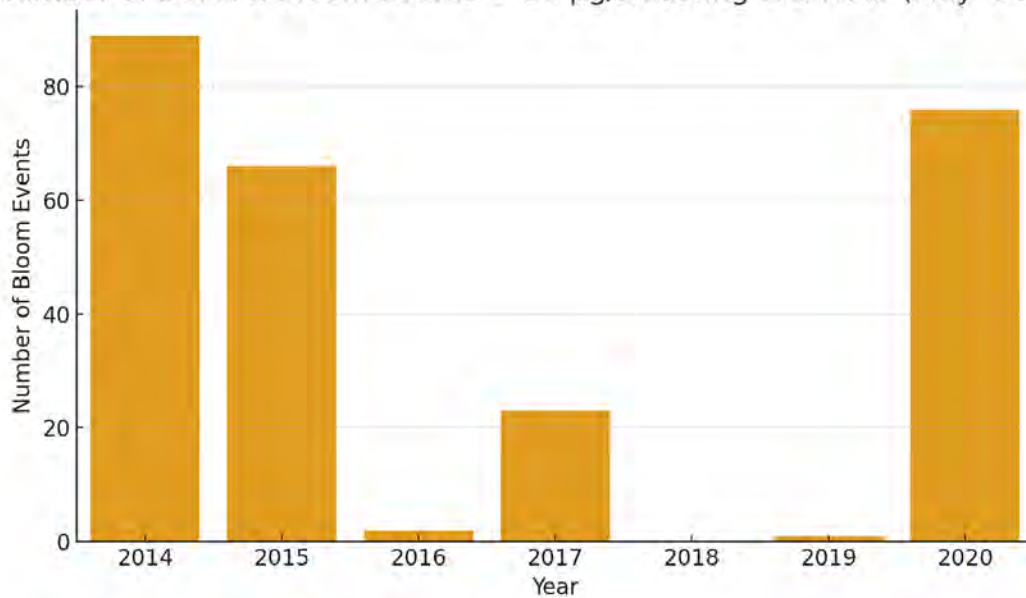


Figure 10. Number of blue-green algae (BGA-PE) bloom events in Duxbury Bay exceeding 25 µg/L and lasting at least one hour from May through October. Elevated bloom activity was observed in 2014, 2015, and 2020, with lower but notable levels in 2017. Minimal or no events were detected in other years. These results highlight interannual variability in bloom frequency and underscore the importance of continuous monitoring to capture episodic cyanobacterial events linked to environmental drivers.

Drivers of BGA and HABs in Duxbury Bay

Cyanobacterial blooms in Duxbury Bay are influenced by a combination of environmental drivers. Elevated concentrations of nitrogen and phosphorus—particularly nitrate and orthophosphate—provide the nutrients necessary for growth. During the summer months, thermal conditions exceeding 25°C, coupled with calm weather and low turbidity, create stable, well-lit conditions that favor bloom persistence and potential dominance by harmful taxa. These findings are consistent with regional studies which link climate-driven warming and altered circulation (in Cape Cod Bay and the Gulf of Maine) to increased HAB frequency and intensity.

Implications for Oyster Aquaculture and Estuarine Health

Duxbury Bay supports one of the largest oyster aquaculture operations in Massachusetts. Harmful algal blooms can pose multiple risks to this industry. Cyanobacteria may produce toxins such as microcystins, which could accumulate in shellfish tissues. In addition, certain BGA taxa interfere with feeding by clogging gills or being rejected by oysters. A shift in phytoplankton community composition toward smaller, less nutritious, or potentially toxic species may reduce food quality and compromise shellfish growth and health.

Category	Characteristic
Organism Type	Cyanobacteria (photosynthetic bacteria)
Size Range	1–100 µm, including picocyanobacteria
Bloom Conditions	Warm, stratified, nutrient-rich, calm waters
Risks to Shellfish	Toxin accumulation, gill clogging, reduced feeding
Known Genera	Microcystis, Anabaena, Dolichospermum

Table 12. Summary of key characteristics and potential risks associated with cyanobacteria observed in Duxbury Bay. These photosynthetic bacteria can form harmful algal blooms (HABs) under warm, nutrient-rich, and low-flow conditions. Such blooms may interfere with shellfish aquaculture by reducing feeding efficiency, clogging gills, and introducing toxins.

2.2.6 Dissolved Oxygen

Why We Track This Indicator

Dissolved oxygen (DO) is a fundamental measure of estuarine health. It supports the survival of fish, shellfish, and benthic invertebrates, and plays a critical role in nutrient cycling and the breakdown of organic matter. Healthy estuarine ecosystems typically maintain DO concentrations above 6 mg/L, while values below 2 mg/L—a condition known as hypoxia—can lead to fish kills, mortality of bottom-dwelling organisms, and a reduction in biodiversity.

In Duxbury Bay, DO concentrations are influenced by a complex interplay of physical, chemical, and biological processes, many of which vary on a diel (24-hour) timescale. These short-term fluctuations are particularly evident during the summer growing season and are shaped by the

following factors:

Photosynthesis and Respiration: During daylight hours, phytoplankton and submerged vegetation produce oxygen through photosynthesis, increasing DO levels in surface waters. At night, photosynthesis ceases but respiration by plants, animals, and microbes continues, consuming oxygen and causing DO to decline—often sharply before dawn.

Temperature: Warmer water holds less dissolved oxygen and can also accelerate microbial respiration. This is particularly important in shallow estuarine systems like Duxbury Bay, where summer water temperatures frequently exceed 25°C, intensifying nighttime oxygen depletion.

Stratification and Mixing: In calm conditions, temperature or salinity gradients can create vertical stratification in the water column, isolating bottom waters from surface reoxygenation. This can lead to hypoxic conditions even if surface DO remains adequate. Wind-driven mixing can break down stratification, redistributing oxygen but also resuspending nutrients and organic matter that contribute to oxygen demand.

Organic Loading and Decomposition: Elevated inputs of nutrients (nitrogen and phosphorus) stimulate phytoplankton blooms, which eventually die off and sink. The microbial decomposition of this organic matter consumes large amounts of oxygen, especially in poorly mixed areas with high residence times, such as tidal creeks and upper embayment zones.

High-frequency monitoring in Duxbury Bay, such as that conducted by CCCE, has captured these diel DO patterns clearly showing midday peaks followed by early morning lows. These fluctuations offer important insight into ecosystem metabolism and stress and can help identify areas most vulnerable to eutrophication and hypoxia.

Monitoring Results

Historical Monitoring (2003–2007: MEP)

The Massachusetts Estuaries Project (MEP) concluded that Duxbury Bay exhibited moderate impairment in its upper reaches, with signs of organic enrichment and declining eelgrass habitats associated with elevated nitrogen and oxygen demand near the Bluefish River. The MEP deployed four DO sensors in Duxbury Bay for a short period in 2013 as part of their system metabolism study. Their sediment flux and nutrient data suggested DO cycling stress during summer.

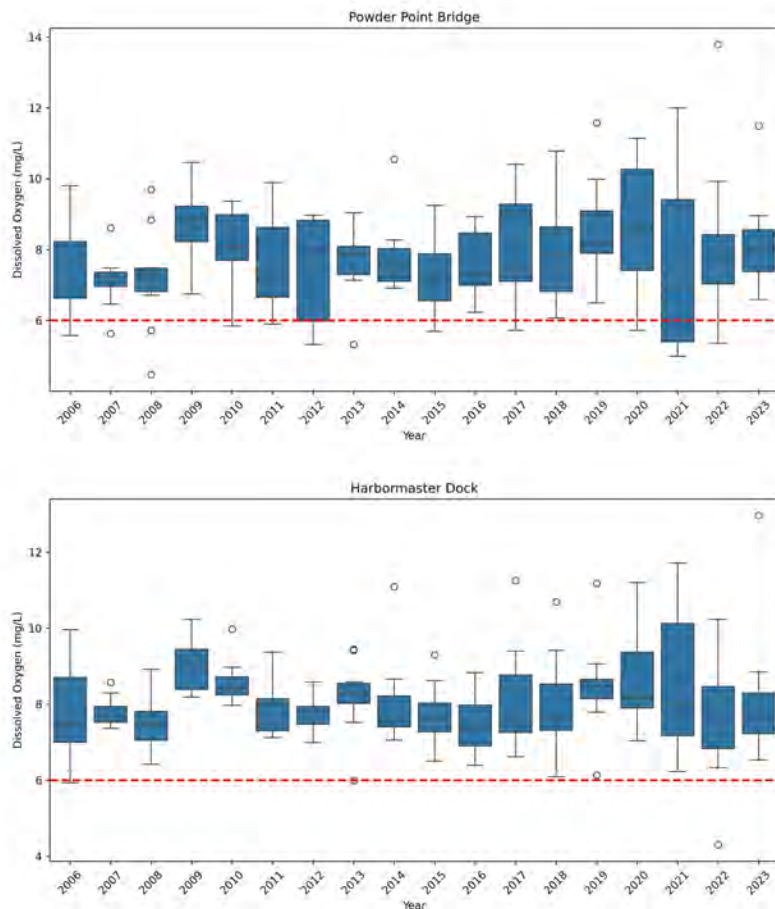
Recent Monitoring (2006–2023: Center for Coastal Studies)

The Center for Coastal Studies (CCS) has conducted monthly spot measurements of dissolved oxygen (DO) at three long-term monitoring sites in Duxbury Bay: Powder Point Bridge, Harbormaster Dock, and Bluefish River Bridge. Among these, Bluefish River Bridge consistently exhibits the lowest DO concentrations, with values frequently approaching or dipping below 4 mg/L during late summer. Harbormaster Dock has shown a gradual decline in DO over time, particularly during the August–September period when some

measurements have fallen below the 4 mg/L stress threshold. While Powder Point Bridge generally maintains healthier oxygen levels, this site is not immune to episodic declines, especially under warm, calm conditions.

Continuous Monitoring (2014–2024: CCCE 15-Minute Intervals)

The Cape Cod Cooperative Extension (CCCE) has supplemented CCS's long-term dataset with high-frequency DO monitoring, using in situ loggers deployed at 15-minute intervals from May through October each year. These data offer a detailed view of diel DO cycling and acute hypoxic events that may be missed by monthly sampling. Frequent pre-dawn lows have been recorded in the upper estuary, particularly at Bluefish River Bridge, where DO concentrations often fall below 4 mg/L—even when daily averages remain above 6 mg/L. Hypoxic events, defined as DO dropping below 2 mg/L for at least one hour, have been detected in multiple years at both Bluefish River Bridge and Harbormaster Dock. These episodes typically occur in August and early September, coinciding with peak water temperatures, high phytoplankton biomass, and minimal wind-driven mixing, all of which contribute to oxygen depletion in bottom waters.



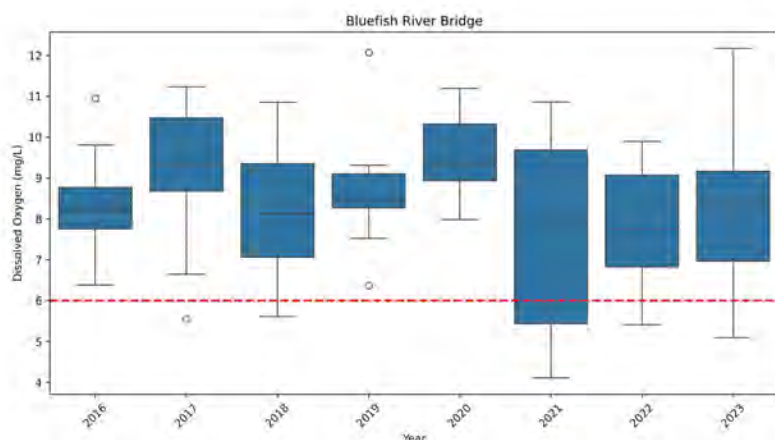


Figure 11. Annual box plots of dissolved oxygen concentrations at the CCS Duxbury Bay monitoring stations. In each plot, the horizontal line represents the median, the box spans the interquartile range (IQR), the whiskers extend to 1.5 times the IQR, and individual points beyond this range are shown as outliers. The 6 mg/L threshold, commonly used as a minimum concentration to support healthy estuarine aquatic life.

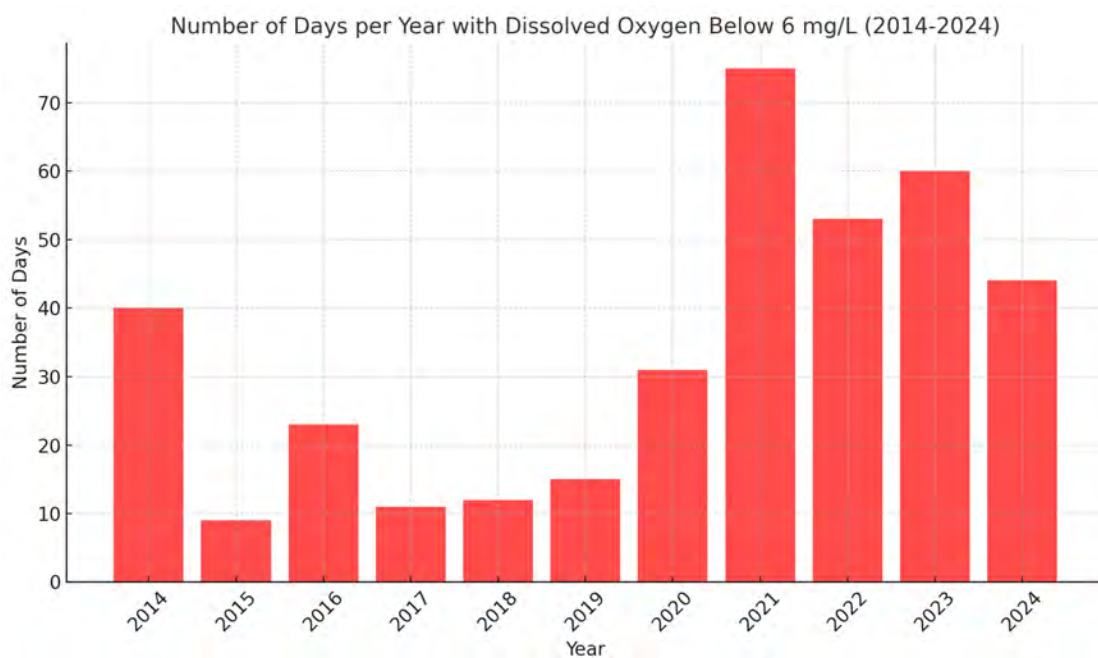


Figure 12. Number of days per year with at least one dissolved oxygen measurement below 6 mg/L in Duxbury Bay, based on CCCE high-frequency sonde data collected from 2014 to 2024. The 6 mg/L threshold is a common ecological benchmark for maintaining suitable conditions for estuarine aquatic life.

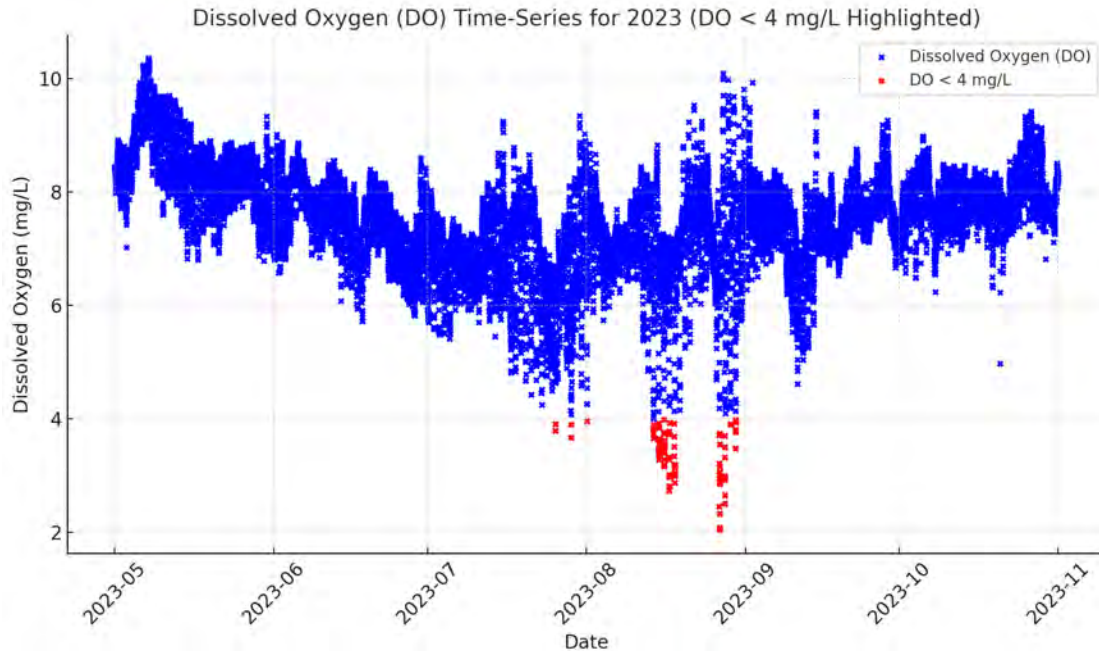


Figure 13. Dissolved oxygen (DO) time-series in Duxbury Bay from May through October 2023, based on CCCE high-frequency (15-minute interval) monitoring. Each blue point represents an individual DO measurement; red points highlight measurements below 4 mg/L, a commonly used stress threshold for aquatic life. Periodic low-oxygen events are most pronounced in August and early September, aligning with peak summer temperatures.

Ecological Significance

Oxygen stress in Duxbury Bay is episodic but appears to be increasing in frequency and severity, particularly in nutrient-impacted and poorly flushed areas such as the upper estuary and the Bluefish River system. Several interacting factors contribute to these low-oxygen events. Elevated nitrogen and phosphorus levels support dense phytoplankton blooms, which upon senescence and decay, drive down oxygen levels through microbial respiration. This process is exacerbated by warm summer temperatures and water column stratification, which limit vertical mixing and oxygen replenishment. Additionally, oxygen demand from organic-rich sediments further intensifies DO depletion near the bottom, placing stress on benthic habitats.

These conditions threaten the long-term stability of the estuarine ecosystem. Prolonged or repeated exposure to low DO reduces eelgrass resilience, weakens benthic invertebrate communities, and disrupts nitrogen cycling processes, including coupled nitrification–denitrification, which is essential for mitigating nutrient buildup.

Powder Point Bridge continues to serve as a useful reference site, generally maintaining healthier DO levels. However, episodic drops in oxygen have also been observed at this station, particularly during calm, warm periods. These emerging trends across the estuary emphasize the need for a multi-pronged response: reducing nutrient inputs at the

watershed scale, restoring hydrologic connectivity and mixing in impaired tributaries, and maintaining high-frequency monitoring efforts to better capture the timing and extent of stress events.

Condition	DO Concentration	Implications
Healthy	> 6 mg/L	Optimal for most aquatic life
Moderate Stress	4–6 mg/L	Sensitive species begin to exhibit stress responses
Episodic Hypoxia	2–4 mg/L	Metabolic stress, disrupted behavior
Severe Hypoxia	< 2 mg/L	Mortality risk, especially for infauna and shellfish
Anoxia	0 mg/L	Catastrophic losses; no oxygen available

Table 13. Dissolved oxygen (DO) condition categories and their ecological implications for estuarine environments such as Duxbury Bay. These thresholds reflect the range of DO concentrations observed in monitoring data and help interpret potential stress levels for aquatic organisms, particularly during warm, stratified periods when oxygen depletion is most likely.

2.2.7 Turbidity

Why We Track This Indicator

Turbidity is a measure of water clarity and reflects the concentration of suspended particles such as sediment, algae, and detritus. It is reported in Nephelometric Turbidity Units (NTU) and is influenced by stormwater runoff, wind-driven resuspension, dredging, algal blooms, and boat traffic.

Elevated turbidity reduces light penetration, impairing photosynthesis in submerged aquatic vegetation like eelgrass. It can also disrupt habitat conditions for fish and invertebrates, increase contaminant transport, and contribute to oxygen depletion when organic particles decompose.

Turbidity Range (NTU)	Ecological Interpretation
Low (1–5 NTU)	Clear, generally healthy
Moderate (5–10 NTU)	Can begin to impact benthic habitat and light availability
High (10–50 NTU)	Harmful to submerged vegetation and filter feeders
> Very High (>50 NTU)	Often signals sediment stress or eutrophic bloom conditions

Table 14. *General guidance for interpreting turbidity levels in estuarine systems. These ranges reflect typical ecological responses to increasing turbidity, from clear and healthy conditions to levels that may indicate sediment resuspension, nutrient-driven algal blooms, or other forms of ecosystem stress.*

Monitoring Results

Historical Monitoring (2003–2007: Massachusetts Estuaries Project)

The Massachusetts Estuaries Project (MEP) did not include turbidity as a directly measured parameter in their assessment of Duxbury Bay. However, water clarity was addressed indirectly through evaluations of eelgrass distribution and habitat quality. The MEP emphasized that reduced light availability—due to factors such as suspended sediments and phytoplankton biomass—can impair eelgrass growth, particularly in nutrient-enriched or poorly flushed areas. While no long-term turbidity data were reported, the importance of maintaining high water clarity to support submerged aquatic vegetation was highlighted as a key management concern.

Recent Monitoring (2006–2023: Center for Coastal Studies)

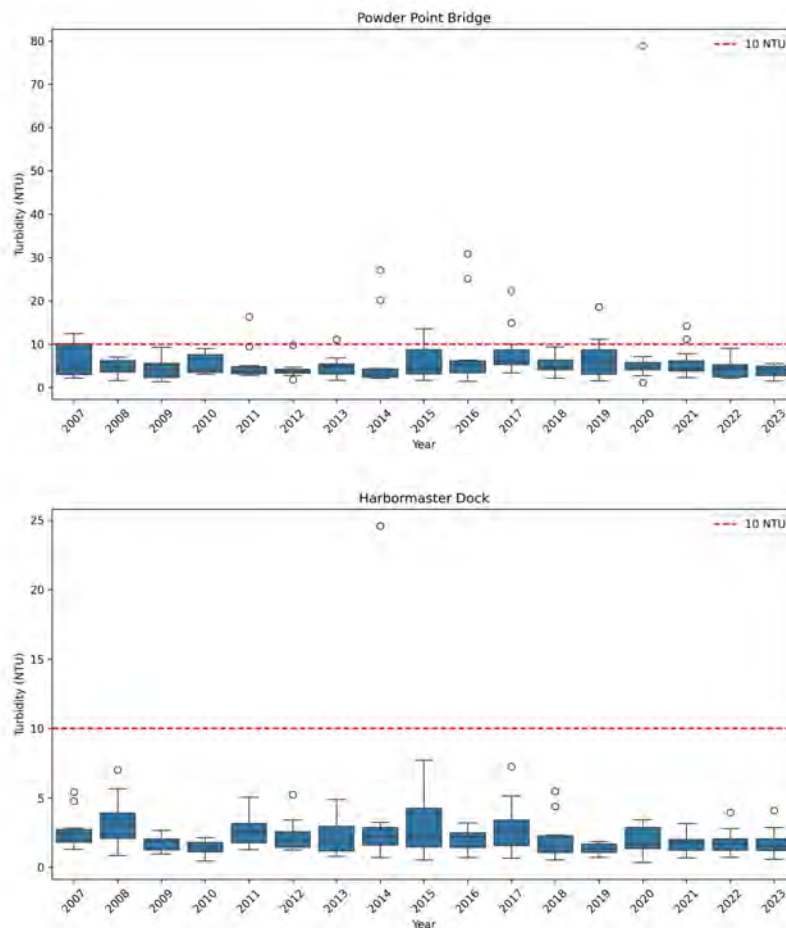
Turbidity has been monitored by the Center for Coastal Studies at three long-term stations in Duxbury Bay: Powder Point Bridge, Bluefish River Bridge, and Harbormaster Dock. These stations reveal distinct spatial and seasonal patterns in turbidity levels across the estuary. Powder Point Bridge exhibits a long-term decreasing trend in turbidity, suggesting an improvement in water clarity over time. In contrast, Bluefish River Bridge tends to maintain moderate turbidity values throughout the monitoring period. This pattern likely reflects limited flushing, continued inputs from the surrounding watershed, and frequent sediment resuspension. Harbormaster Dock shows greater seasonal variability, with elevated turbidity readings during the summer months and following storm events, which are known to stir sediments and increase runoff.

Box plots and time series analyses indicate that turbidity across most of the estuary generally falls within the “low” to “moderate” range according to estuarine health guidelines. However, localized high-turbidity events are occasionally observed, particularly near shoreline discharge points or in areas subject to wind-driven mixing and recreational boating activity.

Continuous Monitoring (2014–2024: CCCE 15-Minute Intervals)

The Cape Cod Cooperative Extension (CCCE) has operated a single mid-bay monitoring station equipped with a data sonde that records turbidity at 15-minute intervals during the growing season (May through October). This high-frequency dataset captures short-term variability in water clarity and identifies episodic events—such as spikes in turbidity

following storms or boating activity—that are often missed by monthly monitoring. Although turbidity at this site typically falls within the “low” to “moderate” range (1–10 NTU), occasional excursions into higher ranges have been recorded, especially following wind-driven resuspension or runoff events. These episodic increases can reduce light availability, posing risks to submerged aquatic vegetation such as eelgrass. CCCE’s continuous monitoring has proven valuable in detecting these dynamics and adds important context to long-term trends observed at other stations in the bay.



