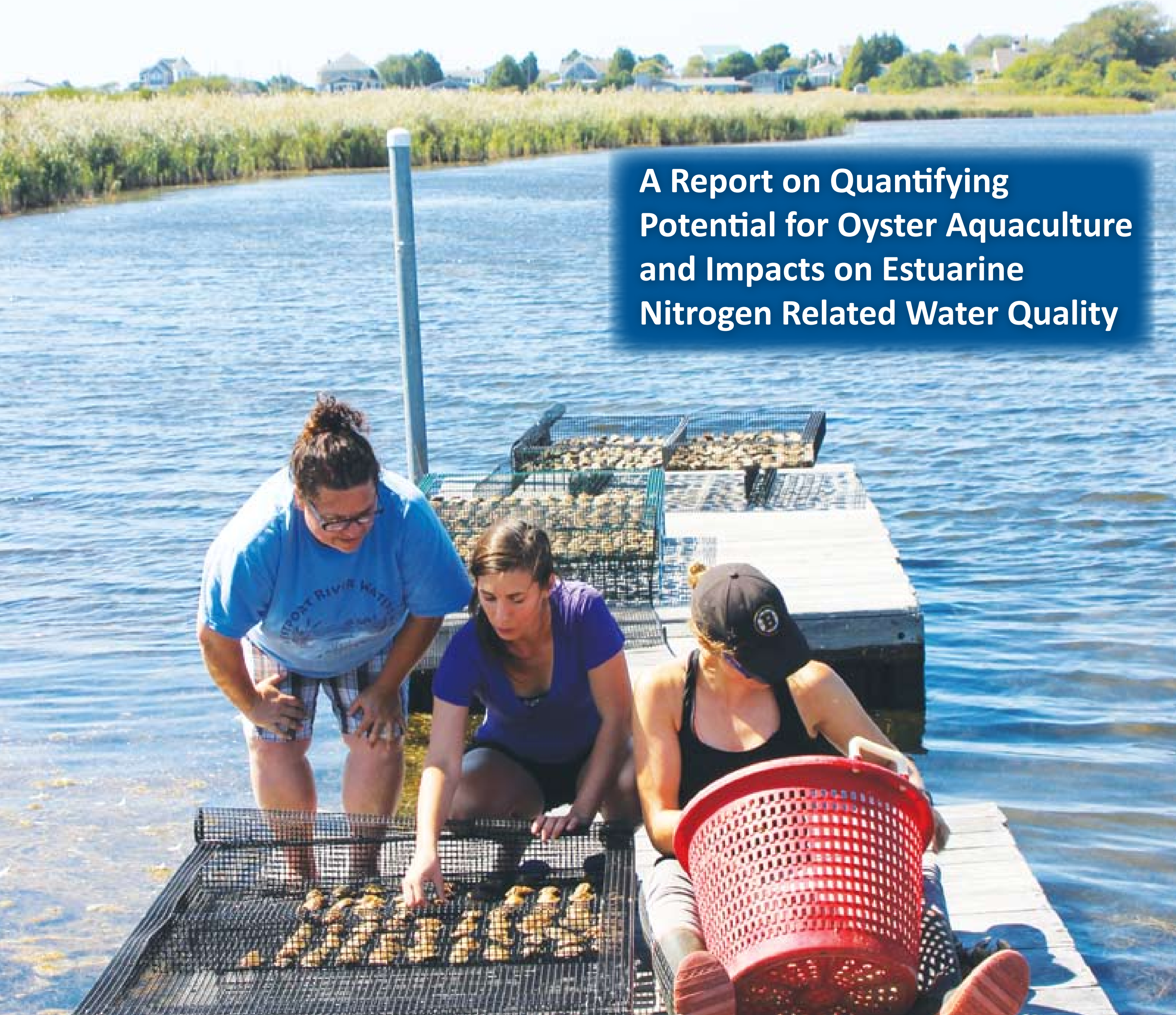
Cockeast Pond as a Living Laboratory: Nitrogen and Oyster Aquaculture

A Report on Quantifying Potential for Oyster Aquaculture and Impacts on Estuarine Nitrogen Related Water Quality



This project was funded by the Southeast New England Program Watershed Grants

To help restore clean water and healthy ecosystems to Southeast New England, Restore America's Estuaries, with financial support from the United States Environmental Protection Agency, launched the Southeast New England Program (SNEP) Watershed Grants. The grants target water pollution, habitat degradation, and other high-priority environmental issues, in order to foster sustainable coastal and watershed communities. SNEP Watershed Grants target integrated approaches to water quality and ecosystem restoration.

SNEP recognizes that clean water, healthy habitats, resilient ecosystems, and prosperous communities are closely interconnected, and that strong partnerships offer the most effective means of meeting Southeast New England's environmental challenges. SNEP grants have funded a variety of successful projects to restore clean water and coastal ecosystems, including this project in Westport. One priority is nutrient pollution to coastal waters.

Nutrients such as nitrogen and phosphorus harm coastal ecosystems throughout Southeast New England by fertilizing excess growth of seaweeds, plankton, and other algae. This reduces the oxygen in the water that fish and shellfish need to survive; degrades coastal habitats such as salt marshes and marine bottoms; and can catalyze outbreaks of toxic algae that pose acute health risks to humans and wildlife. The grants target water pollution, habitat degradation, and other high-priority environmental issues, in order to foster sustainable coastal and watershed communities.

For more information on the Southeast New England Coastal Watershed Restoration Program visit: https://www.epa.gov/snecwrp.

Project Title:

Quantifying Potential for Oyster Aquaculture and Impacts on Estuarine Nitrogen Related Water Quality - Cockeast Pond and the East Branch of the Westport River

Project Partners:

University of Massachusetts Dartmouth, School for Marine Science and Technology, Coastal Systems Program

Westport River Watershed Alliance (WRWA),

Town of Westport Shellfish Department/Marine Services,

Aquaculture Research Corporation (ARC)

The Coastal Systems Program at UMASS received a USEPA Southeast New England Program (SNEP) Watershed Grant– with WRWA as a project partner for a four-year research project using Cockeast Pond as a "natural laboratory". As communities across Southeast New England seek new approaches to lessen the impact and impairment from nitrogen (N) enrichment, oyster aquaculture is a commonly identified approach that is gaining momentum across the region. While the plans to use aquaculture continue to grow, there has been almost no quantification of the effectiveness of the approach. To address this gap, this project used Cockeast Pond, a saltwater pond with a high level of nitrogen enrichment, as seen in 9 years of prior monitoring. Nitrogen removal by oysters was assessed by deploying and supporting a large oyster array, and monitoring the resulting habitat and water quality. The project is to assess and quantify the oyster aquaculture as a method for estuarine nitrogen remediation.

Primary Project Goals:

- Determine the effect of oyster aquaculture on water column nitrogen concentrations;
- Assess total nitrogen removed from a system through oyster aquaculture and subsequent oyster harvest based on varying water quality parameters and oyster growth rates.

Oyster Aquaculture and Nitrogen Removal