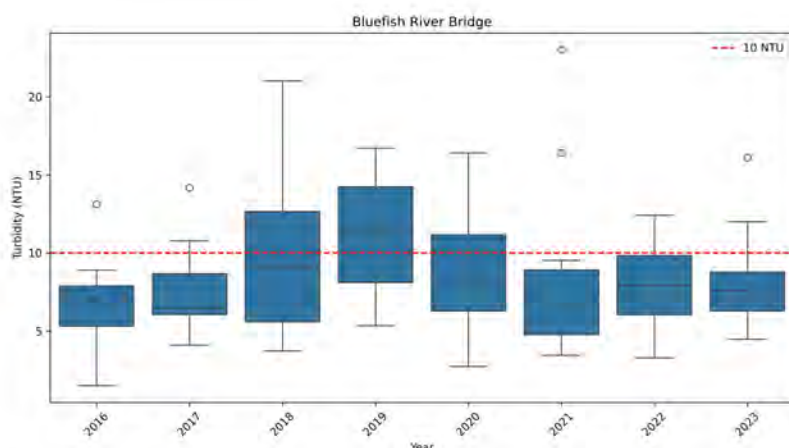


Figure 14. Annual box plots of turbidity measurements at the CCS Duxbury Bay monitoring stations. Each box represents the interquartile range (IQR), the horizontal line indicates the median, whiskers extend to 1.5 times the IQR, and points beyond that range are shown as outliers. The red dashed line marks the 10 NTU threshold, often used to indicate conditions that may begin to limit light availability for submerged aquatic vegetation.

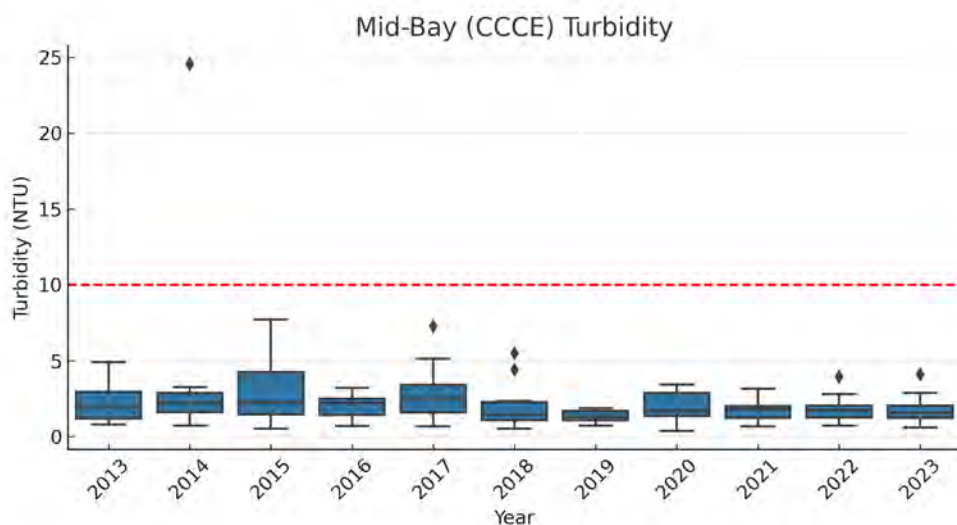


Figure 15. Annual distribution of turbidity (NTU) at the mid-bay CCCE monitoring station in Duxbury Bay. Each box represents the interquartile range of 15-minute turbidity observations during the growing season (May–October), with the red dashed line indicating the 10 NTU threshold commonly associated with potential impacts on water clarity, eelgrass, and filter-feeding organisms. Outliers are shown as individual points.

Ecological Significance

Water clarity, as measured by turbidity, plays a vital role in maintaining healthy estuarine ecosystems. In Duxbury Bay, overall water clarity is generally good, with long-term data from Powder Point Bridge showing a declining turbidity trend. This improvement suggests that watershed management efforts—such as erosion control, stormwater mitigation, and nutrient reduction—may be contributing to reduced sediment and organic matter inputs in this area.

In contrast, the upper estuary near Bluefish River Bridge consistently exhibits moderate turbidity levels. These elevated values can limit the penetration of sunlight into the water column, reducing the availability of light necessary for photosynthesis. This condition may inhibit the growth and survival of submerged aquatic vegetation, such as eelgrass (*Zostera marina*), which requires clear, well-lit conditions to thrive. Eelgrass provides critical habitat for finfish and invertebrates and supports biogeochemical functions like nutrient cycling and sediment stabilization.

Seasonal and episodic increases in turbidity—often associated with storm events, wind-driven resuspension, and boating activity—can further impair water clarity in nearshore and shallow regions. While brief turbidity spikes may be tolerated by established plant beds, persistent or repeated events can reduce eelgrass resilience and hinder restoration efforts, especially in areas already constrained by suboptimal light conditions.

Continued high-resolution monitoring is essential to track these patterns and detect shifts that could threaten the bay's ecological balance. Protecting and enhancing water clarity should remain a key focus of bay-wide management, particularly in support of eelgrass recovery and long-term estuarine health.

2.3 Water Temperature

Why We Track This Indicator

Water temperature regulates nearly all biological and chemical processes in estuarine ecosystems. It affects dissolved oxygen solubility, metabolic and growth rates, reproductive timing, and the spatial distribution of aquatic species. In shallow embayments like Duxbury Bay, temperatures can increase rapidly in response to warm, sunny weather—particularly during the summer months—creating stressful conditions for sensitive organisms such as eelgrass, shellfish, and juvenile fish.

Estuarine systems are experiencing long-term warming trends due to climate change. These shifts are not only extending the duration of the growing season but also intensifying the frequency and severity of short-term thermal stress events. Elevated water temperatures can reduce oxygen availability, disrupt life cycles, and exacerbate the effects of nutrient loading and algal blooms.

Although Duxbury Bay is relatively well-mixed and flushed compared to other embayments, it remains vulnerable to rapid warming, especially in upper, more sheltered regions. Complicating these dynamics, the broader oceanographic setting of Cape Cod Bay influences local temperature regimes. Wind-driven upwelling events, common just outside the mouth of the Kingston-Plymouth-Duxbury (KPD) embayment system, can intermittently bring colder, nutrient-rich bottom waters to the surface. These upwelling pulses may temporarily moderate nearshore temperatures but can also interact with estuarine

circulation patterns in complex ways that influence stratification, productivity, and oxygen dynamics.

Tracking water temperature at high resolution is essential to detect these fluctuations, assess ecosystem responses, and inform resource management in the face of continued climatic and oceanographic change.

Monitoring Results

Historical Monitoring (2003–2007: MEP)

The Massachusetts Estuaries Project (MEP) did not explicitly include water temperature as a core indicator in its assessment of Duxbury Bay. While temperature plays a central role in regulating estuarine processes—such as dissolved oxygen solubility, nutrient cycling, and species physiology—it was not a primary focus of the MEP’s long-term monitoring strategy. Nonetheless, temperature likely influenced many of the project’s findings related to oxygen stress and eelgrass loss. Subsequent monitoring efforts have recognized the need to track water temperature directly, especially given the increasing influence of climate-driven warming in shallow coastal systems.

Recent Monitoring (2006–2023: Center for Coastal Studies)

The Center for Coastal Studies (CCS) recorded water temperature during its monthly water quality sampling at long-term monitoring sites throughout Duxbury Bay. While these discrete observations provide useful context on seasonal temperature conditions, their limited temporal resolution does not capture the rapid fluctuations or short-term extremes that can strongly influence estuarine health. As such, this report relies primarily on the high-frequency data collected by the Cape Cod Cooperative Extension (CCCE), which offer a more detailed and continuous record of thermal variability. These finer-scale data are better suited to assess ecological thresholds, detect extreme events, and track long-term trends associated with climate warming.

Continuous Monitoring (2014–2024: CCCE 15-Minute Intervals)

High-frequency data collected by the Cape Cod Cooperative Extension (CCCE) from 2014 to 2024 offer a detailed view of temperature dynamics in the bay. Measurements were recorded every 15 minutes from May through October were analyzed for the purpose of interannual consistency. This period is the primary growing season for eelgrass and the period of peak biological activity.

Over the past decade, growing season temperatures have gradually increased, particularly in July and August. Several recent years—including 2020, 2022, and 2023—recorded extended periods above 25°C, with 2023 showing the longest total duration of heat

exposure.

Short-term heat stress events, defined as hourly water temperatures above 25°C, have become more frequent and persistent. These events often occur in late summer when solar heating and low wind conditions reduce mixing. The number of thermal stress days has increased over time, contributing to cumulative heat exposure during critical periods for estuarine life.

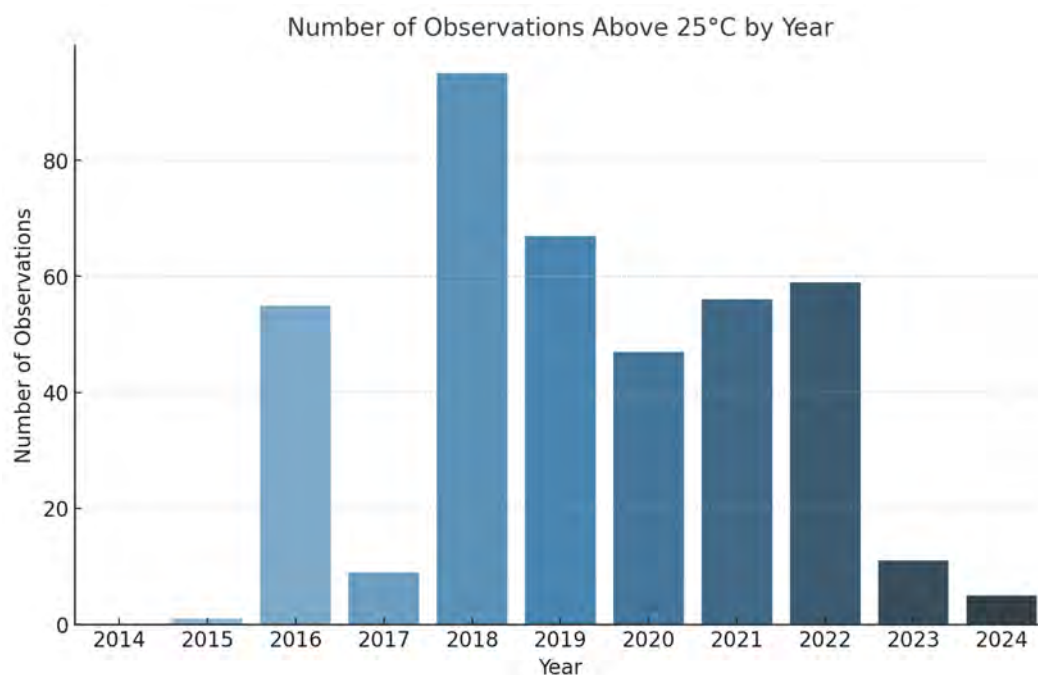


Figure 16. Number of 15-minute observations per year with water temperature exceeding 25°C in Duxbury Bay, based on CCCE high-frequency sonde monitoring from 2014 to 2024. The threshold of 25°C is commonly used to indicate thermal conditions that may stress estuarine organisms or intensify eutrophication-related processes.

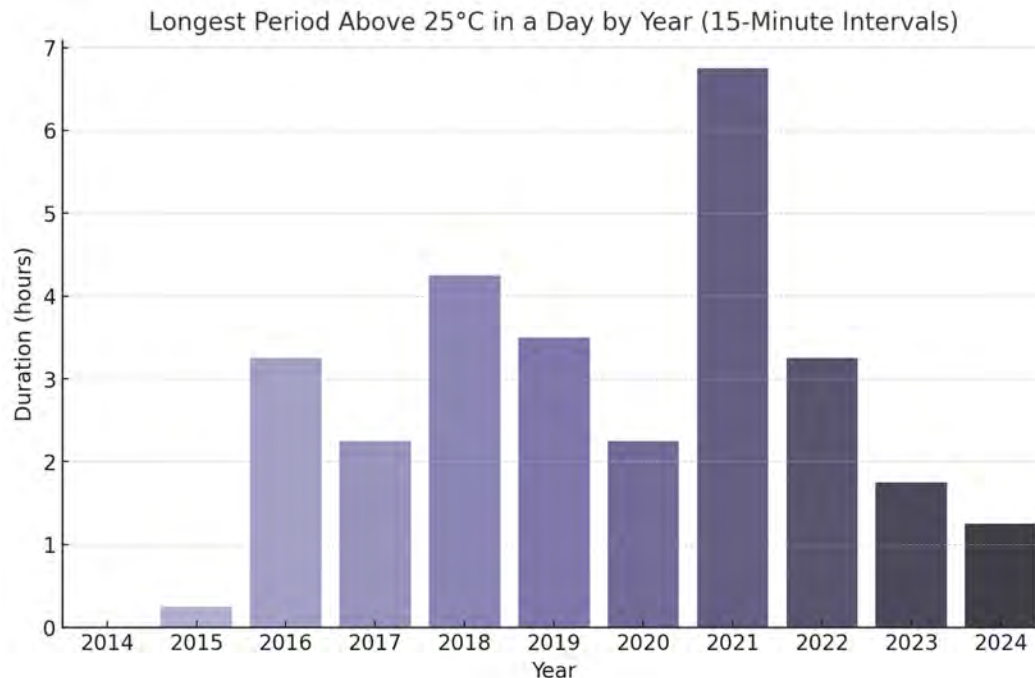


Figure 17. Longest daily duration of water temperature exceeding 25°C in Duxbury Bay by year, based on CCCE high-frequency (15-minute interval) monitoring from 2014 to 2024. Bars represent the maximum number of consecutive hours above the 25°C threshold observed on any single day each year.

Ecological Implications

Prolonged temperatures above 25°C are known to impair eelgrass (*Zostera marina*) by reducing photosynthetic efficiency, shoot density, and habitat stability. These impacts are particularly concerning when combined with poor water clarity or excess nutrients, both of which affect Duxbury Bay’s upper regions.

Estuarine benthic invertebrates, such as polychaetes and bivalves, also experience stress under elevated temperatures. Short-term temperature spikes during larval stages can reduce survival and alter reproductive success, potentially shifting community composition toward more opportunistic species.

Higher temperatures also stimulate phytoplankton—including cyanobacteria—and accelerate microbial processes like decomposition. These changes increase biological oxygen demand, contributing to hypoxia and feedback loops that exacerbate eutrophication symptoms.

Together, these patterns underscore the importance of maintaining nutrient control, habitat resilience, and water clarity to buffer against future warming.

Temperature Thresholds and Ecological Stress

Water temperatures below 20°C are generally within the optimal range for most estuarine species. Temperatures between 20°C and 25°C may begin to induce physiological stress, especially when combined with low oxygen or high nutrient conditions. Temperatures above 25°C are associated with eelgrass stress and may alter invertebrate reproduction, while temperatures exceeding 28°C pose a risk of ecosystem-level disruption.

Temperature Range (°C)	Ecological Interpretation
< 20	Optimal for most estuarine species
20 – 25	Physiological stress possible, especially under low DO or high nutrients
25 – 28	Eelgrass stress and reproductive disruption in invertebrates
> 28	High risk of ecosystem-level disruption

Table 15. *Temperature Thresholds and Associated Ecological Stress in Estuarine Systems.* This table outlines general temperature ranges and their potential biological impacts on estuarine organisms. As temperatures increase, risks to eelgrass, invertebrates, and ecosystem stability also rise, particularly when combined with other stressors such as low oxygen or nutrient enrichment.

2.4. Water Quality / Management Implications

Recent monitoring results highlight several areas of concern for the ecological condition of Duxbury Bay, particularly regarding nutrient enrichment, phytoplankton productivity, and thermal stress. These findings closely align with the 2007 Massachusetts Estuaries Project (MEP), which established nitrogen thresholds to protect eelgrass habitats and recommended targeted load reductions within the watershed. Revisiting and reinforcing these strategies is essential to restoring and protecting the bay's ecological health.

Elevated nutrient concentrations, especially total nitrogen (TN) and dissolved inorganic nitrogen (DIN), persist in the upper bay, with the Bluefish River Bridge consistently exhibiting values above MEP thresholds. These levels are associated with historic and ongoing eelgrass decline and organic enrichment. The MEP report emphasized that the greatest nitrogen load reductions should be achieved in the Bluefish River sub-watershed, which contributes approximately 24% of the total watershed load despite occupying only 8% of the watershed area. Secondary priorities include the Island Creek watershed and sub-areas surrounding the Powder Point Bridge and Kingston/Duxbury interface. Management actions in these areas should include continued improvement of stormwater

treatment, upgrades or removal of septic systems, and land-use zoning to limit future nutrient contributions.

The patterns in phytoplankton indicators, including elevated chlorophyll-a and increasing cyanobacteria prevalence, are consistent with excess nitrogen loading and suggest that the bay remains vulnerable to harmful algal blooms. Nutrient reduction measures described in the MEP remain relevant and critical to mitigating bloom formation and maintaining a stable phytoplankton community.

Dissolved oxygen conditions generally meet ecological criteria in surface waters, but episodic nighttime hypoxia during summer months—especially in the upper estuary—may stress benthic organisms and compromise habitat quality. These observations reinforce the need to reduce organic inputs and maintain strong tidal flushing, particularly in shallow and enclosed embayments such as the Bluefish River and Island Creek.

While turbidity generally falls within acceptable ranges, episodic increases, likely from storm-driven runoff or sediment resuspension, can limit light availability and delay eelgrass recovery. These conditions typically call for targeted efforts to stabilize shorelines, limit construction-related sediment inputs, and manage boat traffic in sensitive areas.

Warming trends in water temperature have already resulted in multiple thermal stress events ($>25^{\circ}\text{C}$) across recent growing seasons. These events increase the risk of low oxygen conditions and may further suppress eelgrass productivity. While temperature itself cannot be directly managed, maintaining good water quality and reducing other stressors—particularly nitrogen—will enhance the resilience of Duxbury Bay's habitats to a warming climate.

In summary, the findings of this report reinforce the nitrogen management priorities first established by the MEP. Achieving meaningful reductions in nitrogen loading—particularly in the Bluefish River, Island Creek, and surrounding sub-watersheds—will be necessary to reverse eutrophication trends, restore eelgrass beds, and safeguard long-term ecosystem functions. These efforts must be accompanied by continued monitoring, community engagement, and coordination among local and regional management agencies.

2.5. Recommendations and Research Priorities

Management Recommendations

1. Reinforce Nitrogen Load Reductions

Nutrient enrichment, particularly from nitrogen, remains the dominant stressor in Duxbury Bay. The most recent data and the Massachusetts Estuaries Project (MEP) both identify the

Bluefish River as the sub-watershed with the greatest need for nitrogen load reductions due to its disproportionately high contribution relative to its size. Targeted actions should include upgrading or replacing aging septic systems, expanding sewer service in high-load neighborhoods, reducing fertilizer use, retrofitting stormwater infrastructure to include green practices (e.g., bioretention, permeable pavement), and preserving or restoring riparian buffers. Success in these areas will help reduce algal blooms, improve oxygen dynamics, and enhance habitat for eelgrass and shellfish. Targeted nutrient source tracking by applying microbial or isotopic techniques to better identify nitrogen and phosphorus sources (e.g., wastewater vs. fertilizer vs. atmospheric deposition) can inform management strategies and allocate responsibility appropriately

2. Eelgrass Restoration and Habitat Protection

Eelgrass beds provide essential ecosystem services such as sediment stabilization, carbon sequestration, and habitat for finfish and shellfish. Historic declines in eelgrass acreage within the bay are closely tied to water clarity and nutrient conditions. Protection of remaining eelgrass through anchoring restrictions and vessel management, combined with strategic restoration efforts where water quality has improved, should be prioritized. Successful restoration depends on light availability, sediment quality, and appropriate hydrodynamic conditions, all of which must be evaluated at candidate sites.

3. Integrated Monitoring and Public Access to Data

A comprehensive monitoring program is needed to track the bay's response to management actions and to detect emerging stressors. Expansion of monitoring frequency and spatial coverage, particularly in the upper bay and tributaries, will improve trend detection. Real-time sensors can provide critical information on temperature, oxygen, and turbidity dynamics. Making these data available through public dashboards or open-access repositories will increase transparency, support academic collaboration, and engage the community in stewardship.

4. Augment Shellfish Propagation for Nitrogen Removal

Explore the expansion of shellfish propagation—especially oysters, clams, or mussels—in upper estuary areas such as the Bluefish and Back Rivers. Research from other Massachusetts estuaries (e.g., Waquoit Bay and the Three Bays system) shows that municipal shellfish propagation programs can provide measurable nitrogen removal benefits through both bio assimilation and sequestration of particulate organic matter in shell and tissue. While Duxbury Bay already supports large commercial shellfish farms, targeted municipal propagation in nutrient-impaired areas could provide supplemental nutrient control. The Massachusetts Shellfish Initiative and EPA's National Estuary Program have both highlighted shellfish as nature-based tools for nitrogen management.

5. Limit Fertilizer Use in Contributing Watersheds

Evaluate the feasibility of seasonal or year-round bans on lawn and turf fertilizer use within the watershed, particularly for non-agricultural properties. Several Cape Cod towns—including Falmouth and Orleans—have adopted fertilizer control bylaws to reduce nitrogen runoff into sensitive estuarine systems. Education campaigns and municipal ordinances can help reduce unnecessary nutrient inputs, especially during the spring and summer growing seasons when estuaries are most vulnerable to eutrophication.

6. Strengthen Public Outreach and Citizen Engagement

Build public understanding of estuarine health through targeted outreach. Promote best practices in landscaping, septic system maintenance, and stormwater management. Encourage public involvement in monitoring efforts and stewardship programs.

Research Priorities

1. Phytoplankton Composition and Bloom Risk

Recent increases in chlorophyll-a concentrations and the detection of cyanobacteria in Duxbury Bay suggest that phytoplankton communities are undergoing shifts potentially linked to warming waters, nutrient enrichment, and changing stratification patterns. However, current monitoring programs rely on bulk chlorophyll-a measurements and optical fluorescence sensors, which provide little taxonomic resolution and cannot distinguish between benign and harmful taxa.

To better understand bloom dynamics and potential ecological or public health risks, expanded research should include taxonomic identification and functional group characterization of the phytoplankton community. For example, Sharpe et al. (2023)¹ identified critical gaps in our understanding of estuarine phytoplankton ecology, particularly the need for more detailed, seasonal, and spatially resolved data that link species composition to environmental drivers. They advocate for a multifaceted approach incorporating microscopy, pigment profiling (e.g., HPLC), and molecular tools such as 18S and 16S rRNA gene sequencing to distinguish phytoplankton taxa and monitor shifts in dominance—especially among bloom-forming or toxin-producing species.

Applying these methods in Duxbury Bay would improve our ability to detect harmful algal bloom (HAB) precursors, understand competitive interactions within mixed phytoplankton assemblages, and assess how nutrient ratios and temperature fluctuations shape community structure. This research would also inform risk assessments for aquaculture

¹ Sharpe, A. E., Francis, C. A., & Kudela, R. M. (2023). Linking phytoplankton community structure with environmental drivers in a California estuary. *PLOS ONE*, 18(2), e0313271. <https://doi.org/10.1371/journal.pone.0313271>

and recreational uses, guide targeted nutrient reduction strategies, and serve as an early warning system for emerging bloom threats.

2. Diurnal and Tidal Variability in Oxygen and Temperature

Many low oxygen events in estuaries occur at night and may not be captured in monthly grab samples. High-frequency measurements—at intervals of 15 minutes or less—are needed to characterize diurnal oxygen depletion and its coupling with temperature, biological oxygen demand, and tidal flushing. Smith et al. (2024)² demonstrate how diel oxygen stress can shape benthic community composition and limit recovery from eutrophication. Deploying sensors at key locations such as the Bluefish River and Harbormaster Dock would provide critical insight into when and where hypoxia occurs.

3. Trophic Interactions and Benthic-Pelagic Coupling

Phytoplankton blooms, suspended sediments, and low oxygen events all affect benthic habitat quality, yet the connections between pelagic processes and benthic community dynamics remain understudied. Research that combines water column data with benthic infaunal surveys can reveal how changes in the upper bay affect shellfish and infaunal biodiversity. The study in *Frontiers in Marine Science* (2024)³ highlights how eutrophication can decouple benthic-pelagic interactions, reducing food quality and oxygen availability for bottom-dwelling species.

4. Climate Change Stressor Interactions

Temperature extremes, sea level rise, and altered precipitation patterns interact with existing stressors to amplify ecological risks. Climate modeling studies suggest that warming will expand the duration and intensity of algal blooms and hypoxia. Scenario-based simulations, coupled with empirical field studies, can help project the impacts of different management strategies under future climate conditions. Long-term planning must account for these interactions to ensure adaptive and resilient decision-making.

5. Ecosystem Services Valuation

Ecosystem services provided by Duxbury Bay—such as water filtration, recreational use, and support for fisheries—can be economically quantified to support cost-benefit analyses of management actions. Valuation studies that estimate the economic returns of eelgrass restoration, improved water quality, and shellfish harvests can help prioritize

² Smith, A. D., Dykman, D., Hall, E. K., & Giblin, A. E. (2024). Diel oxygen stress structures benthic communities and hinders recovery in eutrophic estuaries. *Frontiers in Marine Science*, 11, 1448718. <https://doi.org/10.3389/fmars.2024.1448718>

³ Francis, C. A., Sharpe, A. E., & Kudela, R. M. (2024). Eutrophication weakens benthic-pelagic coupling and reduces resource quality in a temperate estuary. *Frontiers in Marine Science*, 11, 1448718. <https://doi.org/10.3389/fmars.2024.1448718>

investments and engage diverse stakeholders, including local residents, resource managers, and funding agencies.

2.6. Conclusion

This updated State of Duxbury Bay report on water quality and temperature is based on the review, analysis, and synthesis of over a decade of environmental monitoring data and other sources information. Specifically, this report provides revised and expanded assessments of nutrient concentrations, phytoplankton indicators, dissolved oxygen dynamics, turbidity, and water temperature across key locations in the bay. The data were sourced from the Center for Coastal Studies, Cape Cod Cooperative Extension, and other regional partners, and were analyzed in the context of ecological thresholds, seasonal dynamics, and long-term trends.

Key findings highlight the ongoing impact of nutrient enrichment in the upper estuary, particularly in the Bluefish River, where nitrogen concentrations routinely exceed thresholds identified in the Massachusetts Estuaries Project. Patterns in chlorophyll-a, cyanobacteria presence, and episodic hypoxia further underscore the bay's sensitivity to eutrophication and the need for continued nutrient management. At the same time, warming trends in summer water temperatures and short-lived but ecologically significant oxygen sags suggest that climate-related stressors are compounding existing challenges.

The revised environmental indicator sections incorporate recent high-frequency sensor data, interannual monitoring trends, and comparisons to historical MEP findings. Each section has been updated to reflect current conditions, identify emerging stressors, and contextualize trends within the broader ecological framework of the estuary. Data visualizations and summary tables support interpretation of these trends and provide clear communication tools for stakeholders.

In addition to revising existing content, this report expands the original format by including management implications, targeted recommendations, and a forward-looking research agenda. These additions address the secondary objective of enhancing the report with new content related to benthic conditions, nitrogen loading, and future monitoring priorities. The findings and recommendations herein offer actionable insights for decision-makers, nonprofit partners, and the community as they work to restore and protect Duxbury Bay's ecological integrity.

3. Bacteria/Pathogens



Bacteria / Pathogens - Introduction

Duxbury's coastal waters are routinely monitored for bacterial indicators to protect public health and shellfish resources.

Public beaches are monitored by the Duxbury Department of Health who collect weekly samples tested for E. coli at public beaches from Memorial Day through Labor Day. Any sample exceeding its threshold limit (104 cfu/100 mL) triggers advisories or closures until follow-up testing shows improved levels.

Beach Water Quality is consistently very good with few exceedances since 2009. Generally, spikes in measured bacteria correlate with surface runoff events following dry periods causing pet/wildlife waste, failing septic systems, and leaking sewer infrastructure to affect near shore waters.

The Massachusetts Division of Marine Fisheries (DMF) samples approved and conditionally approved shellfishing beds at least five times annually. The 2024 DMF report confirms that all approved areas meet standards, though a few prohibited stations including Eagles Nest Creek, Bluefish River Bridge, and Landing Road exhibit elevated counts.

Mitigation & Recommendations

Ongoing infrastructure improvements and outreach have proven effective. To further safeguard water quality and shellfish industry viability, Duxbury should:

1. Increase sampling frequency during peak storm months.
2. Expand and maintain stormwater Best Management Practices critical watersheds.
3. Enhance septic inspection and upgrade programs.
4. Intensify public education on pet waste and non-point source pollution, such as excess or improper fertilizer use on lawns.
5. Collaborate on targeted research to apportion contaminant sources.

Continued adaptive management and investment in these measures will help ensure continued very good water quality, sustained compliance with regulatory standards and public confidence in Duxbury's recreational and shellfish waters.

3.1 Public Beach Monitoring

Since 2001, Duxbury's Department of Health has been monitoring public beaches during beach season (per Mass Dept of Public Health 105 CMR 445.000). This data is accessible at: <https://matracking.ehs.state.ma.us/Environmental-Data/recreational-water/index.html>

Pollution in beach water is usually associated with human or animal waste caused by:

- stormwater runoff
- pet and animal waste
- poorly functioning septic systems
- leaking sewer pipes
- discharge of sewage by boats

Illness-causing organisms are varied and complicated to measure directly. The testing protocol followed by the town per state regulations assumes that samples containing dangerous pathogens also contain bacteria which are easier to measure. These "indicator organisms" signal concern for the presence and quantity of illness-causing organisms in the water. In Massachusetts, either enterococci or *Escherichia coli* (*E. coli*) are used as indicators that harmful pathogens maybe present in the water sample.

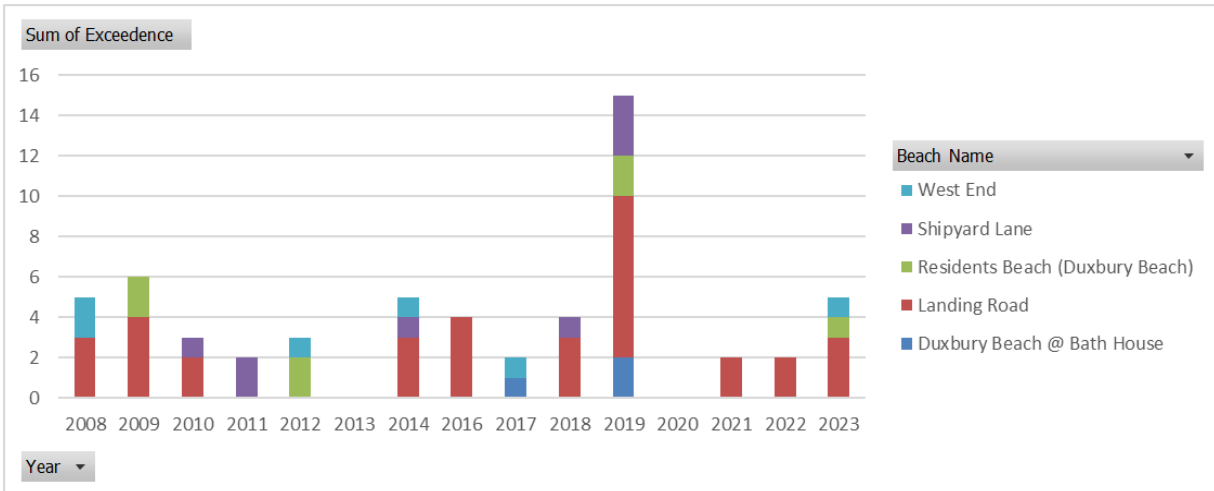
The Massachusetts Department of Environmental Protection (MassDEP) is responsible for coastal beach monitoring but the sampling is conducted by Duxbury's Department of Health. Water samples are collected weekly during the swimming season, typically from Memorial Day through Labor Day, and tested at certified laboratories. MassDEP uses the U.S. EPA standard for single-sample exceedance: a result greater than 104 colony-forming units (cfu) per 100 milliliters of marine water. If levels exceed this threshold, the beach may be posted with an advisory or closed until follow-up tests confirm that bacteria levels have returned to acceptable limits.

A significant contributor to exceedance events is surface runoff from animal waste, which is especially significant soon after a rain preceded by a long dry period. Duxbury has an abundant and diverse wild animal population but there is likely to be some contribution by pet animal waste.

Following are data collected since 2008 organized by the number of exceedances recorded during each year.

The Data

Sum of Exceedence	Colu															
Row Labels	2008	2009	2010	2011	2012	2013	2014	2016	2017	2018	2019	2020	2021	2022	2023	Grand Total
Duxbury Beach @ Bath House	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	3
Landing Road	3	4	2	0	0	0	3	4	0	3	8	0	2	2	3	34
Residents Beach (Duxbury Beach)	0	2	0	0	2	0	0	0	0	0	2	0	0	0	1	7
Shipyard Lane	0	0	1	2	0	0	1	0	0	1	3	0	0	0	0	8
West End	2	0	0	0	1	0	1	0	1	0	0	0	0	0	1	6
Grand Total	5	6	3	2	3	0	5	4	2	4	15	0	2	2	5	58



Changes in Bacteria and Pathogen Levels

1. **Fecal Coliform:** Data from the Massachusetts DEP and local monitoring programs show generally few exceedances have occurred in Duxbury Bay since 2009.

Several factors contribute to maintaining good control over contamination:

- **Stormwater Management:** Implementation of stormwater remediation projects, such as the installation of new structures at outfall locations, has reduced the influx of contaminated runoff into the bay
 - **Septic System Upgrades:** Efforts to upgrade failing septic systems and connect properties to municipal sewer systems have decreased the amount of untreated wastewater entering the bay
 - **Public Awareness Campaigns:** Educational initiatives aimed at reducing pollution from pet waste and other sources have contributed to improved water quality
2. **Enterococcus:** Monitoring data indicate fluctuations in Enterococcus levels, with occasional spikes following heavy rainfall events

These spikes are typically short-lived and are managed through temporary beach closures and public advisories.

3. **Other Pathogens:** While fecal coliform and Enterococcus are the primary focus, other pathogens such as *Vibrio* spp. have also been monitored. There have been isolated cases of *Vibrio* infections linked to shellfish consumption, prompting increased vigilance and monitoring by local health authorities.

Restoration and Mitigation Efforts

To address bacteria and pathogen contamination, several restoration and mitigation efforts have been implemented:

- **Stormwater Infrastructure Improvements:** The Town of Duxbury has received grants to improve stormwater infrastructure, including the construction of new outfall structures and the implementation of best management practices (BMPs) to reduce runoff
- **Septic System Management:** Programs to inspect and upgrade septic systems have been expanded, reducing the risk of untreated wastewater entering the bay
- **Public Education:** Ongoing public education campaigns focus on reducing pollution from pet waste, agricultural runoff, and other sources

3.2 Shellfish Monitoring

The Massachusetts Division of Marine Fisheries (“DMF”) conducts water quality sampling for fecal coliform bacteria at classification stations around the bay to ensure that shellfish beds are safe for harvest. In addition, the Duxbury Board of Health, supported by the Massachusetts EPA, surveys our beaches to ensure the water is safe for swimming. Fecal coliform is an indicator of overall bacteria or pathogen, presence and abundance.

The DMF follows a monitoring protocol that is consistent with methods outlined in the most recent revision of the National Shellfish Sanitation Program (NSSP). “Approved” areas of Duxbury Bay are sampled a minimum of five times annually when open to harvest, and “Conditionally Approved” areas of the bay are sampled monthly when the area is open to harvest. Water samples are tested for fecal coliform bacteria at two DMF laboratories located in Gloucester and New Bedford using the membrane filtration technique (mTEC).

Numeric criteria are applied to decisions on whether certain areas should be open or closed to shellfish harvesting (recreational and commercial). Shellfishing can be closed based on exceedance of criteria including:

- Greater than 10 percent of samples exceed 31 CFU/100ml
- Geometric mean exceeds 14 CFU/100 ml

According to the NSSP, a minimum of the 15 most recent samples collected when the classification area is in the “Open to Shellfishing” status are used to determine whether a station is meeting the numeric criteria, listed above. The DMF 2024 Annual Reports for Duxbury Bay indicate that all “Approved” and “Conditionally Approved” water quality stations currently meet the NSSP requirements for their respective classifications. DMF sampling stations are shown in Figure 1.



The table below summarizes the data collected from sites in Duxbury Bay by DMF since 2015. These numbers are geometric means of all data collected from the respective site during the year.

Site	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	G'Mean
1	1	0.94	1	1.24	1.37	1.14	1.2	1.31	1.57	1.21	1.18
11	3.56	2.18	2.63	5.22	6.78	2.89	13.46	2.36	7.46	6.58	4.48
12	3.56	1.37	1.19	1.24	1.15	0.92	1.71	2	1.81	2.08	1.58
14	2.08	1.25	3.43	3.14	5.63	1.22	2.99	1.63	1.73	2.95	2.33
16	1	0.94	1	0.92	0.9	0.9	1.08	1.34	1.61	1.19	1.07
17	1.44	0.96	1.28	1.47	1.08	1.2	1.01	1.23	1.1	1.2	1.19
20	1	0.94	1.57	1.37	0.92	0.9	0.9	0.98	0.92	1.04	1.04
21	1.44	0.94	1.16	0.92	0.94	0.92	0.94	0.92	1.72	1.34	1.1
23			1	0.93	1.27	0.9	0.96	1.1	1.76	1.21	1.12
11A	1.59	1.39	2.38	2.2	1.06	1.14	0.94	1.37	5.65	1.57	1.66
11B				24	1.52	1.08	4.15	1.61	4.73	1.58	2.95
2A						1.25	1.29	1.63	1.78	1.24	1.42
G'Mean	1.64	1.16	1.5	2.01	1.52	1.14	1.64	1.41	2.13	1.96	1.89

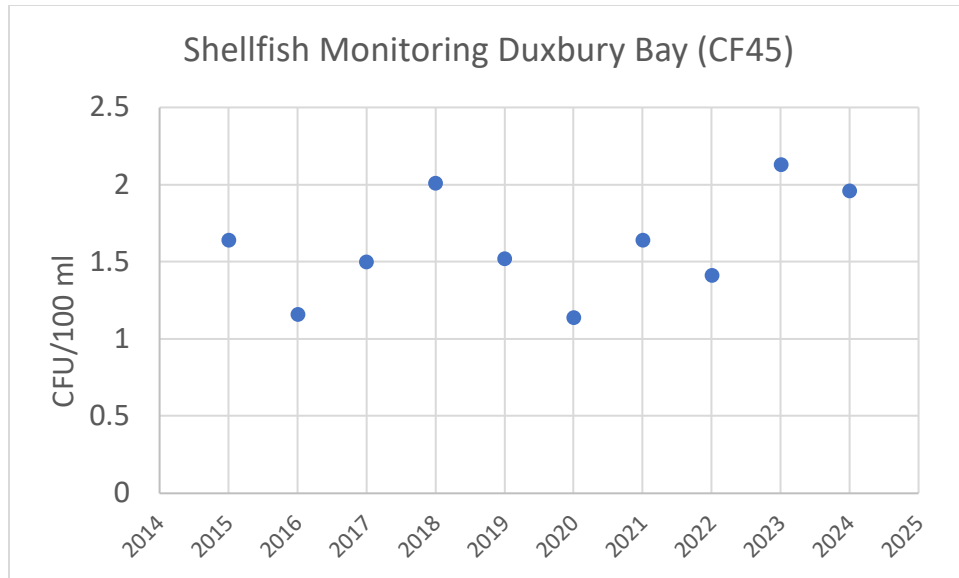


Figure 2 Trend of all data collected in Duxbury Bay.
(There is an insignificant trend in this data)

The table below summarizes the data collected from sites in Kingston Bay by DMF since 2015. These numbers are geometric means of all data collected from the respective site during the year.

											GeoMea
Site	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	n_Site
23			2.99	6.23	3.94	2.93	4.15	1.99	2.98	3.58	3.43
24			6.26	3.42	2.51	2.04	1.85	1.75	2.38	2.57	2.61
B	4	5.48	7.41	9.55	3.84	2.7	6.18	1.95	1.17	14.32	4.48
B2		2.58	5.28	6.18	4.07	2.47	2.47	2.2	0.97	5.55	2.75
B3		1.25	1.07	1.22	1.06	1.04	1.13	0.92	1.85	1.29	1.16
C		2.24	4.25	5.78	6	4.46	10.96	3.93	2.39	10.1	4.15
S2		2.53	5.8	7.2	3.27	3.45	4.66	3.23	4.23	3.74	3.51
S7		2.31	1.71	1.98	1.36	0.91	1.4	1.17	2.25	3.23	1.61
GeoMea											
n_Year	1.26	2.48	3.67	4.34	2.85	2.22	3.14	1.94	2.07	4.29	2.72

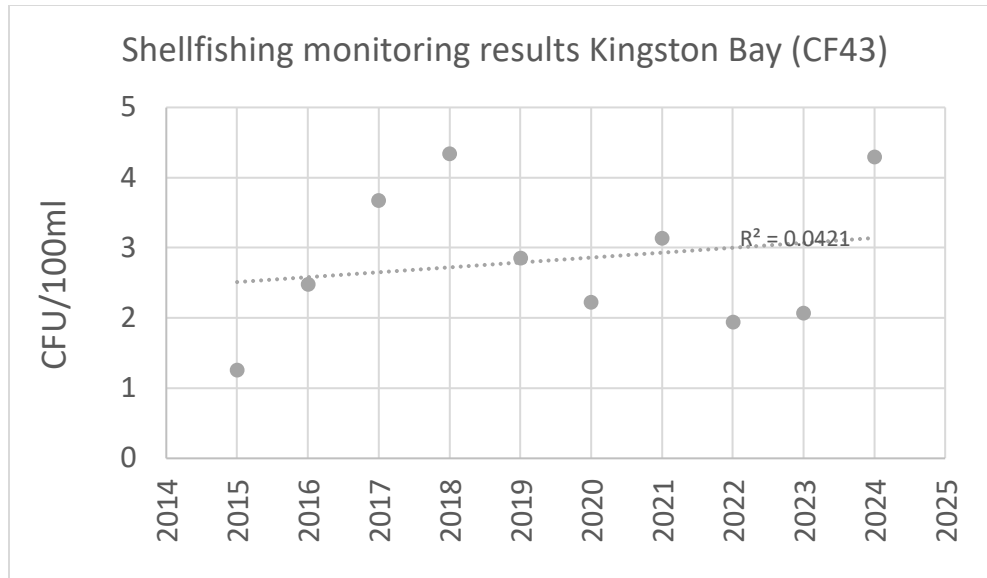


Figure 3 Trend of all data collected in Kingston Bay.
(This data indicates there may be a small upward trend over time)

The table below summarizes the data collected at each individual site in Duxbury Bay in 2024. The Percentage factor indicates the percentage of samples that were measured to be >31 CFU/100mL.

CCB45 - Duxbury Bay

STATION	NAME	CLASS.	# RUNS	GEO MEAN	PERCENTAGE FACTOR*
2A	Outside Bluefish River	Approved	15	1.53	0.0%
16	High Pine	Approved	15	1.37	0.0%
23	100 ft off Creek	Approved	15	1.33	0.0%
21	Middle of the Bay	Approved	15	1.29	0.0%
12	Shipyard Lane	Approved	15	1.96	0.0%
11A	Harden Hill Road	Approved	15	2.3	6.7%
11B	Dock in Eagles' Nest Cove	Approved	15	2.29	6.7%
11	Eagles Nest Creek-Marshall St.	Prohibited	15	5.51	20.0%
14	Duxbury Yacht Club	Cond. Approved	15	1.67	0.0%
17	Saquis Head Cove	Cond. Approved	15	1.14	0.0%
20	Cowyard Buoy #6	Cond. Approved	15	1.01	0.0%
1	Ocean Ave.	Cond. Approved	15	1.24	0.0%

9	Massasoit Road	Cond. Approved	2	-----	-----
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CCB46 - Bluefish River

STATION	NAME	CLASS.	# RUNS	GEO MEAN	PERCENTAGE FACTOR*
2A	Outside CCB46.3	Cond. Approved	15	1.24	0.0%
7	East Side Bumpus Pier	Cond. Approved	15	1.66	0.0%
9	Middle of CCB46.1	Cond. Approved	15	1	0.0%
1E	King Caesar and Russell Rd.	Cond. Approved	15	2.25	0.0%
1D	36 Powder Point Road	Prohibited	15	2.53	0.0%
1	Washington St. Bridge	Prohibited Prohibited	15	3.08	6.7%

CCB47 - Back River

STATION	NAME	CLASS.	# RUNS	GEO MEAN	PERCENTAGE FACTOR*
9	Cove Street Landing	Approved	15	2.18	6.7%
6	Great Wood Island	Approved	15	1.48	0.0%
4	Gunning Channel	Approved	15	1.95	6.7%
3	Powder Point Bridge West Side	Approved	15	1.54	0.0%
7	Snack Bar	Approved	15	2.75	6.7%

MB1

STATION	NAME	CLASS.	# RUNS	GEO MEAN	PERCENTAGE FACTOR*
2	Gurnet Point	Approved	15	1.59	6.7%
5	Powder Point Bridge Parking Lot	Approved	15	1.74	0.0%
3	Duxbury/Marshfield Line	Approved	15	1.86	6.7%

Discussion

The long-term monitoring data of bacterial pathogens in Duxbury Bay and surrounding coastal waters reveal important trends in both recreational water quality and shellfish safety. While overall levels of fecal indicator bacteria such as Enterococci and fecal coliform remain within regulatory thresholds at most locations, periodic exceedances continue to

occur and warrant continued attention.

Public beach data from 2023 show that Landing Road had the highest percentage of exceedances (18.8%) among Duxbury's monitored beaches, while other sites such as the Bath House and Shipyard Lane had no exceedances. This spatial variability suggests that localized factors—such as stormwater inflow, wildlife activity, and septic system proximity—continue to influence water quality outcomes.

In the shellfish growing areas of Duxbury Bay, monitoring by the Massachusetts Division of Marine Fisheries (DMF) indicates that nearly all Approved and Conditionally Approved stations meet National Shellfish Sanitation Program (NSSP) standards. However, a small number of Prohibited sites remain, and several stations—particularly near the Eagles Nest Creek and Washington Street Blue Fish River (? Is this right Jon) Bridge—regularly exhibit elevated bacterial counts and exceedance rates above 6%.

Notably, rainfall events preceded by long stretches of dry weather appear to be key drivers of short-term exceedances. These patterns are consistent with the hypothesis that surface runoff, containing waste from pets, wildlife, and failing septic systems, contributes significantly to bacterial loading. This dynamic is supported by higher exceedance rates observed following storm events in both beach and shellfish datasets.

Despite these challenges, Duxbury has made measurable progress through stormwater infrastructure upgrades, septic system improvements, and public education initiatives. Continued investment in these areas, especially in vulnerable zones near existing Prohibited areas, will be critical to protect both public health and the region's economically important shellfish industry.

Looking forward, adaptive management strategies should include:

- More frequent sampling during storm-prone months,
- Continued maintenance and expansion of stormwater BMPs,
- Enhanced pet waste and septic outreach programs,
- And collaborative research to assess contributions from non-point sources.

Conclusion

Overall, while water quality related to pathogens in Duxbury Bay remains largely safe and compliant, the presence of periodic exceedance events highlights the need for continued monitoring, responsive management, and public engagement

4. Eel Grass and habitat



Please see 2024 report and eelgrass survey from the North South River Watershed Association, per link below for recent study and survey of eel grass loss in Duxbury Bay

<https://www.nsrwa.org/2024-eelgrass-survey-results/>



Fig 1. Eelgrass loss from 1995 to 2017 (MA DEP)

Introduction

Eelgrass (*Zostera marina*) is a vital marine plant that forms underwater meadows, providing essential habitat for various marine species, improving water quality, and stabilizing sediments. However, eelgrass meadows in Duxbury, Kingston, and Plymouth (DKP) Bays have experienced significant declines over the past several decades

Eelgrass Die-Off

The decline of eelgrass in DKP Bays has been well-documented. The Massachusetts Division of Marine Fisheries (DMF) and the Massachusetts Department of Environmental Protection (DEP) have mapped eelgrass extent using aerial photos from 1951, 1995, 2001, 2006, and 2012. These maps indicate a 45% loss of eelgrass over the studied period. By 2014, further assessments revealed that eelgrass was no longer present in several areas previously mapped

Several factors contribute to eelgrass die-off, including:

- **Eutrophication:** Increased nutrient levels, particularly nitrogen, lead to phytoplankton blooms that reduce light penetration, essential for eelgrass photosynthesis
- **Physical Disturbance:** Activities such as boating, dredging, and aquaculture can physically damage eelgrass beds
- **Climate Change:** Rising water temperatures and changes in salinity can stress eelgrass, making it more susceptible to disease and other stressors
- **Wasting Disease:** A disease caused by the pathogen *Labyrinthula zosterae* has been linked to significant eelgrass declines

Restoration Efforts

Efforts to restore eelgrass in DKP Bays have been ongoing, involving multiple stakeholders, including DMF, DEP, and local environmental organizations. Key restoration strategies include:

1. **Mapping and Monitoring:** Accurate mapping of eelgrass meadows using remote sensing technologies such as drones, airplanes, satellites, and side-scan sonar is crucial for tracking changes and planning restoration efforts

Regular monitoring helps assess the health and extent of eelgrass beds and identify areas needing intervention

2. **Water Quality Improvement:** Reducing nutrient inputs from agricultural runoff, wastewater, and stormwater is essential to mitigate eutrophication. Implementing best management practices (BMPs) and upgrading wastewater treatment facilities can help improve water quality
3. **Physical Protection:** Establishing protected areas and implementing regulations to limit activities that disturb eelgrass beds can help preserve existing meadows. Boating restrictions, designated anchoring areas, and careful planning of aquaculture activities are examples of protective measures.
4. **Direct Restoration:** Collecting eelgrass seed pods in the spring from healthy donor sites, propagating them over the summer, and redispersing them in the fall in areas that have the appropriate conditions for successful restoration is a proven restoration technique used in other coastal bays on the east coast. The Duxbury Bay Management Commission is collaborating with the North South River Watershed Association (NSRWA) on eelgrass restoration project planning in the bay. The NSRWA was recently awarded a 2-year grant to implement eelgrass restoration in conjunction with the Massachusetts Division of Marine Fisheries. The DBMC and local volunteers will be participants in this effort.
5. **Community Involvement:** Engaging local communities in restoration efforts through education and volunteer programs can enhance the success of restoration projects. Public awareness campaigns and citizen science initiatives can foster a sense of stewardship and support for eelgrass conservation

Conclusion

The decline of eelgrass in Duxbury, Kingston, and Plymouth Bays is a complex issue driven by multiple factors. However, ongoing restoration efforts, including mapping, water quality improvement, physical protection, direct restoration, and community involvement, offer hope for the recovery of these vital marine habitats. Continued collaboration among stakeholders and sustained commitment to conservation practices are essential to ensure the long-term health and resilience of eelgrass meadows in DKP Bays.

Massachusetts Division of Marine Fisheries Report
Massachusetts Bays Program
North and South Rivers Watershed Association

5. Duxbury Beach – Focal Species / Species of Concern

The following report was provided to the Duxbury Bay Management Commissions for the State of the Bay – 2025 report from the Duxbury Beach Reservation, executive Director, Cris Luttazi, and Duxbury Beach Reservation Coordinator, Joey Negreann.



Duxbury Beach – State of the Bay 2025

Duxbury Beach is a 7.5-mile barrier beach system located in the towns of Duxbury and Plymouth Massachusetts. The barrier is connected to the mainland at the north and extends south into Cape Cod Bay thus creating the eastern boundary of Duxbury Bay. The barrier averages approximately 200 feet in width and covers 550 acres. While narrow a dune system still exists and is made up of a combination of sand, pebble, and cobble sediment.

Duxbury Beach serves a critical role in coastal protection as a barrier beach by absorbing wind and wave energy generated in Cape Cod Bay. In addition, wetlands lining the west side of the barrier create a healthy and well-maintained system that provides a natural buffer and safeguards the bay and the coastal community of Duxbury. The waves sourced from Cape Cod Bay break along the beach, rather than the highly developed mainland. Thereby reducing Duxbury Bay and inland impacts of storm surge, flooding, erosion, and high winds.

Duxbury Beach Reservation, a private non-profit manages more than 4.5 miles and 350 acres of the barrier beach system. As part of the organizations mission, the Reservation, through grants and donations, maintains the coastal dune and coastal beach resources which consists of a combination of mixed sediment of sand and cobble.

Ecological Impacts of Duxbury Beach

As a prominent coastal ecosystem in Massachusetts, Duxbury Beach supports a diverse range of wildlife, including 284 species of birds (ebird.org), 12 species of mammals, 89 species of invertebrates, and 206 species of plants (107 native, 90 non-native and 13 invasive). The entirety of Duxbury Beach is mapped by NHESP as Priority Habitat of Rare Species and Estimated Habitat of Rare Wildlife. Fourteen (14) rare species have been recorded on Duxbury Beach, however only four species have been observed breeding on the beach. As such, the maintenance of Duxbury Beach is critical for preserving these coastal ecosystem benefits. A brief summary of listed and other important species that rely on Duxbury Beach is presented below.

Duxbury Beach and Duxbury Bay - Focal Species / Species of Concern

The most prominent listed species present on Duxbury Beach are the piping plover (*Charadrius melodus*) and the least tern (*Sternula antillarum*). In 2024, there are only two (2) other sites in the state that support more piping plover pairs, including one national wildlife refuge (MassWildlife 2024).

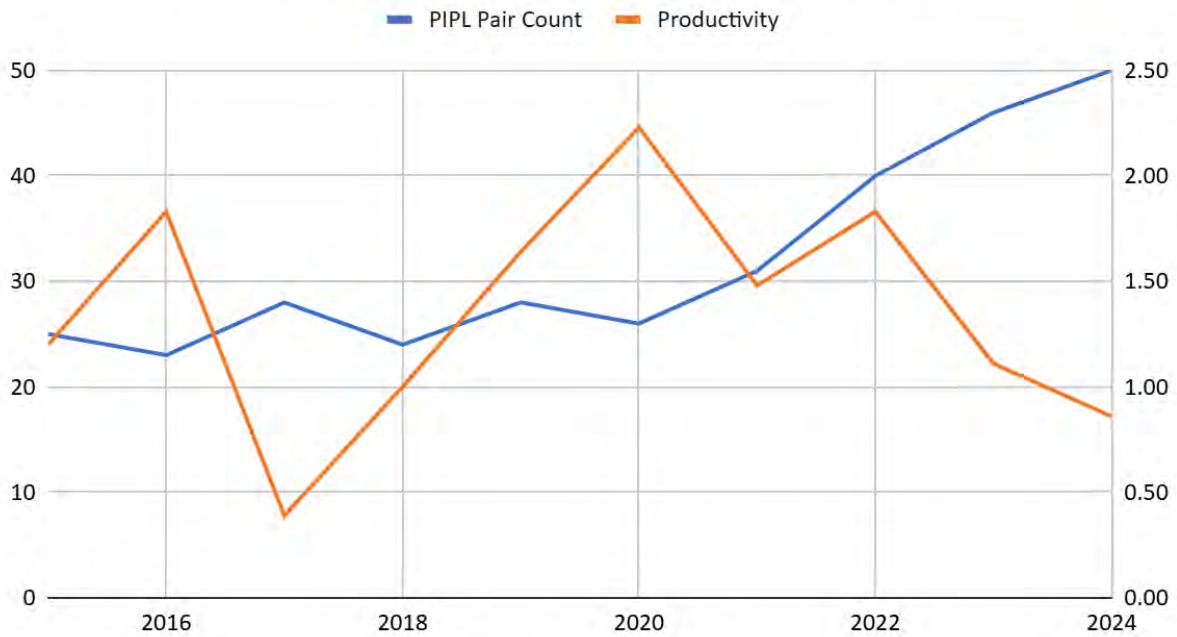
Piping Plover

Understanding nesting success of piping plovers, a species listed as threatened under the Endangered Species Act, at Duxbury Beach can provide insight into the health of Duxbury Bay. Nesting piping plovers at Duxbury Beach utilize both oceanside and bayside habitat of the barrier beach to raise their chicks. Every year many pairs of piping plovers lead their chicks from oceanside, where they primarily lay their nest, to the bayside mudflats which provide optimal foraging opportunities. Piping plover population dynamics are stochastic in nature as success is dependent on different variables from season to season. Some variables that influence success include foraging opportunities, beach use, predation, weather events, etc. Pairs at Duxbury Beach have been stable and increasing since 2009, and doubled from 2014 to 2024. The increase at Duxbury Beach follows the population trend for the species in Massachusetts. This suggests that Duxbury Beach and the mudflats found on the bayside provide a suitable and healthy ecosystem for piping plovers to thrive.

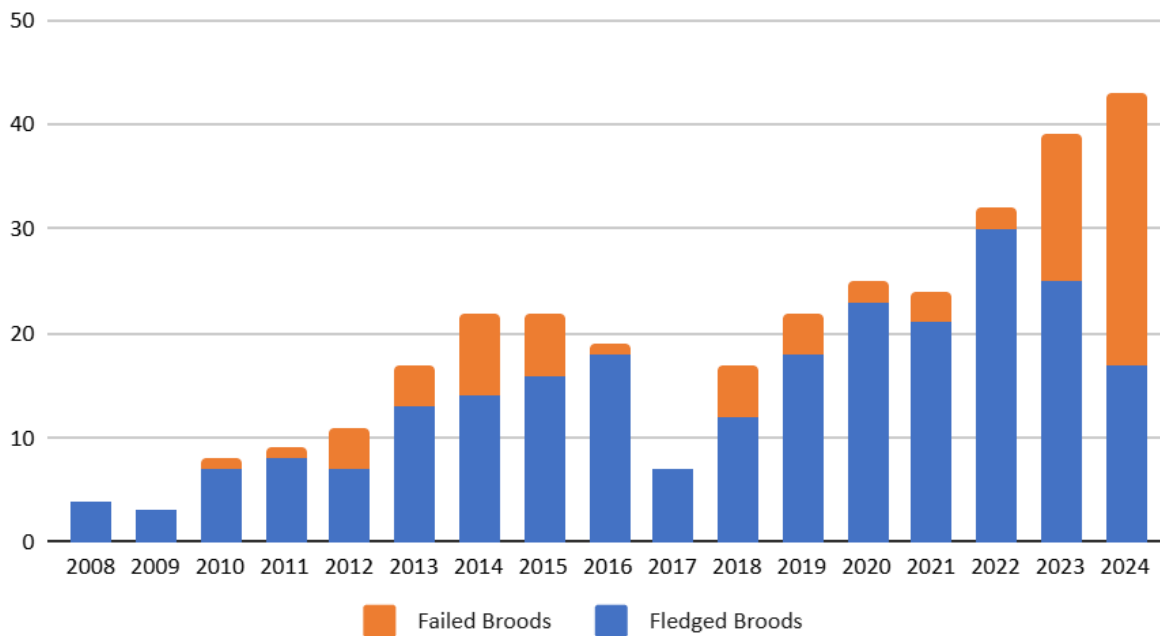
Duxbury Beach Piping Plover Data, 2009-2024.

Year	Piping Plover Pairs	# of Chicks Fledged	Productivity
2009	11	4	0.36
2010	11	16	1.45
2011	12	19	1.58
2012	14	13	0.93
2013	17	33	1.94
2014	26.5	24	0.91
2015	25	30	1.20
2016	23	42	1.83
2017	28	11	0.39
2018	24	24	1.00
2019	28	46	1.64
2020	26	58	2.23
2021	31	46	1.48
2022	40	73	1.83
2023	46	51	1.11
2024	50	43	0.86

PIPL Pair Count and Productivity Over Last Decade



Brood Presence on Duxbury Beach 2008-2024

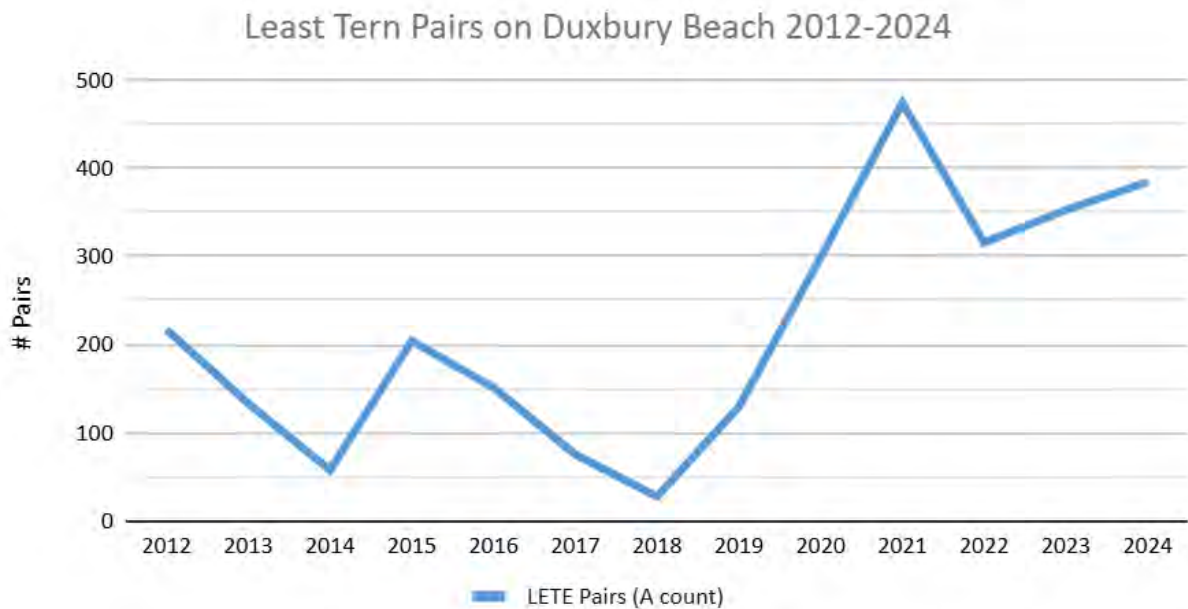


Least Terns

Least terns are listed as a species of special concern under the Massachusetts Endangered Species Act. Duxbury Beach has long been identified as an important breeding site for these species. Least tern population dynamics and pair counts are heavily impacted by their life history. They are a long-lived species that will try to nest in most years but often have boom and bust years when it comes to nesting success. In addition, they are not as faithful to a nesting site as other species, such as piping plovers, and will readily move from one beach to another based on different variables. They can also make local movements during a nesting season and nest at two different sites in the same season if a colony is abandoned at one beach. This can happen due to predation, human disturbance, or lack of foraging opportunities among other reasons. Least terns are a fishing species and small fish and other invertebrates make up all of their diet. Considering their life history, the consistent high number of pairs at Duxbury Beach, and a high number of chicks fledged since 2019, it is encouraging that Duxbury Beach and Bay are providing the key elements for this species to be successful.

Duxbury Beach Least Tern Data, 2009-2024.

Year	Least Tern Pairs (A Count)	Least Tern Pairs (B Count)	# chicks fledged
2012	217	-	-
2013	133	-	-
2014	57	-	5
2015	204	-	-
2016	151	-	40
2017	75	44	0
2018	27	152	65
2019	129	159	134
2020	299	310	211
2021	475	298	24
2022	316	388	137
2023	353	-	130
2024	385	296	12



Saltmarsh Sparrows

In addition to beach nesting birds, the four distinct saltmarshes that are protected by the Duxbury barrier beach system provide breeding habitat to saltmarsh sparrows (*Ammodramus caudacutus*). As of 2024, this vulnerable sparrow species has been confirmed breeding in one of the four saltmarshes. It is suspected that they also breed in at least one or two of the other saltmarshes.

Duxbury Beach also supports breeding populations of non-listed beach nesting bird species, including American Oystercatchers, Willets, and Horned Larks. American Oystercatchers have laid nests in the past two years after an eight-year absence of any breeding attempts. Oystercatchers diet almost completely consists of food foraged from intertidal areas, including bivalves, mollusks, crustaceans, worms and other marine invertebrates (Birds of the World). With vast mudflats at low tide Duxbury Bay provides ample foraging opportunities and nesting indicates the Oystercatchers view the bay as viable for raising chicks.

The glacial till known as High Pines and areas at Plum Hills, with their tall woody vegetation and dense understory, support a wide range of breeding passerines including gray catbirds, northern mockingbirds, yellow warblers, and Song Sparrows and many others.

Duxbury Beach also serves as an important migratory stopover point for shorebirds and seabirds. Many migrant birds roost on the beach at high tide and forage in the bay itself or along the mudflats. Notable species that utilize the beach are Red Knots and Roseate Terns

among others. Both Species utilize the beach and the bay during the fall to help gain fat for their long migratory journeys. Red Knots are listed as threatened under the Massachusetts and US Endangered Species Act, while Roseate Terns are listed as endangered under both.

Due to Duxbury Beaches importance as a stop over site for many species of migratory shorebirds Manomet Bird Observatory identified Duxbury Beach as one of their very first sites for International Shorebird Surveys. These surveys have been completed on Duxbury Beach since the 1970's and have helped contribute to understanding the decline of shorebird species.

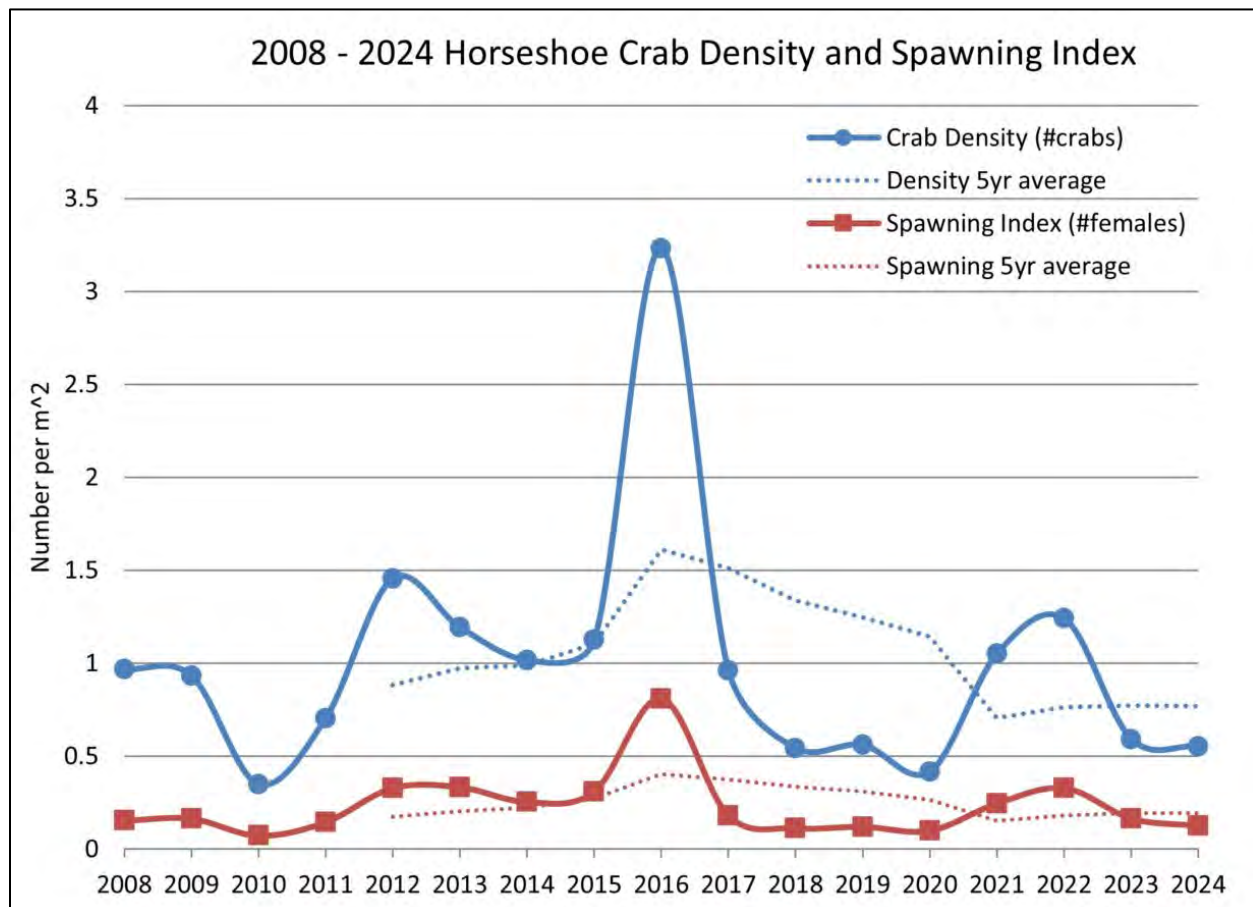
In addition to the abundant avian life on Duxbury Beach, the barrier beach system provides habitat for other types of wildlife as well. Duxbury Beach's low-lying dunes support healthy stands of vegetation, particularly American beach grass and *Rosa rugosa*. Dense patches of vegetation provide excellent habitat for small mammals including voles, rabbits, and mice. This in turn provides a stable food source for predators, ranging from common predators like coyotes and foxes to rarer threatened predators such as snowy and short-eared owls.

The embayment created by the Duxbury Beach barrier beach system has also creates suitable habitat for many aquatic and marine species. The Plymouth, Kingston, and Duxbury Bay complex was identified as essential fish habitat for juvenile sand tiger sharks (Kneebone et al 2012). Duxbury Bay, between Powder Point and Duxbury Beach, was determined to be an important nursery for juvenile sharks. Likewise, the Bay sustains a prominent population of horseshoe crabs in the state, being one of 15 areas that is regularly monitored for horseshoe crab populations (mass.gov). In addition to their biomedical research importance, horseshoe crab eggs and larvae also play a role as an important food source for migratory shorebirds (Botton 2009).

Horseshoe Crabs

Horseshoe crab data are available for the years 2008 through 2024. Duxbury is one of sixteen state-wide sites where the MA Division of Marine Fisheries collects data. The Duxbury horseshoe crab surveys are conducted by volunteers under a program managed by the North and South Rivers Watershed Association. Data are collected during the spawning season around the full and new moon high tides in May and June. Surveys are conducted on the bay side of Duxbury Beach from the bridge to Blakeman's. Crabs found within 25-meter square quadrats are counted. Both males and females are counted. Sex can readily be determined because the females are much bigger than the males and males have unique front legs. The males attach themselves behind the females with these specialized pincher claws, and the front of the males' shells are curved to fit over the back of the females' shells. The females bury into the mud/sand to deposit their eggs.

Anecdotal accounts indicate that today's crab populations are smaller than they were 40 years ago. Historically, there was pressure on populations because the crabs predate on clams. There was a bounty on crabs delivered to the town dump (now Transfer Station). More recently, horseshoe crabs are used as bait in the Channeled Welk fishery. Additionally, horseshoe crab blood has been used in medical research. Companies that extract the blood claim that they return them to the water with minimal mortality.



Trends in the Data /Observations / Recommendations

Piping Plover

- Increase in Nesting Success:** The State of Massachusetts, has observed an increase of piping plover pairs by 9x since being listed in 1985. A similar nesting population increase has been observed Duxbury Beach. The production rate (fledglings per nest) has generally increased from 2009 to 2024, indicating improved breeding success. The fledglings/nest ratio has averaged 1.3 during that time period. The USFWS stated recovery fledge per pair needed to maintain a stationary population is 1.24.

- **Increasing Pair Numbers:** The number of pairs has steadily increased from 2009-2024, suggesting a growing population of nesting pairs.

Least Terns

- **Steady Growth:** The number of pairs has overall increased from 2009 to 2024. The fledgling success is variable from year to year and adults can make local movements within a breeding season or across multiple breeding seasons. It is more difficult to discern how the population is doing on a site by site basis.
- Duxbury Beach is one of the top ten most important sites for least tern abundance and productivity in the state of Massachusetts, Duxbury Beach supports greater than 300 nesting pairs since 2020.

Horseshoe Crabs

- **Population Stability:** The density of horseshoe crabs surveyed has generally stayed stable from 2008 to 2024.
- **Stable Spawning Index:** The spawning index (females/quadrat) has been stable, indicating consistent reproductive activity in the survey area.

Overall, the data suggest positive trends for the piping plover and least tern populations, with increasing or stable pair numbers returning the beach to nest annually. The horseshoe crab population also appears to be stable, with consistent reproductive activity and density. These trends indicate successful conservation efforts and a healthy ecosystem in Duxbury Bay.

Several factors contribute to the observed trends in the data for piping plovers, least terns, and horseshoe crabs in Duxbury Bay:

Conservation Efforts

1. **Habitat Protection and Restoration:** Duxbury Beach Reservation (DBR) has been actively involved in habitat protection and restoration projects. These include dune and beach renourishment, cobble berm restoration, planting a diverse mix of vegetation, including grasses and woody shrubs, invasive species removal, road elevation, roadway elevation, sturdy drift fence installation, swale construction and other coastal resiliency projects. These efforts help create stable and suitable ecosystems for a host of species.

2. **Species Monitoring and Protection Programs:** Duxbury Beach Reservation participates in the Massachusetts Habitat Conservation Plan and has established a robust listed shorebird monitoring program for piping plovers and least terns.

The DBR Endangered Species Program involves employing hiring shorebird technicians, shorebird monitors to oversee nesting sites, implementing protective measures, and ensuring compliance with the federal and state Endangered Species Acts.

In addition, each year Duxbury Beach Reservation (DBR) collaborates with numerous environmental organizations to conduct scientific research on the beach. This collaboration expands the depth of Duxbury Beach Reservation's reach.

3. **Community Involvement:** Volunteers play a significant role in data collection and conservation activities. Programs include invasive species removal program, planting events, saltmarsh surveying and horseshoe crab population sampling to list a few.

Community support and involvement in conservation efforts help maintain and improve the health of local ecosystems.

Environmental Changes

1. **Climate Resiliency Initiatives:** Starting in 2018, Duxbury Beach Reservation has taken a proactive approach to coastal resiliency planning and execution on Duxbury Beach. In 2021, DBR submitted an extensive permit filing initiative to ensure that when materials or funding was available, DBR would have the permits in hand to immediately begin work.

Efforts to mitigate the effects of climate change, such as sea level rise and increased storm frequency, contribute to the stability of local wildlife populations.

2. **Improved Water Quality:** Efforts underway to improve water quality in Duxbury Bay, such as understanding man made sources of nitrogen runoff in Duxbury Bay, ensuring septic systems are in good operating conditions all contribute to water quality in Duxbury Bay.

Better water quality supports a diverse range of species and contributes to the overall health of the ecosystem.

Regulatory and Policy Measures

1. **There are a host of laws and agencies that protect wetlands, habitats and species.**
 - Mass Wildlife (MA Wetland Protection Act and MA Endangered Species Act)
 - US Fish and Wildlife (US Endangered Species Act)
2. Town of Duxbury Conservation Commission (Wetlands Protection Act and the Town's Wetlands Bylaws) which aims to protect wetlands, related water resources, and adjoining land areas. The Town's bylaw helps regulate activities that could have adverse effects on these critical habitats, ensuring their preservation for future generations.
3. **Habitat Conservation Plans:** The DBR's participation in the statewide Habitat Conservation Plan for Piping Plovers provides legal flexibility in managing these birds while balancing recreational access. The plan aids to protect listed species while allowing for sustainable human activities.

Overall, the combination of dedicated conservation efforts, community involvement, proactive environmental management, and supportive regulatory measures has contributed to the positive trends observed in the data for piping plovers, least terns, and horseshoe crabs in Duxbury Bay.

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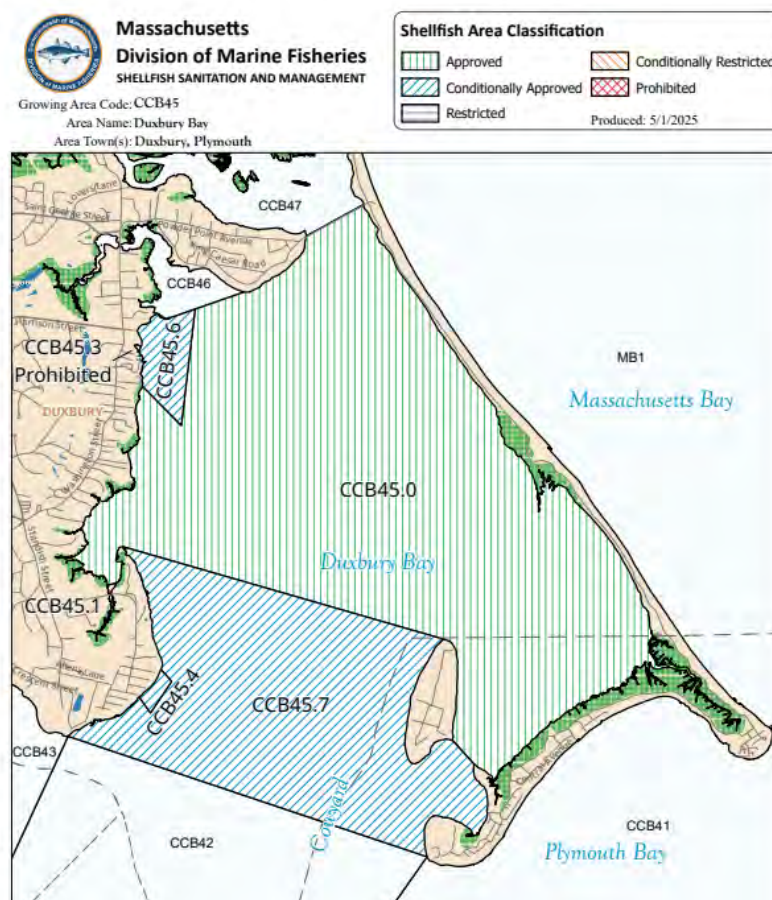
6. Recreational and Commercial Shellfish Activity in Duxbury Bay



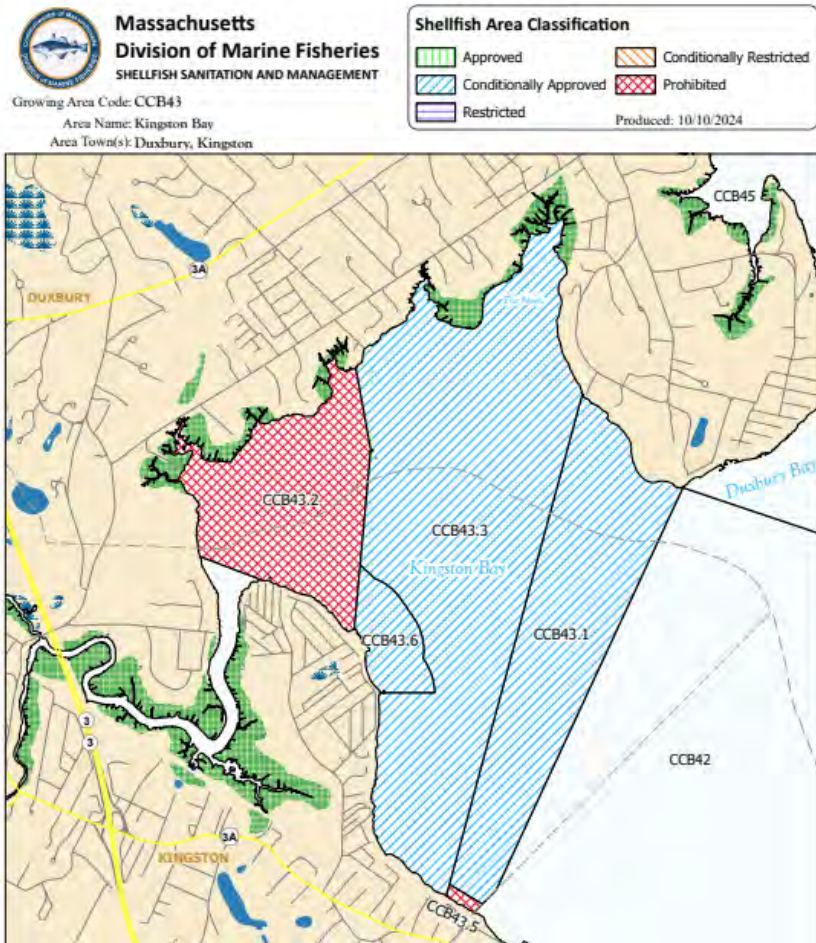
Recreational Shellfish Activity

Since 2009, recreational shellfish harvesting in Duxbury Bay has remained a popular activity among residents and visitors. The bay's productive shellfish beds support a variety of species, including soft-shell clams and quahogs. The Duxbury Harbormaster Department issues recreational shellfish permits annually, and the number of permits issued has seen a steady increase over the years, reflecting the growing interest in this activity.

Recreational shellfish activity is regulated by the Department of Marine Fisheries who routinely monitors for bacterial contamination. This has led to the establishment of five categories of approval including: approved, conditionally approved, restricted, conditionally restricted, and prohibited. Following is the current map of Duxbury and Kingston Bay.



<https://www.massmarinesfisheries.net/shellfish/dsga/CCB45.pdf>



<https://www.massmarinefisheries.net/shellfish/dsga/CCB43.pdf>

Commercial Shellfish Activity

Duxbury supports three types of commercial shellfish licenses: Mussel, Razor Clam, and Commercial Combination. The mussel and razor clam licenses are both limited-entry and non-transferable, intended to conserve the resource by restricting the number of active harvesters rather than imposing catch limits. When one of these licenses is retired, it is reassigned to the next person on a waiting list. In contrast, the Commercial Combination license is open to all Duxbury residents, with conservation achieved through seasonal restrictions and bag limits.

There are 10 mussel licenses in total. The mussel resource has been in serious decline since the 1990s for reasons that remain unclear—potentially related to cyclical patterns, environmental conditions, or disease. Most license holders continue to renew annually in the hope that the fishery will rebound. The license currently costs \$160 per year.

The razor clam fishery currently allows 15 licenses. Landings have declined significantly from their peaks in the 1990s and 2000s, which could reflect a diminished resource, weaker markets, or simply the fact that many long-time fishermen have retired or shifted their focus to aquaculture. These licenses are seldom relinquished and cost \$295 annually, at present.

The Commercial Combination license, which currently costs \$240 per year, allows the harvest of seaworms, eels, and various shellfish species during special “bonus” seasons approved by the Shellfish Constable, Shellfish Advisory Committee, and Select Board. The number of these licenses fluctuates each year depending on interest and the abundance of local shellfish, particularly hard-shell and soft-shell clams.

Historically, Duxbury supported a productive commercial shellfish industry harvesting quahogs, razor clams, mussels and soft-shell clams. However, since around 2010, total commercial landings have declined by roughly 75% from the 2011–2012 peak. This decline is not believed to indicate habitat degradation, with one notable exception below, but rather a shift in effort—many former shellfish harvesters now focus on the more profitable and stable oyster aquaculture industry. (The Division of Marine Fisheries records zero harvest in years when fewer than three permit holders report landings).

The notable exception is the significant decline in the mussel population which is not isolated to Duxbury Bay. It is estimated that there has been a nearly 60% decline in blue mussel population over the past 40 years in the intertidal zone from Cape Cod north to the Canadian border.⁴ There is a strong correlation between this drop and water temperature rise and a recent paper estimates a roughly tenfold decrease in mussel recruitment for each half-degree Celsius rise in August water temperature.⁵

Over the past decade, oyster harvests in Duxbury Bay have far exceeded those of all other shellfish combined, and the oyster industry is discussed separately later in this report.

⁴ Sorte, et al. *Glob Change Biol*, 23: 341-352. <https://doi.org/10.1111/gcb.13425>

⁵ O'Brien, et al *PLoS One*. 2025 Sep 9;20(9):e0324387. doi: [10.1371/journal.pone.0324387](https://doi.org/10.1371/journal.pone.0324387)

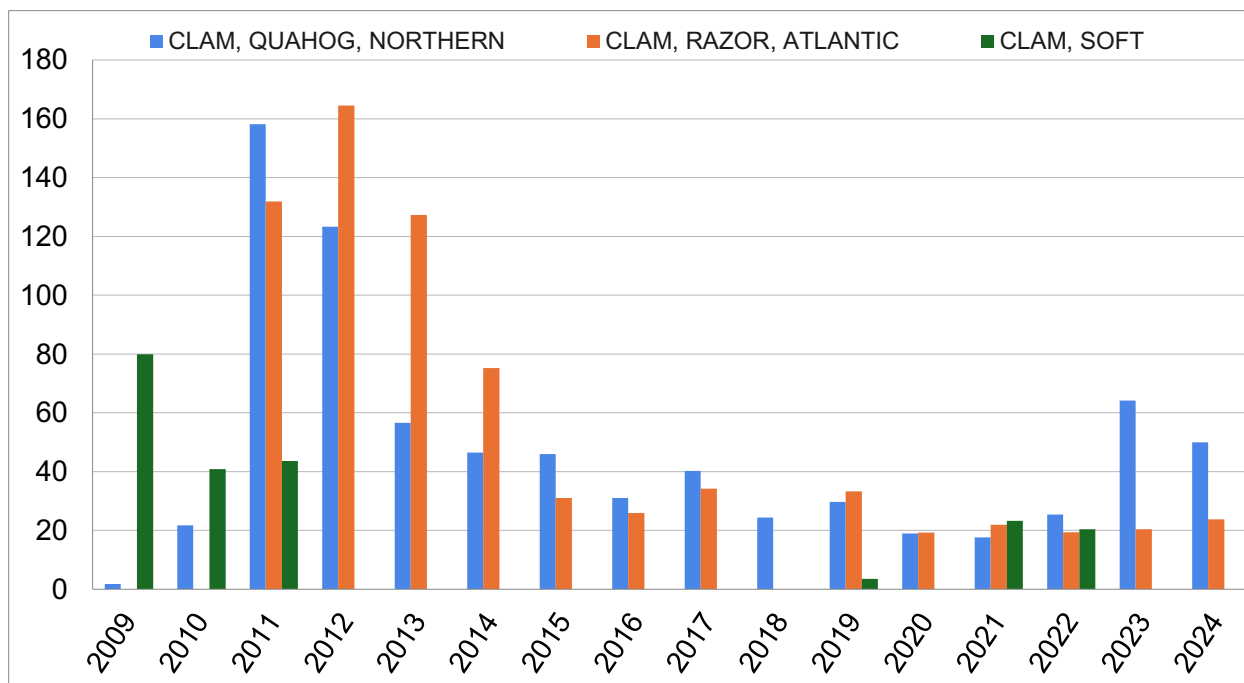


Figure 1 Shellfish Landings in Duxbury Bay (excl oysters). Numbers are in pounds

Source: Erich Druskat Mass Div of Marine Fisheries

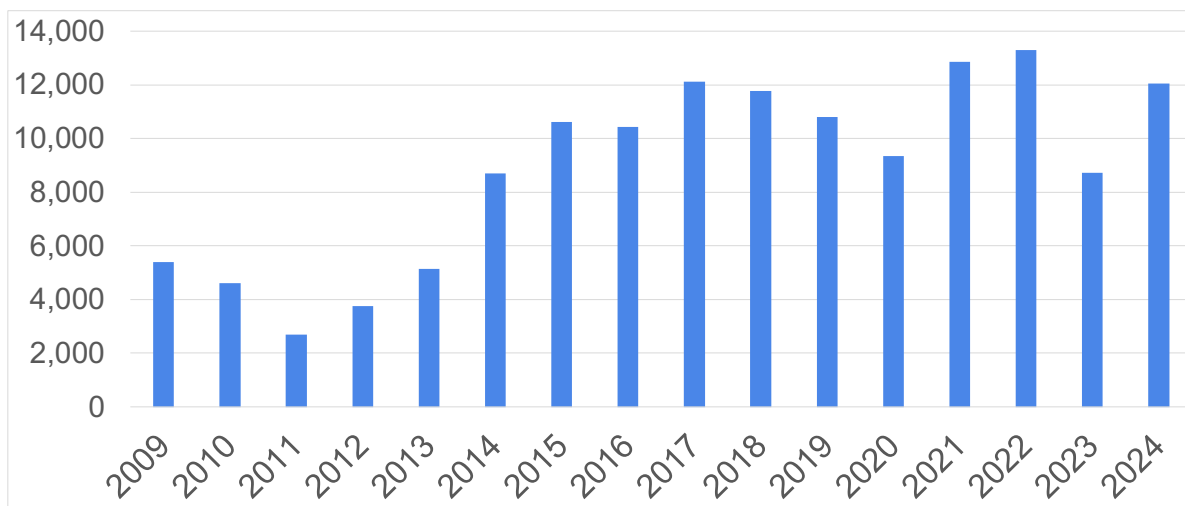


Figure 2 Oyster Harvests in Duxbury Bay. Numbers are in thousands of pieces.

Source: Erich Druskat Mass Div of Marine Fisheries

Table 1 Commercial Shellfish harvests in Duxbury Bay. Numbers are in pounds except as noted. Source: Erich Druskat Mass Div of Marine Fisheries

	CLAM, QUAHOG, NORTHERN	CLAM, RAZOR, ATLANTIC	CLAM, SOFT	OYSTER, EASTERN (PIECES)
2009	2	0	80	5,390
2010	22	0	41	4,611
2011	158	132	44	2,698
2012	123	165	0	3,760
2013	57	127	0	5,131
2014	46	75	0	8,691
2015	46	31	0	10,620
2016	31	26	0	10,438
2017	40	34	0	12,118
2018	24	0	0	11,775
2019	30	33	4	10,797
2020	19	19	0	9,337
2021	18	22	23	12,853
2022	25	19	20	13,291
2023	64	20	0	8,723
2024	50	24	0	12,055

7. Invasive Species



Photo (Patriot Ledger)

Introduction – Invasive Species

Duxbury Bay has experienced a dramatic increase in invasive marine species—most notably the European green crab and a variety of tunicates- since monitoring began. These species, introduced primarily via ballast-water discharge and hull fouling from international vessels, threaten native ecosystems, local fisheries, and aquaculture operations.

European green crabs reproduce rapidly and have few native predators. They have negatively impacted eelgrass beds and prey on juvenile shellfish, undermining both wild and farmed stocks.

A variety of Tunicates have developed dense fouling layers on docks and gear, smothering native invertebrates and increasing maintenance costs.

Since 2006, the Massachusetts Office of Coastal Zone Management (CZM) has trained volunteers to survey over 140 sites, including Duxbury Harbor, for both established invaders and potential newcomers. Citizen-science data have improved early detection and informed local rapid-response actions.

Numerous mitigation strategies have been developed, including:

1. Ballast-water management: Implementation of the IMO Ballast Water Management Convention (2004) and U.S. Coast Guard rules has significantly reduced new introductions when strictly enforced (IMO Ballast Water Management Convention, 2004).
2. Hull-fouling prevention: Regular hull cleaning and anti-fouling coatings—proven effective in jurisdictions with rigorous oversight—help limit species transport (California State Lands Commission).
3. Volunteer monitoring: CZM’s Marine Invader Monitoring and Information Collaborative enhances detection response times but does not prevent initial introductions (Massachusetts CZM).

Complete eradication of established populations is rarely feasible; control measures (e.g., trapping, manual removal) are labor-intensive and offer only local relief. Moreover, climate-driven warming increases the likelihood that invasives already present in the Gulf of Maine will ultimately arrive and colonize in Duxbury Bay.

Recommendations

1. Integrated management: Encourage strict ballast and hull-fouling enforcement.

2. Habitat restoration: Invest in eelgrass bed and oyster-reef projects to bolster ecosystem resilience.

3. Adaptive practices: Encourage aquaculture methods and infrastructure designs that anticipate shifting species distributions and environmental conditions.

Overview

Invasive species are organisms introduced to a new location by human activity that often become dominant because they have no natural predators. As a consequence, they can cause harm to the environment, economy, or public health. They are primarily attributed to ballast water discharges or hull scrapings from vessels traveling to the US from abroad. The history of invasives in New England dates back centuries but the volume and numbers of invasive marine species are steadily increasing due to increased marine traffic and also warming waters.

More than 60 invasive species have been documented in the coastal waters of New England, though this is likely an underestimate. Notable invasives that are being observed in Duxbury Bay include:

- European Green Crab (*Carcinus maenas*): Introduced in the 19th century, this species has caused significant harm to shellfish populations and eelgrass beds³. Green crabs have been observed by shell fishermen and are known to feed on young oysters. Their presence poses a threat to both natural and cultivated shellfish populations. Green crabs can multiply rapidly due to the absence of natural predators, making them a significant concern for the local ecosystem.
- Asian Shore Crab (*Hemigrapsus sanguineus*): First documented in the 1980s, it competes with native crabs for habitat and food³.
- Tunicates: Various species have colonized docks and aquaculture equipment, threatening native ecosystems⁴. They are concerning because they can cover the bay bottom and harm both natural and cultivated shellfish and eelgrass. These include
 - *Ascidella aspersa* and *Palaemon elegans*, also called sea-squirts;
 - *Botrylloides violaceus*, also called chain tunicate;
 - *Botryllus schlosseri*, also called the star tunicate; Note- there are native forms of this tunicate and distinguishing them requires genetic analysis which has not been performed.
 - *Didemnum vexillum*, also called pancake batter tunicate;
 - *Diplosoma listerianum*, gray encrusting compound tunicate
- Bryozoa
 - *Bugula*: This is a stationary marine animal that is normally found in temperate and tropical waters but has recently been observed in Duxbury. It

can form dense mats on hard substrates including docks and aquaculture gear.

- Membranipora membranacea, also called coffin box: is a type of bryzoan: simple, invertebrates characterized by a thin, mat-like encrustation.
- Tricellaria inopinata, these form erect, bushy, branched colonies which are cream-to-buff in color and attached to hard substrates by rhizoids
- Caprella Mutica, known as Japanese skeleton shrimp,
- Palaemon elegans, also called rock pool shrimp, is native to the eastern north atlantic but considered invasive in our waters.

Since 2006, the Mass office of Coastal Zone Management [Link](#) has been training volunteers to monitor for marine invasive species at more than 140 sites in New England, including Duxbury.

Citizen scientists look for established marine invasive species and potential invaders (species that may be introduced to our region but have not yet been observed). Types of species monitored include seaweeds, filter-feeding organisms such as bryozoans and tunicates, crustaceans, and other organisms including anemones and shellfish

Below is a summary of observed invasives at the Duxbury Harbormaster's dock.

<i>MEDIAN of name</i>	<i>year</i>													
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2023	2024
<i>Ascidella aspersa</i>						4	2.5	3	2	4				2
<i>Botrylloides violaceus</i>	1	3	2	2	4	1	2.5	2.5	4	4	3.5	3	1	2
<i>Botryllus schlosseri</i>	1	2.5		4	2	3	1.5	2.5	3	4	3.5	3	4	4
<i>Bugula neritina</i>													4	
<i>Caprella mutica</i>				3	3.5	2		3	2	2.5	2	2	4	4
<i>Carcinus maenas</i>													3.5	4
<i>Didemnum vexillum</i>		4	2	2	2					4	2.5		4	1
<i>Diplosoma listerianum</i>													2	3
<i>Hemigrapsus sanguineus</i>						1							4	4
<i>Membranipora membranacea</i>													4	
<i>Palaemon elegans</i>													2.5	2.5
<i>Styela clava</i>	1	2.5	3	1	3.5	1				3	2	4	4	2.5
<i>Tricellaria inopinata</i>													3	3

Invasives monitoring at Duxbury Harbor. Values are median scores.

1=rare, 2=few, 3=common, 4=abundant

Note: No monitoring was performed during the Covid 19 pandemic.

Evidence regarding the effectiveness of mitigation strategies to reduce marine invasive species is mixed and context-dependent:

Effectiveness of Mitigation Strategies:

- **Ballast Water Management:**

Strategies like ballast water exchange at sea or treatment systems have reduced new introductions significantly. The IMO Ballast Water Management Convention (2004) and U.S. Coast Guard regulations have demonstrated measurable success in reducing new invasions when rigorously enforced.

Source: IMO Ballast Water Management

- **Hull Fouling Prevention:**

Regular hull cleaning and anti-fouling coatings have been effective in reducing invasive species transported via hull fouling, notably in areas with strict enforcement (e.g., Australia and New Zealand).

Source: California State Lands Commission

- **Community and Citizen Monitoring:**

Volunteer monitoring programs have enhanced early detection and rapid response capabilities, often helping to manage and reduce impacts effectively, though they do not prevent introductions.

Source: Massachusetts Coastal Zone Management

Eradication of already established marine invasive species is rarely successful, and ongoing control efforts are often costly and labor-intensive. Given the inevitability of some invasions and ongoing environmental changes (warming seas, sea-level rise), adaptation strategies become essential:

- **Ecosystem Resilience:**

Strengthening native species resilience through habitat restoration (like eelgrass beds or oyster reefs) can mitigate invasive impacts indirectly.

- **Adaptive Aquaculture and Fisheries Management:**

Adjusting aquaculture practices to cultivate species resilient to invasives or climate impacts (warmer waters, changing salinity) helps maintain economic stability.

- **Flexible Infrastructure:**

Developing marine infrastructure adaptable to sea-level rise, increased storm frequency, and shifting species distribution can minimize economic disruptions.

It is increasingly evident that the volume and diversity of invasive species are both increasing in Duxbury Bay since monitoring efforts have begun.

European green crabs have become especially common in Duxbury Bay since 2009 and may be adversely impacting eelgrass as well as nurseries for fish and invertebrates. They also prey heavily on juvenile bivalves, threatening both wild and cultured shellfish stocks.

Colonial tunicates have formed extensive fouling layers on docks, aquaculture gear, and natural substrates. These mats smother native sessile organisms, reduce biodiversity, and increase maintenance costs for shellfish growers.

This trend is fueled by two primary trends:

- discharge of ballast water and hull fouling from international shipping transports, despite the introduction of the IMO Ballast Water Management Convention (2004) and regional biofouling guidelines.
- warming sea temperatures, especially in the Gulf of Maine region

Preventive measures have yielded mixed results. Rigorous ballast water treatment and hull-cleaning protocols have probably reduced the rate of new introductions. However, once established, invasive populations are difficult to eradicate. Control efforts—such as trapping green crabs or manual removal of tunicate colonies—are labor-intensive and often only locally effective.

Citizen science initiatives, notably the Marine Invader Monitoring and Information Collaborative (MIMIC) led by Mass. CZM, have strengthened early detection and rapid response capacities. Volunteers monitoring Duxbury Harbor and nearby sites provide valuable occurrence data. Yet these programs cannot prevent initial introductions and must be paired with strong biosecurity measures.

Conclusions and Recommendations

An integrated management strategy is essential. Continued enforcement of ballast water and biofouling regulations must be coupled with targeted control of established populations. Enhancing habitat resilience—through eelgrass and oyster reef restoration—can mitigate invasive impacts. Finally, sustained volunteer monitoring and genetic studies to distinguish native from invasive tunicates will inform adaptive management in Duxbury Bay.

In conclusion, while preventive measures have shown some success, it is critical to balance these with adaptation-focused strategies. The complexity of marine ecosystems and ongoing climatic changes strongly suggests that a combination of mitigation, adaptive management, and increased ecological resilience will offer the best pathway forward.

8. Recreational and Boating Activity



Introduction

Duxbury is known for its vibrant boating community. Since 2009 there have been changes in recreational activity on the Bay, influenced by factors such as population growth, increased interest, infrastructure improvements, and environmental regulations. This summary provides an overview of these changes.

Changes in Recreational & Boating Activity

1. Increase in Population & Visits

- Over the past two decades, Duxbury has experienced close to a 15% expansion in population as well as growing tourism. The town's scenic coastline, access to Cape Cod Bay, well-maintained facilities, and new points-of-destination have attracted increased activity along its waterfront and beaches. In 2016 Duxbury was highlighted in *Vogue* as "New England's Best-Kept Secret".

2. Increased Interest in the Bay

- The Duxbury Bay Maritime School promotes recreational activities by offering various programs and events that both educate and encourage community interaction with the Bay.
 1. In addition to power boating and sailing instruction, DBMS has successfully launched an outstanding high school and adult rowing program.
 2. There has been a 40% increase in participants in DBMS programming since 2010, and a remarkable 400% increase since 2000 (over 2,500 individual participants in 2014 vs 600 in 200).
- Since 2009, Bayside Marine mooring service is stable and the numbers served have increased very little, but the marina has had to establish a waitlist for their in/out service for the first time.
- Likewise, the Harbormaster reports the waitlist for deep water moorings has grown to nearly 700 names in 2025, and the basin flats now have a waitlist half that size.
- While the Bay continues to see windsurfing and kayaking, its protected waters and potential for gusting wind have similarly attracted pursuits of newer sports such as kite surfing and foiling.

3. Infrastructure Improvements

- Since 2009, the town has invested in improving boating infrastructure, including the expansion of boat ramps, docks, and re-configuring the mooring field.

- In 2009, the town issued approximately 1,200 mooring permits. By 2025, this number had risen to over 1,500 permits
- Since 2009 Bayside Marine has been able to slightly increase its rack capacity from 145 to 180 boats.
- DBMS has overseen the construction of a new boathouse for their racing shells, as well as an indoor rowing tank, which has allowed their high school program to shift its focus from Plymouth to Duxbury Bay.

4. Environmental Regulations

- The Town of Duxbury has established specific regulations for mooring permits to ensure fair allocation and environmental protection. These regulations include requirements for annual inspections, proper mooring equipment, and adherence to designated mooring areas. The waiting list for permits prioritizes residents and long-term applicants
- In order to protect Duxbury Bay's delicate ecosystem, the rise recreational activity has necessitated enhanced management efforts to mitigate potential environmental impact and impact upon native species.
- Regulations include measures to reduce pollution from boating activities and protect eelgrass beds and other sensitive habitats.
- The town has also promoted eco-friendly boating practices, such as proper waste disposal.

Conclusion

Since 2009, recreational and boating activity on Duxbury Bay has experienced significant growth, driven by increased popularity and infrastructure improvements.

The town's commitment to maintain recreational use while ensuring environmental protection will be essential for the sustainable future of the Bay.

9. Aquaculture

9.1 Oyster Industry



Aquaculture – Duxbury Oysters - Introduction/Background

Shellfish aquaculture has been a part of Duxbury's history for more than a century. Early aquaculture was often referred to as "grants", as individuals and businesses were granted the exclusive rights to certain parts of the bay. These grants were issued in areas that were void of natural shellfish and primarily used for storing shellfish harvested in the wild, for favorable market conditions. In the early 1900's there was a large grant given on the east side of the bay for the transfer and grow-out of Chesapeake Bay oysters; however, that plan was abandoned after a severe winter storm.

Today's shellfish aquaculture industry began in the late 70's into the early 80's. With the advent of a local, commercial shellfish hatchery, a small shellfish aquaculture industry had been established in Wellfleet and several Duxbury residents wanted to give it a try here in Duxbury. The Duxbury Shellfish advisory committee, along with the Duxbury harbormaster/shellfish department researched local municipal aquaculture programs and designed the regulations that were adopted by the State and that are remain largely what we have today. Several licenses were issued in the early 80's but failed as the industry was new and there was little experience and knowledge and as a result these early efforts were not sustained. Under the regulations, it is important to note that today's oyster farms are not grants or leases, they are licenses that give the license holder the exclusive right to the shellfish on that site, and allow the permit holder to possess seed (juvenile shellfish) and to conduct very specific farming activities as outlined in State regulations.

In 1991 the first license was issued for a three-acre farm in Duxbury Bay to grow quahogs. In 1995 the farm was devastated by a protozoan parasite that is common in area with an established population of wild quahogs. In an attempt to get through this unfortunate event, the farmer was permitted to purchase seed oysters from a hatchery in Maine, and so began the industry we have today. In the few years that followed, a several more licenses were permitted and those farmers pioneered the oyster industry in Duxbury. By the mid 2000's there was a growing interest in shellfish farming in Duxbury, and the Board of Selectmen received many additional applicants that wanted to be a part of this new industry.

In 2024, as advised by the Town of Duxbury Bay Management Commission, the Selectboard recognized that the number of licenses had reached a level where there were significant impacts and potential users of Duxbury Bay conflicting priorities and resource

pressure, but transitioned from a moratorium to a limited entry program as defined by MA DMF regulations.

Current state of shellfish aquaculture in Duxbury

Today there are 30 farms that occupy 82 of the roughly 10,000 acres of tidal flats in Duxbury. The crops are primarily oysters but recently there has been some promising success in growing hard-shell clams or quahogs (*m.mercenaria*) and some advances in growing bay scallops (*argopecten irradians*) and surf/sea clams (*spisula solidissima*). Many of the original license holders are still active on those license sites today while some of those licenses have been transferred to new farmers.

Harvested number of oysters fluctuates based on the success of crops from year to year, market conditions and most recently, COVID. Below is the most recent data from the Harbormaster Department. Of note, it is difficult to get numbers on other species as they are lumped together with wild harvest and as a result of confidentiality, if only one grower is growing a specific species. While reporting to the State is required, getting that data is very difficult.

<u>Year</u>	<u>Seed purchase request</u>	<u>Harvest amount</u>
2020	66,500,000	N/A
2021	68,900,000	12,852,525
2022	70,220,000	13,291,493
2023	64,170,000	8,722,981
2024	70,595,000	12,054,693

Regulations and Management

Duxbury's regulations pertaining to shellfish aquaculture represent hundreds of hours of work by the Shellfish Advisory Committee, The Bay Management Commission, The Harbormaster Department, the industry, the Board of Selectmen and residents of Duxbury. Today's regulations are a product of decades of evolution - having been debated and altered over the years. In 1991, the maximum acreage was changed from 1 acre to 3 as it became apparent that one acre was not sufficient for a shellfish aquaculture license holder to be economically viable. Shortly after, mechanical harvest was included in the regulations as a means of dragging oysters from a boat.

Transfer of permits on a private basis has been debated at both Shellfish Advisory and Bay

Management Commission, ultimately being deemed as the best way for a farmer to move on from an active license and allowing that farmer to sell the shellfish on the license site as well as any gear that belongs to the farm. It's also worth noting that most municipalities in the Commonwealth, that have aquaculture programs, have used Duxbury's aquaculture program as a template for their own.

Duxbury's shellfish aquaculture rules and regulations are a product of the framework found in the Massachusetts general laws Chapter 130, Section 57. Ultimately the tidelands in Duxbury Bay belong to the Commonwealth of Massachusetts or private upland land owners.

Regulatory costs and complexity have increased meaningfully over the past 20 years, largely due to food safety and public health concerns. Beginning around 2012 the US FDA began imposing new regulations on oyster farmers to minimize the risk of illness from eating oysters. The primary changes from these regulations was to ensure that harvested oysters spent a minimum amount of time in warmer environments, and to provide traceability and record keeping as part of the FDA food safety.

These regulations were considered beneficial to ensure that oysters were in good condition when delivered to market, but also added to the cost and complexity of oyster farming operations. In addition, these new regulations made it more difficult and expensive for growers to become wholesale dealers of shellfish, forcing most farms to sell to a small number of certified dealers also reducing the opportunity for potentially higher revenue distribution alternatives for Duxbury's oyster farmers.

To manage the increasing interest in shellfish aquaculture the Duxbury Shellfish Advisory Committee together with the Duxbury Bay Management Commission (DBMC) have developed and implemented an Aquaculture Management Plan. [Link](#) This plan improves the sustainability of the resource as a result of the following guidelines:

- **Moratorium and adaptive leasing**

The plan proposed a moratorium on new leases while a science-based review is completed. It limits each lease to a maximum of 3 acres and requires renewal (up to 10 years) only for operations demonstrating "good aquaculture practices and a viable business" on a farm-by-farm basis. This moratorium was recently rescinded and the Duxbury selectboard approved a transition to a limited entry program as defined by MA DMF regulations.

- **Stakeholder engagement and governance**

An ad hoc committee—comprising members of the Bay Management Commission, Shellfish Advisory Committee, Growers Association, and

Agriculture Commission—works jointly with state associations (e.g., Mass. DMF, NOAA) to assess ecological impacts and carrying capacity before any new leases are considered town.duxbury.ma.us.

- **Controlled footprint and site guidelines**

By capping total leased area at roughly 1.27 % of the bay and providing clear site-selection criteria (e.g., avoiding eelgrass beds, marking gear uniformly), the plan aims to balance aquaculture with other uses like navigation, recreation, and wild shellfish harvests

- **Environmental monitoring**

Growers participate in water-quality monitoring through SEMAC and the Jones River Marine Ecology Center. Recent grants fund permanent in-bay sensors for disease forecasting and ecosystem health assessments, feeding data back into lease-allocation and management decisions

- **Local stewardship and economic vitality**

Requiring all leaseholders to be town residents ensures that economic benefit like employment and local spending stay within the community and foster a culture of stewardship.

- **Limited Entry Fishery**

In 2024, the Duxbury Bay Management Commission recommended to the Duxbury Selectboard to end the moratorium on new oyster leases, and transition to a limited entry fishery, which the Duxbury Selectboard voted to implement.

Benefits of the Oyster industry to Duxbury

With the growth of a commercial aquaculture industry in Duxbury over the last thirty years, there have been some increased conflicts over resource use, in particular such as the limited water access and space at Mattakeesett Court town landing. The following is an overview of the benefits, or the positive impacts that the industry has on our town and the overall health of Duxbury Bay

Economic benefits

Shellfish aquaculture has a relatively high economic multiplier, meaning that dollars earned in the industry ripple through our local economy at a relatively high rate in comparison to other industries - most likely due to the requirement that any license holder who operates a shellfish operation in Duxbury, must be a Duxbury resident. As a result, the aquaculture industry revenue has a positive impact on our local economy, supporting restaurants, stores, boat yards, coffee shops, etc. Aquaculture is the largest industry in Duxbury, supporting hundreds of jobs.

Another economic benefit is associated with the dollar value of the landings. When the Town is applying for state and Federal grants for things such as dredging of the harbor, improvements to the waterfront and town sewage projects, these grants are often prioritized for communities with significant commercial shellfish landings – which increases the priority for state and federal grants which impact Duxbury Bay.

The oyster industry also supports various local businesses, including equipment suppliers, processing facilities, and transportation services. This creates a ripple effect, boosting the overall economic activity in the region.

Duxbury Oyster industry has increased tourism in Duxbury, and the “branding” of Duxbury regionally and nationally. Duxbury oysters have gained a reputation for their quality, attracting tourists and seafood enthusiasts to the area. This has helped promote Duxbury as a destination for culinary tourism, further enhancing the local economy

The growth of the oyster industry in Duxbury has a substantial positive impact on the local economy, providing employment, and supporting various related businesses. The continued success of this industry is impactful for the economic well-being of the community. Relatedly, the health of the recreational shellfish activities in Duxbury Bay and continued efforts to protect and enhance the bay's natural resources are essential to maintaining the reputation for future generations.

Environmental Benefits

There are significant environmental benefits from shellfish aquaculture, perhaps the most important being the ability of shellfish to remove excessive nutrients, largely nitrogen, from the bay. Nutrient levels continue to rise in Duxbury Bay from sources such as septic systems and fertilizers. Excess nutrients in the water has a very negative impact on the Duxbury Bay ecosystem and is a primary threat to Duxbury Bay in the future. Excessive nutrients from septic system and fertilizer runoff, can result in excessive algal blooms which lead to hypoxia (low oxygen) or anoxia (no oxygen) which can kill marine life, loss of biodiversity, loss of sea grasses – including eel grass which has evidenced a significant die off in Duxbury Bay in the past 25 years, which further depletes dissolved oxygen.

NOAA published in the fall of 2024; a peer review Nitrogen remediation “calculator” that calculates the amount of Nitrogen removed from aquaculture farming in Duxbury Bay. Using the latest harvest figures from 2024, 12,054,693 Oysters were harvested, with an average size of just under 3”. Using the NOAA calculator , <https://www.fisheries.noaa.gov/resource/tool-app/aquaculture-nutrient-removal->

[calculator](#), 3,750 lbs. of Nitrogen removal. According to the Buzzards Bay National Estuary Program, the average septic system contribution per capita per year to Nitrogen pollution of bays and estuaries is 5.95 lbs. per person.

The oyster industry in Duxbury removed the amount of nitrogen equivalent to annual contribution from 625 Duxbury residents through their septic systems, or roughly offset 5% of nitrogen pollution from the population of Duxbury.

Shellfish also sequester carbon to build their shells, helping to remove carbon from the atmosphere and locking it up for as long as the shell remains intact - potentially for hundreds or even thousands of years, offsetting some of the negative effects of climate change.

Farming shellfish increases biodiversity. The Nature Conservancy has done extensive research on this in Duxbury Bay and found that shellfish gear creates habitat, sort of an artificial reef, which supports a diverse community of organisms such as small fish, crabs, shrimp and invertebrates. These organisms become part of the food chain to support diverse life such as larger fish and crustaceans as well as birds.

Water Quality Impact from Duxbury Oysters – Summary

Together, harvest and microbial processing improve water clarity and lower summertime chlorophyll and dissolved inorganic nitrogen levels. In Duxbury Bay, the recent surge in oyster aquaculture likely contributes appreciably to counteracting nutrient inputs from runoff and wastewater.

Trends and Challenges

Duxbury Bay's shellfish industry has undergone much growth, with oyster aquaculture expanding to dozens of licensed sites. In parallel, the Town of Duxbury, DBMC and others have enacted a data-driven stewardship plan—upgrading stormwater infrastructure, managing runoff, restoring the historic herring run, and conducting regular water-quality monitoring—to safeguard ecosystem health. Yet this progress is threatened by the rapid proliferation of invasive species, notably the European green crab, whose booming populations—fueled by warming coastal waters—pose a serious risk to native shellfish beds throughout the bay

- **Growth in Aquaculture:** The industry's expansion has had a positive impact on the local economy and provides employment opportunities. The success of Duxbury oysters has also enhanced the bay's reputation as a prime location for shellfish aquaculture.

- **Environmental Stewardship:** Ongoing efforts from the Duxbury Bay Management Commission and others in the community to monitor water quality and restore habitats include storm drain systems, proactive runoff management, and restoration of the historic herring run.
- **Invasive species:** Counterbalancing these initiatives, the rapid rise of numbers and types of invasive species poses a significant threat to the shellfish habitat and to the shellfish themselves.

Changing Environment

In 2009 Duxbury experienced a massive and devastating outbreak of a ubiquitous oyster disease commonly referred to as MSX (*Haplosporidium nelsoni*). This disease has been a problem for the Atlantic oyster population since the 1950's. It took nearly 15 years for it to become a problem in Duxbury and continues to cause mortalities to the farmed oyster populations today although at a much lower level than in 2009.

MSX is not unique to this region; it exists on the East Coast of the US in all areas that have an established population of oysters. Another common oyster disease, most often referred to as Dermo (*Perkinsus marinus*), is also present in oysters in Duxbury Bay. Dermo has yet to cause significant mortalities of growing oysters here in Duxbury. There are several other pathogens that exist at background levels that could impact the health of oysters in Duxbury.

While not really a disease, mud blisters (*Polydora* spp) burrow into the oyster's shell and degrade the quality of the oysters and stress the animals making them more susceptible to other pathogens. Mud blisters have been especially bad in the past few years – it is too soon to tell if this increase in mud blisters is a trend or a recent episodic event.

Other significant environmental challenges include fouling from macroalgae and tunicates. The proliferation of macroalgae is most likely symptomatic of eutrophication caused from the enrichment of nutrients in Duxbury Bay. These organisms can suffocate juvenile as well as adult oysters which has led to oyster mortalities and more labor costs required for an oyster to grow to market size. Macro algae attaches to juvenile oysters and acts as a sail, carrying the oysters away with the current. Tunicates are often described as sea squirts, they're an invasive marine invertebrate which colonize on juvenile oysters, once again causing oyster mortalities and or reduced growth rates, and more labor costs per oyster.

Juvenile oysters have become more challenging to grow in recent years in Duxbury Bay.

There is not yet a consensus for the underlying cause of these challenges, but theories that range from episodic periods of low dissolved oxygen to toxic algae blooms or a change in the constitution of microalgae and bacteria – more discussion of this issue, and some recommended future research recommendations is contained in the Water Quality section of this report.

Periodic shell harvesting or redistribution can help maintain sediment health and optimize both production and water-quality goals.

Lastly, weather conditions are a constant challenge. A significant percent of oysters perish during the fall or winter due to silt moving around in heavy wind and during winter months ice picking up the oysters, depositing them away from the licensed site.

Financial challenges

One of the biggest challenges facing the aquaculture industry today is the relative lack of change in the price of oysters in spite of the increased in popularity and demand for oysters. In the thirty years that the oyster industry has existed in Duxbury, the average price paid to oyster farmers has essentially remained the same, while adjusted for inflation, that price should be more than double. Even though demand has increased, supply has grown in a way that has kept pace or even exceeded the growth in demand, resulting in a decrease in pricing that is very significant on an inflation adjusted basis. The lack of ability for oyster farmers to pass along increased costs to the distributors, restaurants, and ultimately the consumers of oysters, is a significant threat to the future of the industry here in Duxbury.

Recommendations

- Education on the benefits of the industry. A one-sheet that could be circulated to the Board of Selectmen, DBMC, Shellfish Advisory and anyone interested in learning about the industry. Perhaps a presentation by outside experts such as WHOI and/or Sea Grant.
- DBMC and Shellfish Advisory discuss potential for more bioremediation through new farms, a town led shellfish propagation program and oyster reef building.
- Support ongoing water quality monitoring program and consider expansion of the testing to include potential changing biology of Duxbury Bay (see Water Quality Section of this report)
- Utilize the Duxbury Bay Management Commission as a resource to minimize user conflicts

By coupling ongoing rigorous environmental monitoring with stakeholder governance and local-resident lease requirements, Duxbury's model for the Oyster Industry offers a template for harnessing economic gains while safeguarding bay health.

9.2 Aquaculture -New developments/opportunities



Overview

Kelp farming is an emerging activity in Duxbury Bay, adding to the diversity of aquaculture practices in the area. Kelp farming offers numerous environmental benefits, including nutrient removal, habitat creation, and carbon sequestration. The cultivation of kelp, particularly sugar kelp (*Saccharina latissima*), occurs in the winter because the species thrives in cold water. Kelp aquaculture has gained interest due to its potential for sustainable production and positive ecological impact.

Recent Developments

In recent years, there have been efforts to establish kelp farming aquaculture in Duxbury Bay. At this time, one permitted kelp farm operates in Duxbury Bay on a 10-acre section using a novel approach to aquaculture designed to minimize impact on marine life, including North Atlantic Right Whales.

Benefits of Kelp Farming

- **Nutrient Removal:** Kelp absorbs excess nutrients, such as nitrogen and phosphorus, from the water, helping to improve water quality and reduce the risk of harmful algal blooms.
- **Habitat Creation:** Kelp farms provide habitat for various marine species, including fish, invertebrates, and other seaweeds, enhancing local biodiversity.
- **Carbon Sequestration:** Kelp captures carbon dioxide from the water, contributing to carbon sequestration and helping to mitigate climate change.
- **Economic Opportunities:** Kelp farming can create new economic opportunities for local communities, including jobs in cultivation, processing, and marketing of kelp products.

Challenges and Considerations

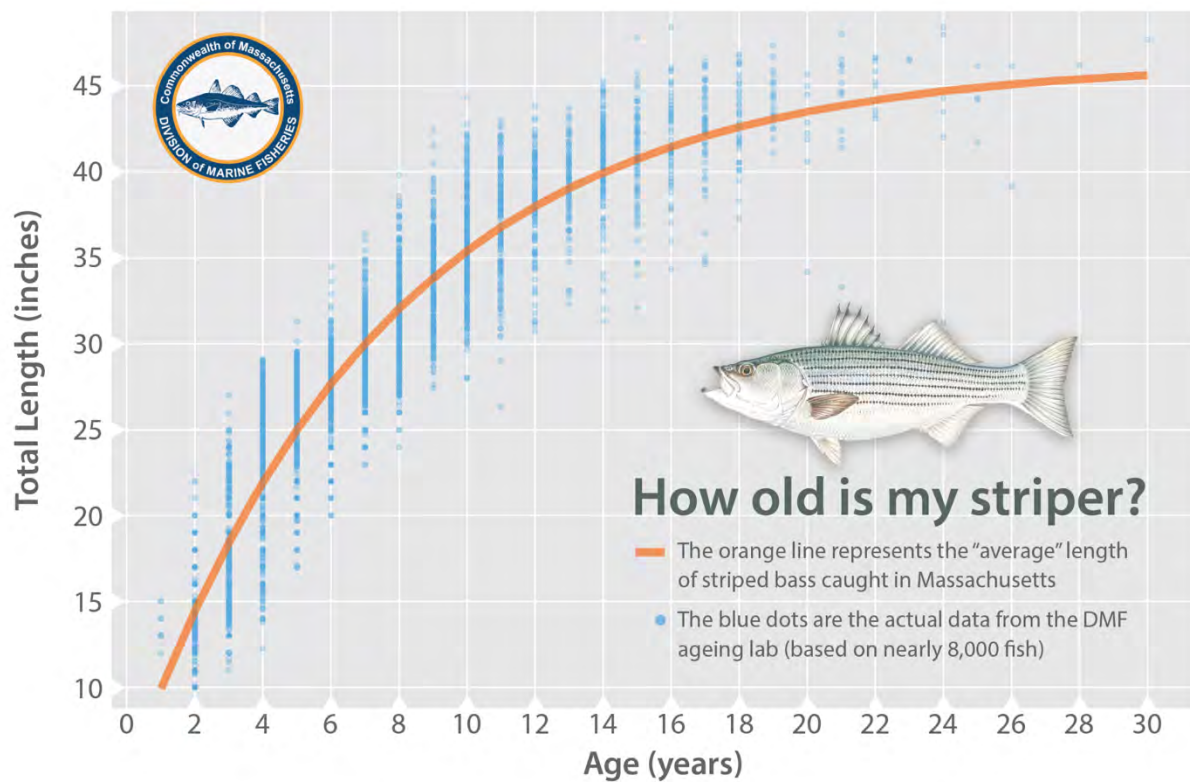
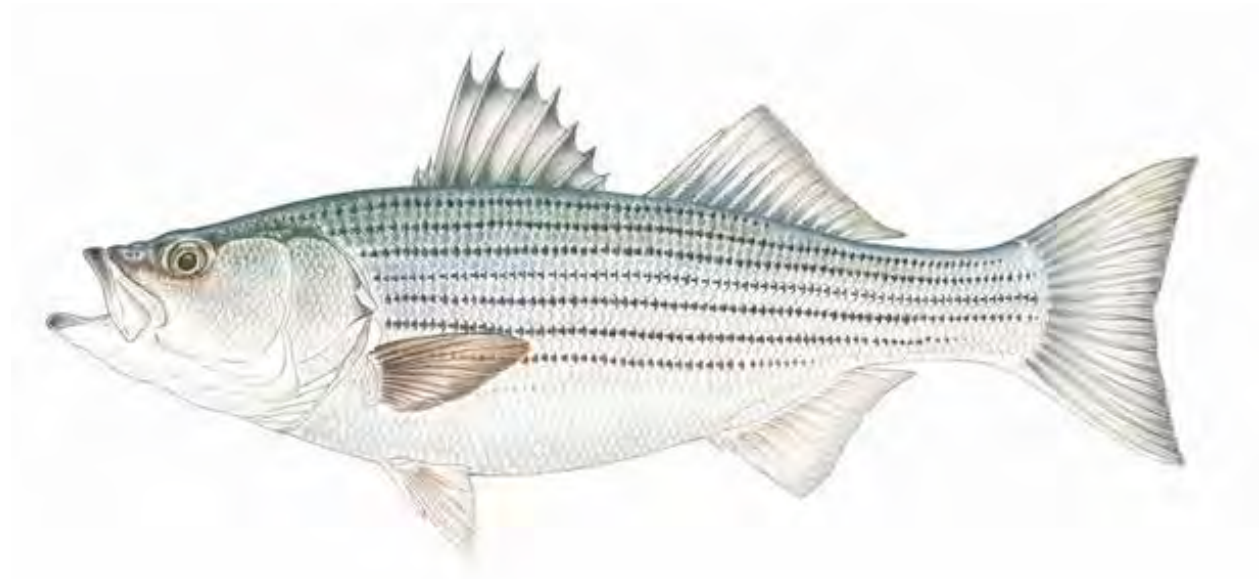
- **Regulatory Approvals:** Kelp farming operations require approvals from various state and federal agencies, including the Division of Marine Fisheries, the Massachusetts Department of Environmental Protection, and the US Army Corps of Engineers.

- **Environmental Impact:** Ensuring that kelp farming practices do not negatively impact native species and habitats is crucial. The use of innovative technologies, such as rope less rigging, helps address these concerns.
- **Market Development:** Developing a market for kelp products, including food, fertilizers, and biofuels, is essential for the economic viability of kelp farming.

Conclusion

Kelp aquaculture in Duxbury Bay represents a promising addition to the area's aquaculture activities. With its environmental benefits and potential for economic growth, kelp farming can contribute to the sustainability and resilience of the local marine ecosystem. Continued efforts to develop and implement innovative farming practices, along with regulatory support and market development, will be key to the success of kelp aquaculture in Duxbury Bay.

10. Recreational Fishing in Duxbury Bay



Overview

Recreational fishing remains a popular and culturally significant activity in Duxbury Bay. Residents and visitors alike are drawn to the bay for its scenic beauty and its diversity of marine life. The protected waters, accessible shoreline, and community-based fisheries culture have sustained consistent interest in angling, whether from boats, piers, or along the beach.

Commonly Caught Species

Anglers in Duxbury Bay regularly target a variety of fish species, most of which are seasonally present and support robust recreational fisheries:

- **Striped Bass (*Morone saxatilis*)** – A highly prized sportfish, known for strong runs and size. Most active from late spring through early fall.
- **Bluefish (*Pomatomus saltatrix*)** – Aggressive feeders and exciting to catch; present during warmer months.
- **Black Sea Bass (*Centropristis striata*)** – Provides both sport and high-quality table fare; increasingly targeted due to management success.
- **Winter Flounder (*Pseudopleuronectes americanus*)** – A traditional catch in colder months, although less abundant than in previous decades.
- **Summer Flounder / Fluke (*Paralichthys dentatus*)** – A sought-after flatfish, appreciated for both sport and culinary value.

Cape Cod Bay Species Accessed by Duxbury Anglers

Many Duxbury-based recreational fishers extend their activity beyond the immediate bay to Cape Cod Bay, where additional species are seasonally available:

- **Haddock (*Melanogrammus aeglefinus*)** – Increasingly targeted by small boat anglers in spring, especially near Stellwagen Bank.
- **Atlantic Cod (*Gadus morhua*)** – A historically significant fishery now under tight rebuilding measures due to decades of overfishing.
- **Bluefin Tuna (*Thunnus thynnus*)** – Cape Cod Bay remains a premier destination for giant tuna fishing. These highly migratory fish draw anglers from across New England and beyond.

Recreational Lobstering

Recreational lobstering is a longstanding tradition in Duxbury Bay. Using pots or diving, residents harvest lobsters in compliance with Massachusetts Division of Marine Fisheries (DMF) guidelines. Approximately 150 local recreational permits are active, allowing individuals to fish up to ten pots per person. The recreational lobster fishery promotes stewardship of marine resources while sustaining a meaningful connection to the bay's working heritage.

Fish Stock Health and Trends

The health of fish stocks in and around Duxbury Bay has remained relatively stable over the past 15 years, though each species faces distinct pressures. Regional and federal management measures including: slot limits, seasonal closures, and gear restrictions, continue to underpin stock recovery and sustainability for the recreational fishery.

- **Striped Bass** (*Morone saxatilis*): Populations fluctuate with water-temperature shifts, prey availability, and fishing pressure. The Duxbury Bay Management Commission strongly recommends that anglers practice Catch-and-Release practices to help sustain the striped bass fishery. Recent data from the Massachusetts Division of Marine Fisheries [Striped Bass Citizen Scientist Project \(2023–2024\)](#), documented more than 3,700 logged catches, and confirms that air exposure, high summer water temperatures (>75 °F), and deep hooking with bait or treble hooks sharply reduce post-release survival.

Recommended Best Practices for Catch-and-Release

- **Limit air exposure:** Keep fish in the water or release within **30 seconds**; never exceed **2 minutes**.
- **Handle gently:** Wet hands or rubberized nets; support fish horizontally and avoid squeezing.
- **Use single, barbless (or circle) hooks:** Reduce injury and handling time; treble hooks and baited rigs show higher injury rates.
- **Avoid fishing in heat stress conditions:** Release survival drops during periods when water temperature exceeds **75 °F**.
- **Prefer lures over bait:** Artificial lures cause fewer deep-hook injuries; if using bait, non-offset circle hooks are required in MA.

- **Revive lethargic fish:** Gently move fish in the water to oxygenate gills until it swims off strongly.
- **Bluefish** (*Pomatomus saltatrix*): Stocks remain variable, reflecting Mid-Atlantic trends and periodic over-harvest. Current bag limits appear to be stabilizing numbers.
- **Black Sea Bass** (*Centropristis striata*): A management success story—size and bag limits have produced a steadily improving, stable population.
- **Winter & Summer Flounder** (*Pseudopleuronectes americanus*, *Paralichthys dentatus*): Persistent challenges from habitat degradation and warming waters limit recovery, particularly for winter flounder.

Continued adherence to science-based regulations and adoption of the above best practices will help safeguard recreational fish populations for future generations.

Environmental and Regulatory Considerations

Several ongoing issues could impact the long-term health of recreational fishing in Duxbury Bay:

- **Water Quality:** Excess nitrogen from fertilizers and septic systems contributes to algal blooms and oxygen depletion.
- **Climate Change:** Warmer waters alter fish migration, spawning success, and overall distribution.
- **Habitat Loss:** Development and erosion are degrading essential habitats like eelgrass beds and salt marshes.
- **Fishing Pressure:** Increased angling activity underscores the need for responsible catch-and-release practices and compliance with regulations.

Conclusion

Recreational fishing in Duxbury Bay remains a cherished tradition and vital community activity. With a variety of species available and ongoing access to both nearshore and offshore fishing grounds, the bay supports a robust recreational fishery. However, protecting this resource requires continued attention to water quality, responsible angling practices, and adaptive management to address climate and ecosystem changes.

Responsible stewardship by both individuals and agencies will ensure the sustainability of fishing in Duxbury Bay for generations to come.

Before fishing, all anglers aged 16 and older must obtain a Massachusetts Recreational Saltwater Fishing Permit, [available through the MassFishHunt system](#). The permit is free for residents 60 and older and required by law. Anglers are also responsible for knowing and complying with current regulations including: bag limits, size limits, and seasonal closures which are updated annually by the Massachusetts Division of Marine Fisheries.

11. Rising Sea Level – Risks to Duxbury

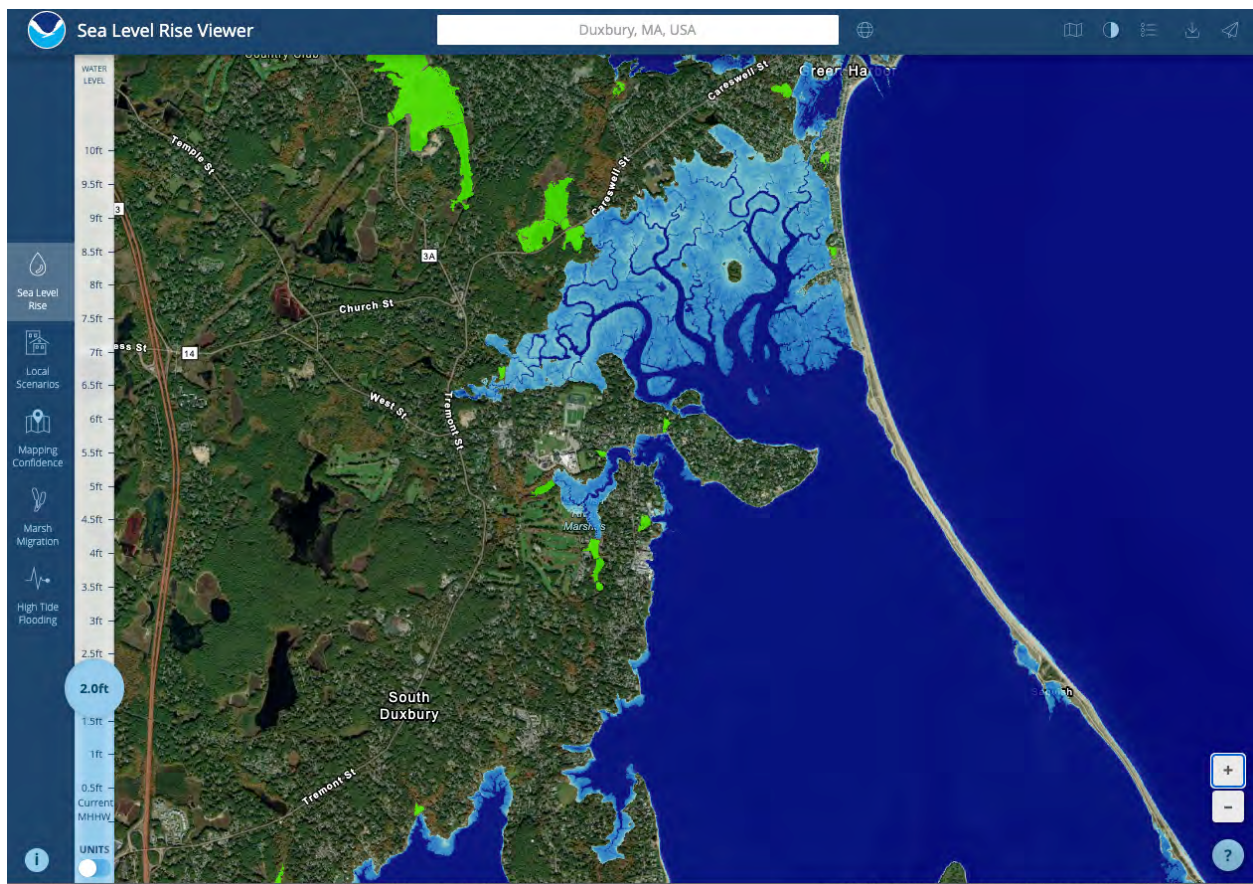


Illustration of high tide flooding with assumed 2 ft of sea level rise by end of century in Duxbury, MA – using NOAA sea level rise model and visualization

Background

Duxbury, Massachusetts, like many coastal towns in the Northeast, faces increasing risks from sea level rise and coastal flooding due to climate change. Since the 1990s, satellite measurements have been used to measure sea level over the global ocean. Those data unequivocally show a rise in sea level. In addition, computer models are being used to predict flooding impacts locally, using models such as NOAA's, "Sea Level Rise Viewer". "Places that never used to see this high-tide flooding are now seeing it several times a year, and in the next couple decades, it's going to be happening tens of times a year", according to Woods Hole Oceanographic Institute's Chris Piecuch, a physical oceanographer and sea-level scientist.

Accelerating Sea Level Rise

Sea levels along the U.S. East Coast, including Massachusetts, are projected to rise by 10–14 inches by 2050, which is as much as the total rise over the past century. This acceleration is driven by melting land ice and the thermal expansion of warming ocean waters.

Increased Flooding Frequency

Even modest sea level rise significantly increases the frequency of nuisance or high-tide flooding. These events, which used to be rare, are now occurring several times a year and are expected to happen tens of times annually in the coming decades. This can disrupt transportation, damage infrastructure, and overwhelm stormwater systems.

Localized Risk Modeling

The Massachusetts Coast Flood Risk Model (MC-FRM) provides high-resolution, dynamic flood risk projections for towns like Duxbury. It simulates flooding from both hurricanes and nor'easters, incorporating tides, storm surge, wave action, and sea level rise. For Duxbury and similar South Shore communities.

Infrastructure and Adaptation Needs

Critical infrastructure, such as evacuation routes and public buildings, may require adaptation or relocation. The MC-FRM helps identify vulnerable areas and prioritize protective measures like seawalls, berms, or natural buffers.

Appendix 1

Summary of MA Estuaries Project – Draft Report, December 2017

About the Mass Estuaries Project - Historical Context and Origin

The Massachusetts Estuaries Project (MEP) was initiated in 2001 as a cooperative initiative between the Massachusetts Department of Environmental Protection (MassDEP) and the University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST). This was aimed to provide a science-based framework for assessing nitrogen impairment in coastal estuaries in compliance with the Clean Water Act, specifically Section 303(d), which mandates development of Total Maximum Daily Loads (TMDLs) for impaired waters.

There were evident signs across southeastern Massachusetts, including Duxbury, of water quality degradation including declining eelgrass coverage, poor water clarity⁶, and shellfish bed closures⁷. These trends are largely attributed to elevated nitrogen loads from septic systems, stormwater runoff, and fertilizers. The MEP was structured to standardize the scientific methodology for TMDL development and to provide municipalities with the data and modeling tools useful to formulate nutrient management plans.

Methodology for Estimating Nitrogen TMDLs

The MEP utilizes a "Linked Watershed-Embayment Model" to assess nitrogen dynamics. This is an intricate model that combines several components:

- **Watershed Delineation and Land Use Analysis:** Detailed mapping of land use and wastewater treatment infrastructure was conducted to quantify estimated nitrogen sources. Parcel-level data were used to estimate contributions from septic systems, impervious surfaces, and fertilizer application.
- **Hydrologic and Hydraulic Modeling:** Groundwater travel times and surface water flows are simulated using USGS and MEP-developed models to account for nitrogen attenuation in freshwater systems before reaching the estuary.
- **Water Quality Monitoring:** The report states the model was validated using data on salinity, nitrogen concentrations, dissolved oxygen, and chlorophyll-a were collected from two sentinel stations over several years.

⁶ Duxbury Bay's extensive marshes including Back River and Bluefish River are an abundant source of natural organic sediment that contributes to turbidity but is not indicative of degraded quality.

⁷ Shellfish closures are not due to Nitrogen loading but are based on bacteria monitoring

- **Embayment Circulation and Flushing:** Hydrodynamic modeling simulates tidal flushing rates and residence times, critical for estimating how nitrogen is diluted or retained within the estuary.
- **Scenario Testing:** The model allows for simulation of present, build-out, and no-load conditions to understand the impact of land use changes and evaluate management alternatives.

Rationale for TMDL Thresholds

TMDL thresholds are based on model-derived data, validated by some empirical testing, correlating nitrogen concentrations with habitat quality indicators. The key ecological indicators used include:

- **Eelgrass Distribution:** Eelgrass is sensitive to light attenuation caused by algal growth. Thresholds are typically set to maintain nitrogen concentrations at or below 0.4 mg/L in sentinel locations to support eelgrass restoration.
- **Benthic Community Health:** The presence and diversity of shellfish are used to evaluate the impact of nitrogen on sediment quality and oxygen availability.
- **Dissolved Oxygen and Chlorophyll-a:** Persistent low oxygen or high chlorophyll-a levels indicate eutrophication, guiding threshold development.

For the Plymouth-Kingston-Duxbury (PKD) embayment system, the nitrogen concentration threshold was set at approximately 0.33 mg/L at two sentinel stations. These thresholds were set more conservatively than the standardized 0.40 mg/L established for eelgrass impact based on the presumption that there was already local impact and also that there is less flushing in areas further up into Duxbury Bay.

Results of TMDL estimation for Duxbury Bay.

The table below summarizes the estimated nitrogen loads from sources leading into Duxbury Bay. Based on the model, the estimated nitrogen concentrations at sentinel stations under present conditions exceed this threshold. Modeled values range between 0.37 mg/L and 0.40 mg/L during the summer season at the two sentinel locations (see figure below). These values are not direct field measurements but are derived from the model after accounting for attenuation (see below).

Note that these projections were based on the state of residential development around 2010. The model projects an increase of about 20% in nitrogen loading based on estimated increased future residential development.

Also, there are natural sources of attenuation that mitigate the ultimate discharge into Duxbury Bay including from plant uptake, denitrification from bacteria, and sedimentation, which is estimated to reduce the actual load by about 25%.



Figure 1 Location of the two sentinel stations the model considered

Watershed Name	Waste water	wwtf	lawn fertilizer	cran bogs	agricultural fields	Golf Courses	Landfill	Impervious Surface Runoff	Wetlands	Atmospheric Deposition	"Natural" Surfaces
Careswell Pond2	361		25				47		-	129	31
Duxbury Marsh3	8,079	80	681	653		252		1,041	-	29	606
Dux Marsh Estuary Surface										2,040	
Blue Fish River TOTAL	5,839		292	149		925	247	537	-	599	336
North Hill Pond4	188		14	60		98		22	-	476	51
Blue Fish River LT105	3,720		171	63		715		284	-	46	144
Duxbury PWS17	71		4			95		13	-	-	6
Duxbury PWS210	354		23					42	-	-	14
Duxbury PWS36	260		11			18		21	-	-	34
Bluefish River GT10 N8	376		19	8			247	60	-	-	43
Bluefish River GT10 S11	760		42					84	-	10	25
Duxbury Harbor surface										21,598	
Totals	20,008	80	1,282	933	-	2,103	541	2,104	-	24,917	1,290

Table 2 Total estimated unattenuated nitrogen load in Duxbury Bay (numbers are kg/yr)

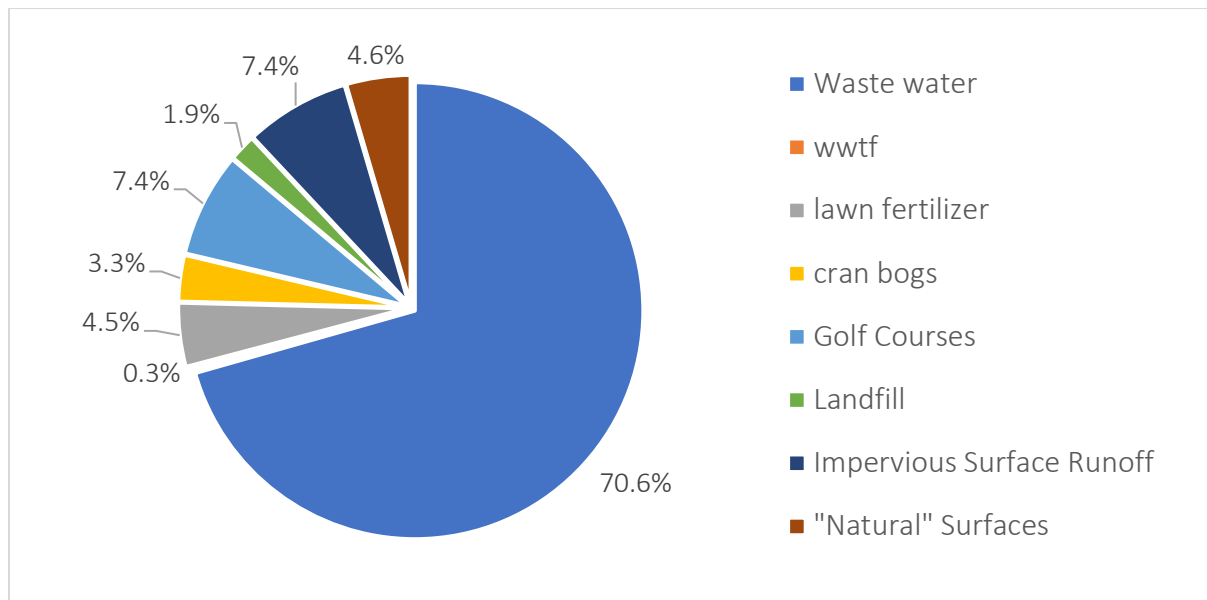


Figure 2 Estimated proportional contribution of Nitrogen by source, excluding atmospheric deposition.

The figure above was created from the model projections for sources leading into Duxbury Bay (it would look slightly different in Kingston or Plymouth Bays and in total). It can be readily seen that wastewater (i.e. septic sources) is the major projected contributor. At the time this report was drafted (in 2017), it was concluded that there are signs that Duxbury Bay showed signs of impairment from water quality but only marginally. This suggests that small changes to nitrogen loading could be helpful.

It should be noted that the sentinel locations chosen are both areas of the bay that undergo significant flushing relative to other areas, such as Back River or Bluefish River. In these latter areas, local sources such as natural surface runoff and fertilization probably have a more significant impact.

Impact of exceeding Total Maximum Daily Loads (TMDL)

Aside from the esthetic, environmental, and reputational cost of degraded water quality, there are important regulatory consequences of exceeding TMDL. The state will confer with the US EPA, once the draft report is approved, to determine whether the estuary should be listed as impaired. If that occurs, municipalities are required to take action by either creating what's called a Comprehensive Wastewater Management Plan (CWMP) to reduce nitrogen loading below TMDL or by obtaining a Watershed Permit, which could allow the town more time to achieve the target TMDL. Failure to comply with this requirement could have the following consequences:

- **Rejection of local development plans or sewer expansion proposals under MEPA or Title 5 regulations.**

- Denial of state or federal funding for infrastructure improvements.
- Increased scrutiny under EPA's enforcement of the Clean Water Act.
- Legal challenges or consent orders requiring action under a defined timeline.

Status of MEP and recommendations

The report this data is based on has not been formally approved by the Mass DEP. That will probably occur but as of the last state update in 2024, it was not projected to occur before the end of 2025 and will likely be later than that.⁸

As shown the figure, the Mass DEP may consider Duxbury separately from Kingston and Plymouth, with regard to approving the MEP report and whether the estuary will be listed as impaired. But, because we share this embayment together, it will be important to coordinate together to improve the impact of any mitigation effort and also to demonstrate to the Mass DEP and the US EPA that we are cooperating to respond to this mandate.

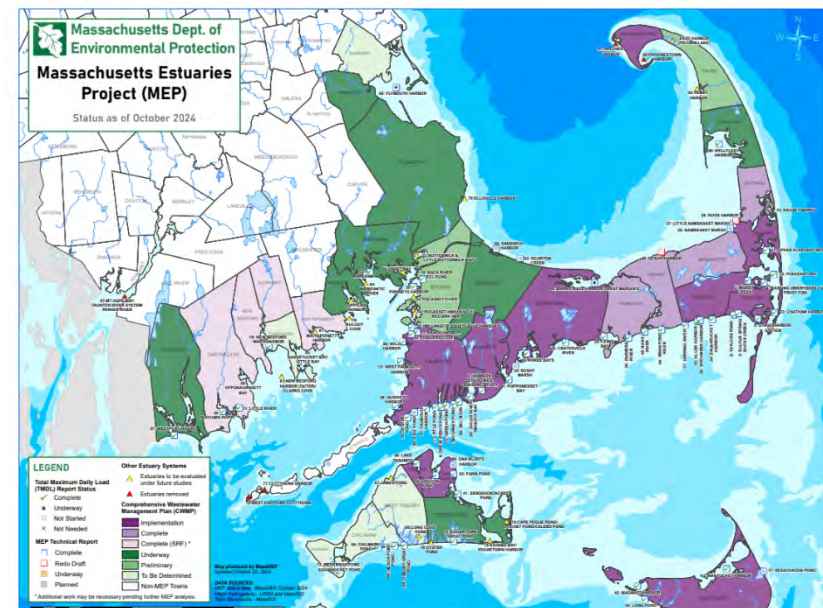


Figure 3 Status of MEP for coastal communities as of 2024

⁸ <https://www.mass.gov/doc/final-massachusetts-integrated-list-of-waters-for-the-clean-water-act-2022-reporting-cycle/download>

A Summary of the Massachusetts Estuaries Project Findings and Management Recommendations

1. What Did the Massachusetts Estuaries Project Find?

The Massachusetts Estuaries Project (MEP) conducted an extensive scientific assessment of water quality and habitat conditions in the Plymouth-Kingston-Duxbury (PKD) Embayment System between 2006 and 2013, with modeling scenarios completed through 2014. Their findings include:

- Most of Duxbury Bay supports healthy ecosystems, including eelgrass beds and benthic (bottom-dwelling) animals.
- Upper Duxbury Bay, especially the Bluefish River area, is showing signs of moderate nutrient-related degradation.
- Over the past ~20 years, about 330 acres of eelgrass habitat have been lost (approximately 60%). Diversity of benthic animal species in the upper bay is lower, indicating stress.
- Nitrogen concentrations in the upper bay are above healthy thresholds, leading to increased phytoplankton growth and degraded habitats.

2. What Is Causing the Water Quality Impairment?

The primary cause of habitat decline in upper Duxbury Bay is excess nitrogen. Key sources include:

Septic Systems

Bluefish River sub watershed contributes disproportionately.

Many properties rely on conventional septic systems which are ineffective at nitrogen removal.

Stormwater Runoff

Developed areas contribute nitrogen-rich runoff into the river and bay.

Fertilizer Use

Excess use on lawns and fields leads to nitrogen runoff during rainstorms.

Atmospheric Deposition

A smaller amount falls from the atmosphere directly into the water or land.

3. What Are the Recommended Solutions?

The MEP concluded that reducing nitrogen inputs, especially in the Bluefish River watershed, is the most effective restoration strategy. Recommendations include:

Septic System Upgrades or Sewer Connections

- Upgrade to advanced nitrogen-removal systems
- Extend sewer service to priority areas
- Implement cluster wastewater systems

Fertilizer Use Restrictions and Education

- Strengthen local fertilizer bylaws
- Promote use of slow-release fertilizers

Stormwater Management Improvements

- Install green infrastructure (e.g., rain gardens, swales)
- Improve maintenance of stormwater systems

Riparian and Wetland Buffers

- Restore and protect vegetated buffers along streams

Public Engagement and Incentives

- Provide cost-share or tax incentives for septic upgrades
- Launch community outreach programs

4. How Much Nitrogen Reduction Is Needed?

The MEP recommends reducing average nitrogen concentrations in upper Duxbury Bay from approximately 0.345 mg/L to 0.33 mg/L. To achieve this target, a 13% reduction in total septic nitrogen loads across the system is required, with specific focus in Duxbury as follows:

Required nitrogen reductions by sub watershed within Duxbury:

- Bluefish River: 25% reduction in septic nitrogen load
- Duxbury Bay: 50% reduction
- Duxbury Back River: 25% reduction

Appendix 2

**Presentation by John Brawley to Duxbury Bay Management Commission
April 21, 2025**

**Summary of Data and Findings from Review of Water Quality Measurement Data
from 2006 – 2024**

Duxbury Bay

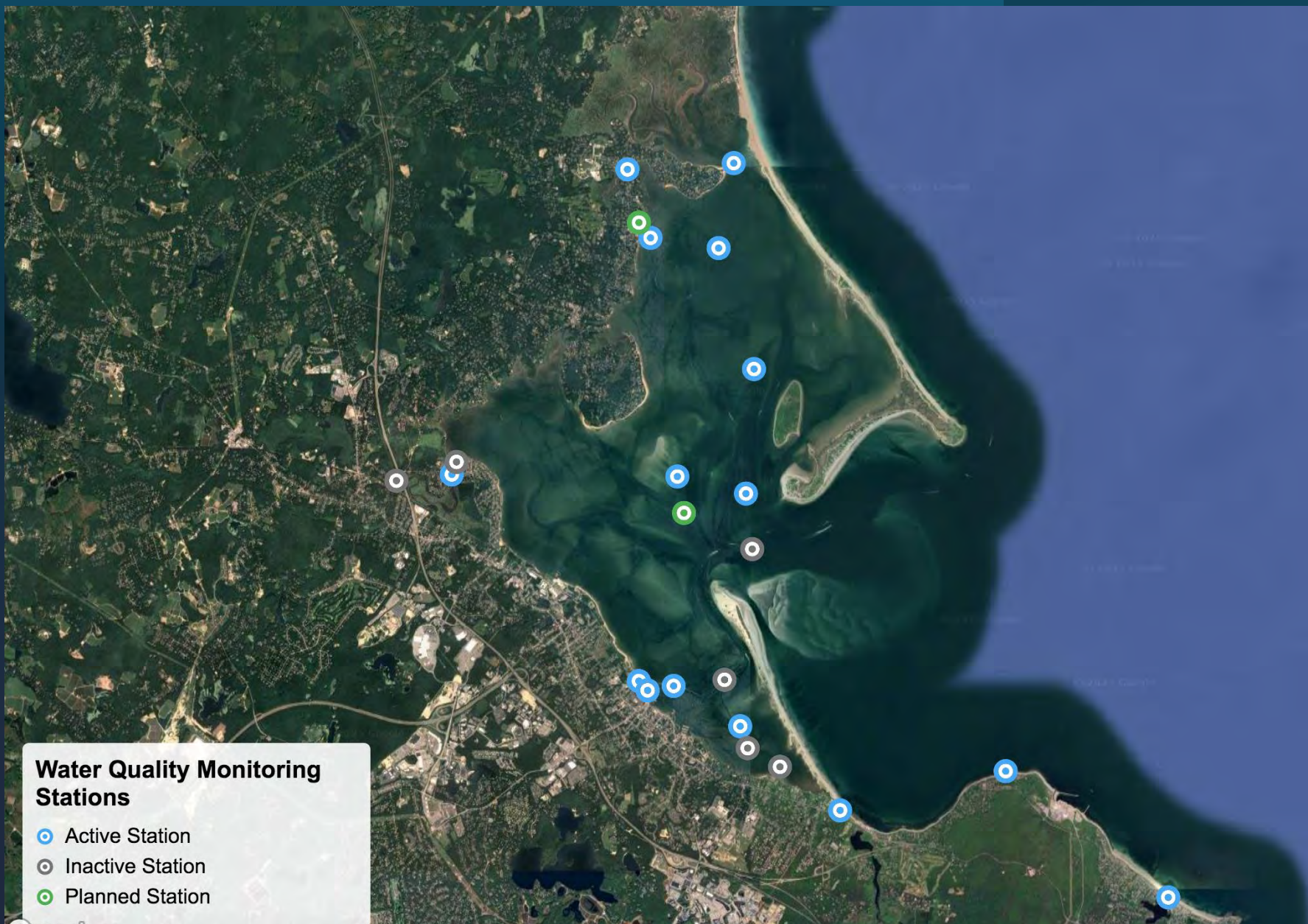
Overview of Results

John Brawley

June 18, 2025

Water Quality Monitoring Stations

- Active Station
- Inactive Station
- Planned Station





Information Sources

- Center for Coastal Studies
- Cape Cod Cooperative Extension
- EPA Region 1 & MassBays NEP
- UMASS/DEP (No Data)
- Local/other

Massachusetts Estuary Project (MEP)

MEP Conclusions:

Only moderate impairment found in the upper reach of Duxbury Bay

Elevated chlorophyll

Organic rich sediments

But elevated nitrogen levels in water column and modest organic matter enrichment in upper Duxbury Bay (near Bluefish River).

Specific target for Duxbury Bay is 0.331 – 0.335 mg/L (23.6 to 23.9 μ M)

Significant eelgrass decline correlated with elevated TN concentrations

Most prevalent downgradient of Bluefish River

Nitrogen management is needed to recover eelgrass

Septic load reduction of 50%

Total watershed load reduction of 42%

Center for Coastal Studies

Primary Sampling Sites in Duxbury Bay:

Powder Point Bridge

Bluefish River Bridge

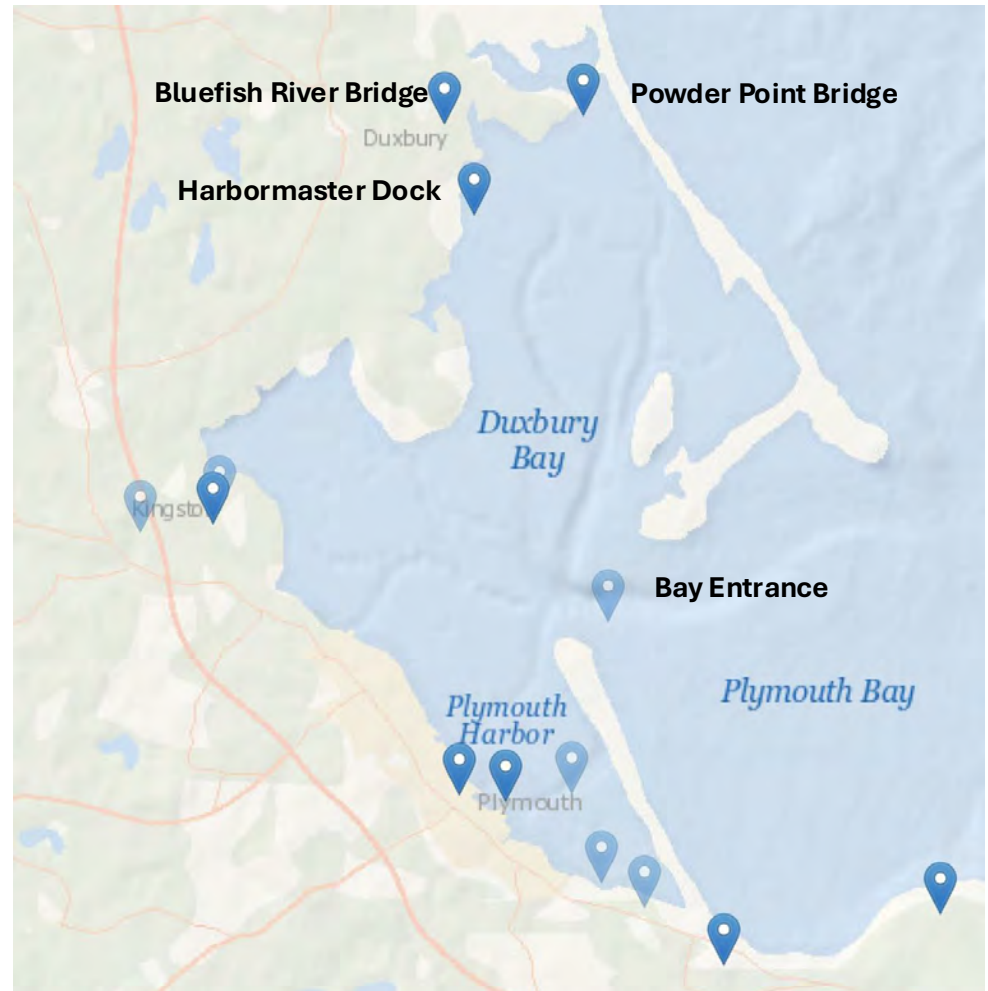
Harbormaster Dock

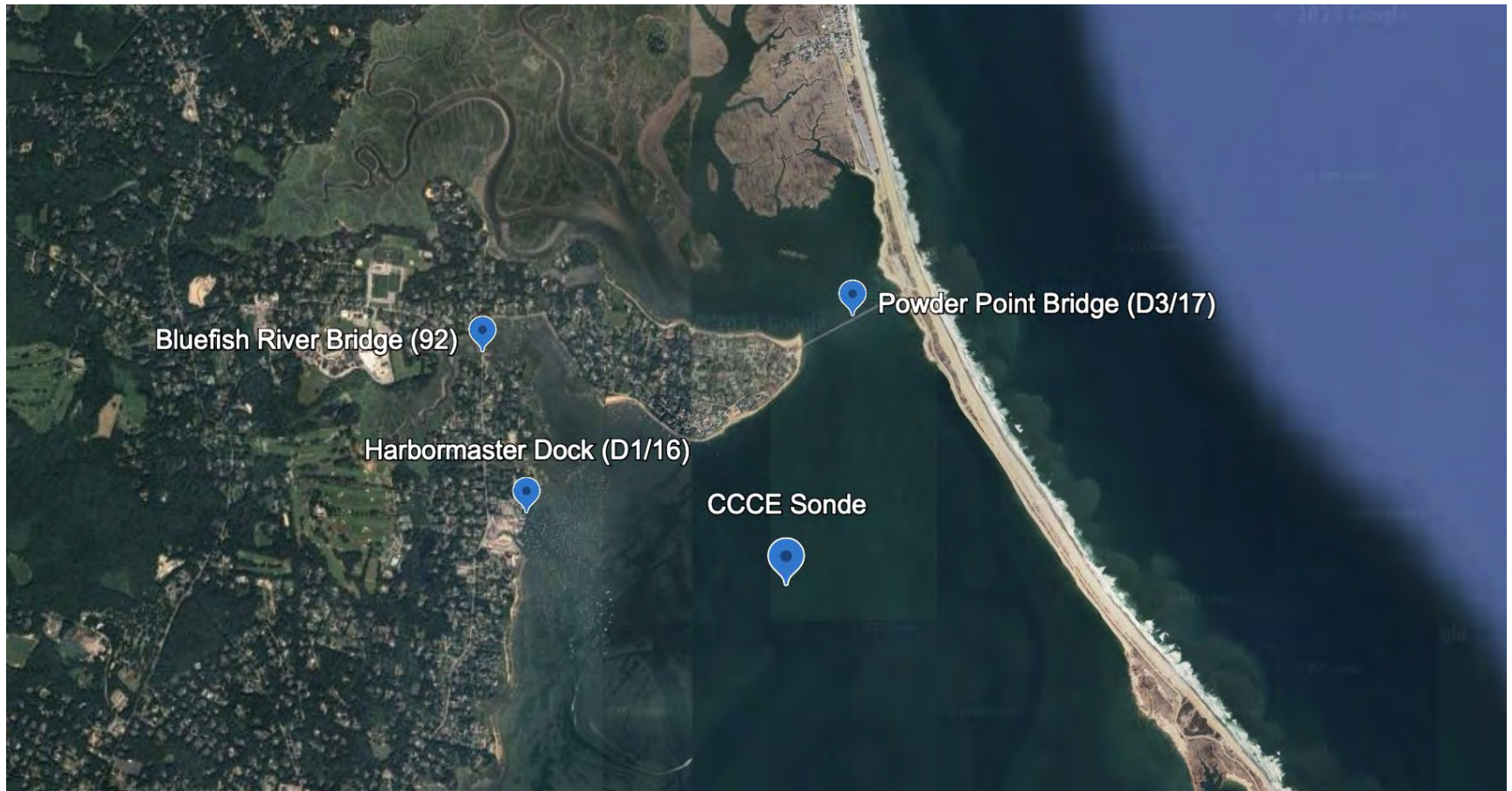
Other Sites:

Jones River

Plymouth Harbor

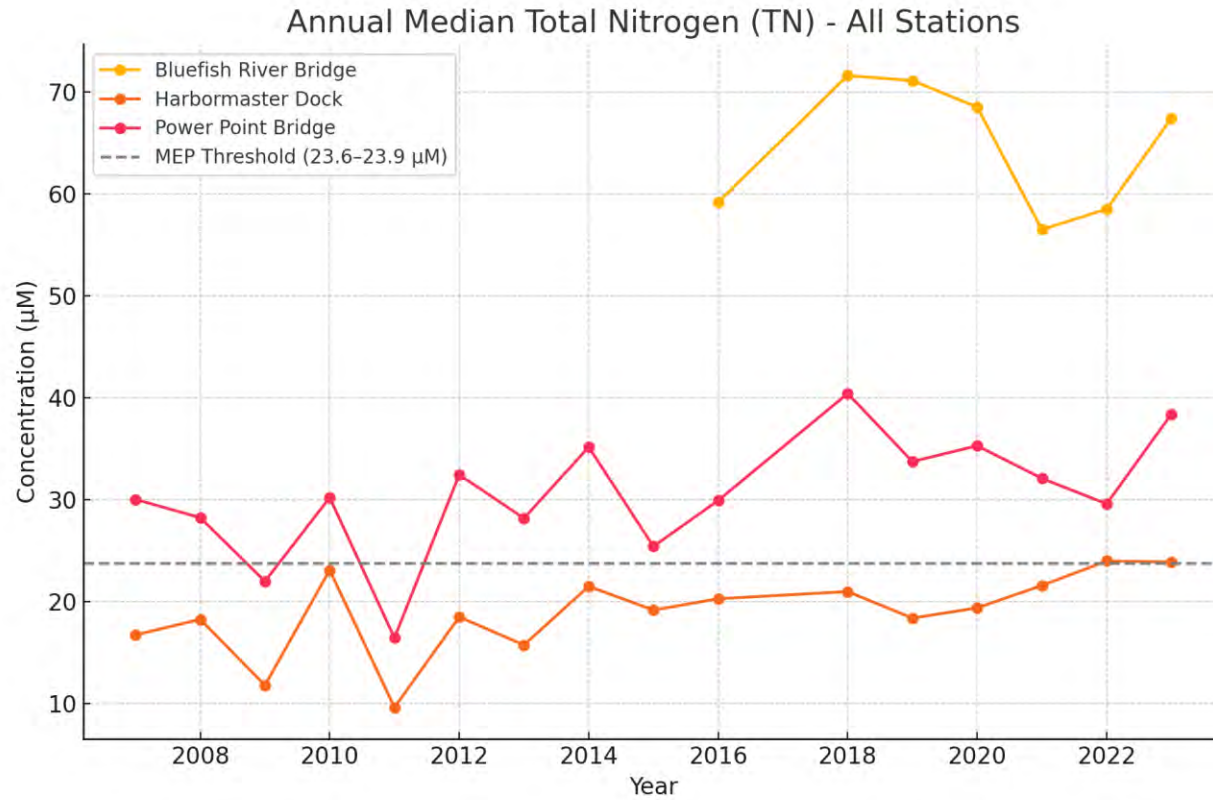
Offshore

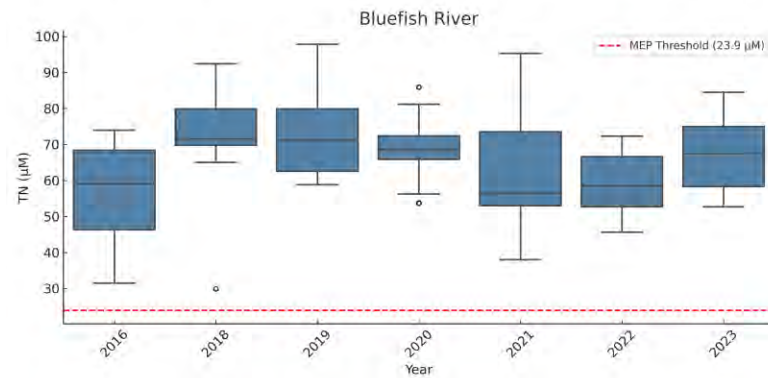
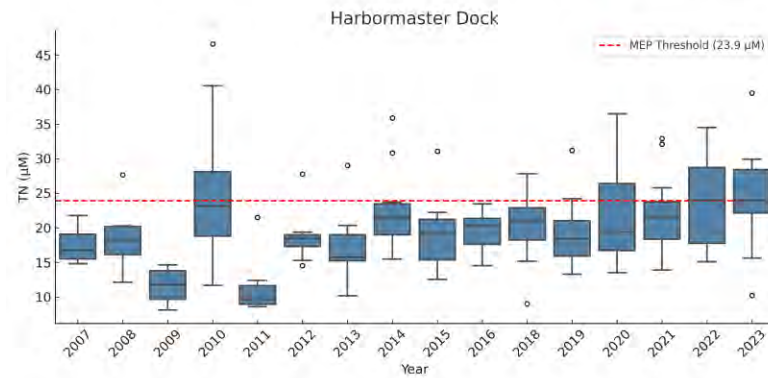
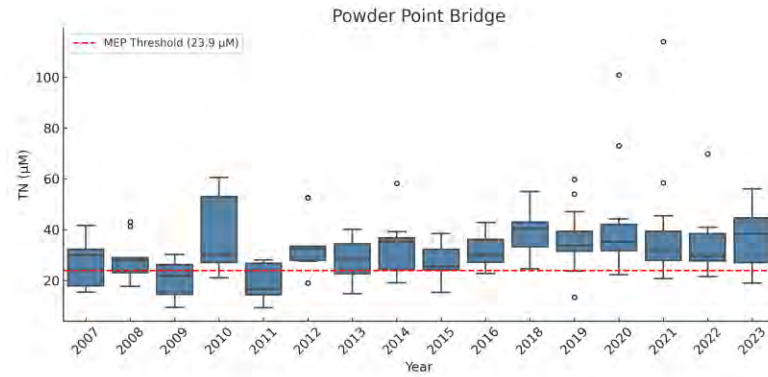




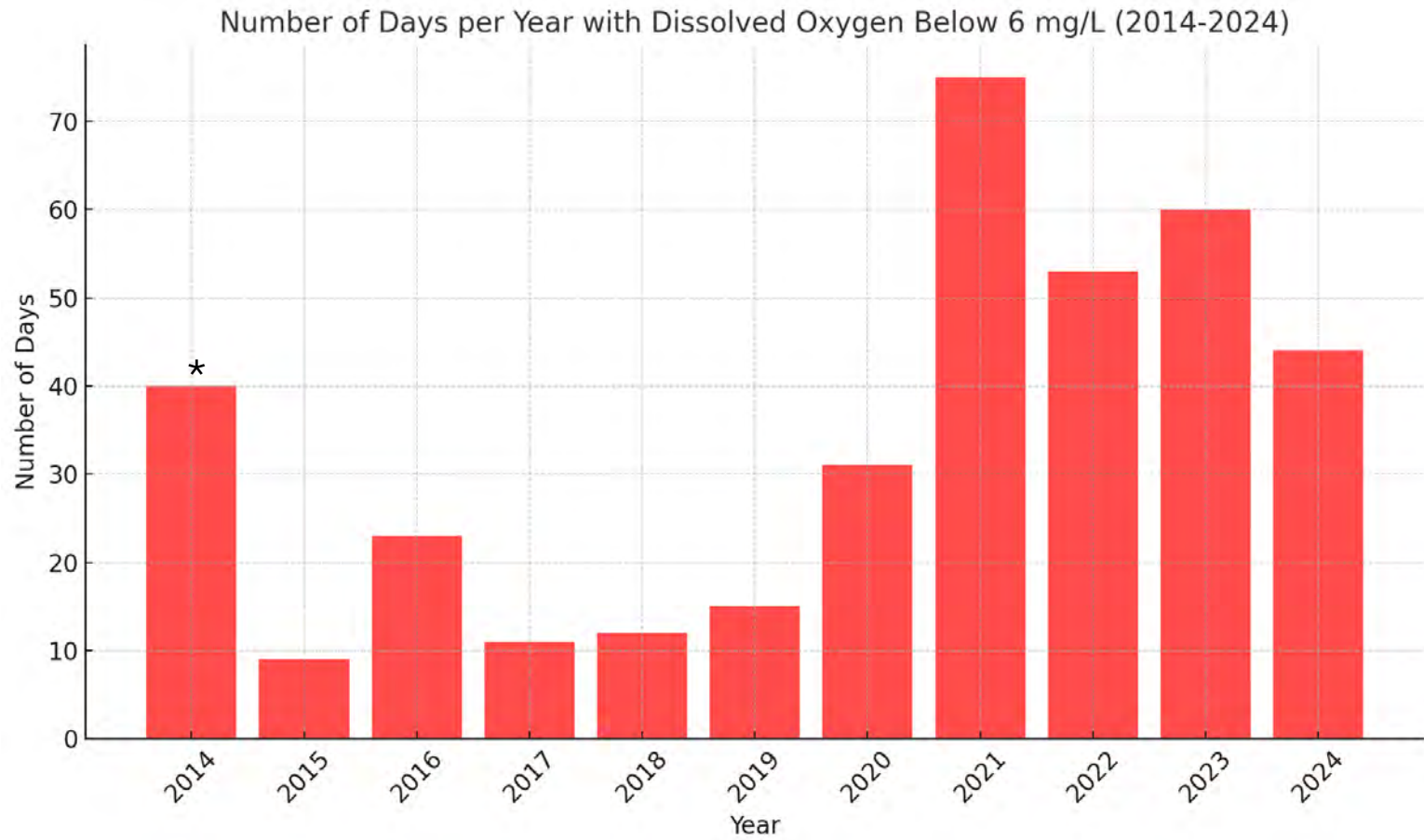
Locations of long-term water quality monitoring stations in Duxbury Bay. The Center for Coastal Studies (CCS) maintains stations at Bluefish River Bridge (Station 92), Harbormaster Dock (D1/16), and Powder Point Bridge (D3/17). The Cape Cod Cooperative Extension (CCCE) operates a high-frequency monitoring sonde at a mid-bay location.

Total Nitrogen (TN)

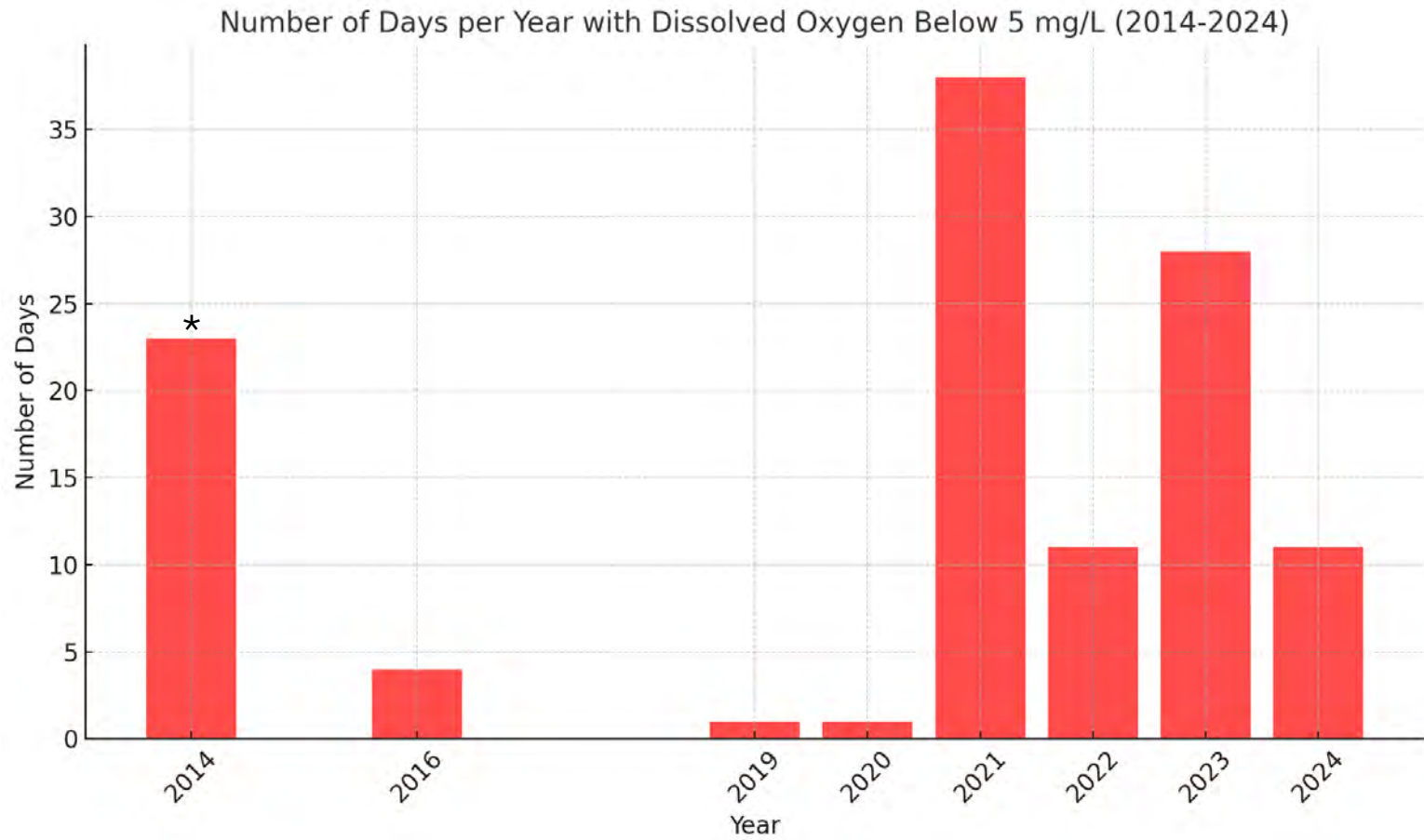




Dissolved Oxygen (DO) – CCCE



Dissolved Oxygen (DO) – CCCE



Trends

Location	Total Nitrogen	Nitrate+Nitrite (NO3+NO2)	Ammonium (NH4)	Chlorophyll-a	Dissolved Oxygen	Turbidity	Years
Powder Point Bridge (D3)	Yes (+)	Yes (+)	No	Yes (+)	No	Yes (+)	2007-2023
Harbormaster Dock (D1)	Yes (+)	Yes (+)	No	Yes (+)	No	No	2007-2023
Bluefish River Bridge (92)	No	No	No	No	No	No	2016 - 2023
Bay Entrance (C3)	No	No	No	No	No	No	2007 - 2015

Executive Summary – Key Components

Water Quality Indicators:

Nitrogen concentrations are highest in the Bluefish River and exceed ecological thresholds at multiple sites.

Phosphorus shows seasonal peaks in the upper bay, particularly north of Powder Point Bridge.

Chlorophyll-a (phytoplankton) is elevated in the upper bay, with increasing trends at some stations.

Blue-green algae (cyanobacteria) blooms are detected periodically, raising concern for aquaculture and ecosystem stability.

Executive Summary – Key Components

Water Quality Indicators:

- **Dissolved oxygen** is generally above thresholds but short-term hypoxic events occur during warm summer periods.
- **Eelgrass** has declined by over 60% in 20 years—a major ecological concern.
- **Turbidity** is low at Harbormaster and Powder Point, but persistently high at Bluefish River.
- **Water temperature** is increasing; thermal stress events $>25^{\circ}\text{C}$ are more frequent.

Conclusions:

Duxbury Bay remains productive but is increasingly vulnerable to nutrient and climate-related stress.

Upper bay areas are most degraded due to chronic nutrient loading and episodic hypoxia.

Future housing development could increase nitrogen loads by 10–30% above 2012 levels.

Septic systems and fertilizer use are the primary nutrient sources.
Ongoing monitoring and management are essential to protect estuarine health.

Management Recommendations

Reduce Nitrogen Loads

Target the Bluefish River and other high-load sub-watersheds through septic upgrades, stormwater retrofits, fertilizer reduction, and buffer restoration.

Restore Eelgrass and Protect Habitat

Focus on protecting existing eelgrass beds and restoring in areas where water clarity and conditions are suitable.

Expand Monitoring and Data Access

Increase frequency and spatial coverage of monitoring, and make real-time data publicly available to support decision-making and public engagement.

Use Shellfish for Nutrient Removal

Explore municipal shellfish propagation (e.g., oysters) in impaired areas to assist with nitrogen removal through biofiltration.

Management Recommendations

Limit Fertilizer Use

Consider local ordinances or seasonal bans on non-agricultural fertilizer use, modeled after similar Cape Cod towns.

Enhance Public Outreach

Engage the public in stewardship through education on septic maintenance, fertilizer use, and participation in monitoring programs.

Research Priorities

Phytoplankton Composition and Bloom Risk

Use microscopy, pigment profiling, and genetic tools to identify phytoplankton species and detect harmful algal bloom risks.

Diurnal and Tidal Oxygen & Temperature Cycles

Deploy high-frequency sensors to capture short-term fluctuations in oxygen and temperature that drive hypoxia.

Benthic-Pelagic Interactions

Study how phytoplankton, oxygen stress, and sediment dynamics affect bottom-dwelling organisms and habitat quality.

Climate Stressor Interactions

Model how warming, sea level rise, and nutrient loading interact to affect estuarine conditions under future scenarios.

Valuation of Ecosystem Services

Quantify the economic benefits of eelgrass, clean water, and shellfish to support cost-benefit analysis and investment in restoration.



The End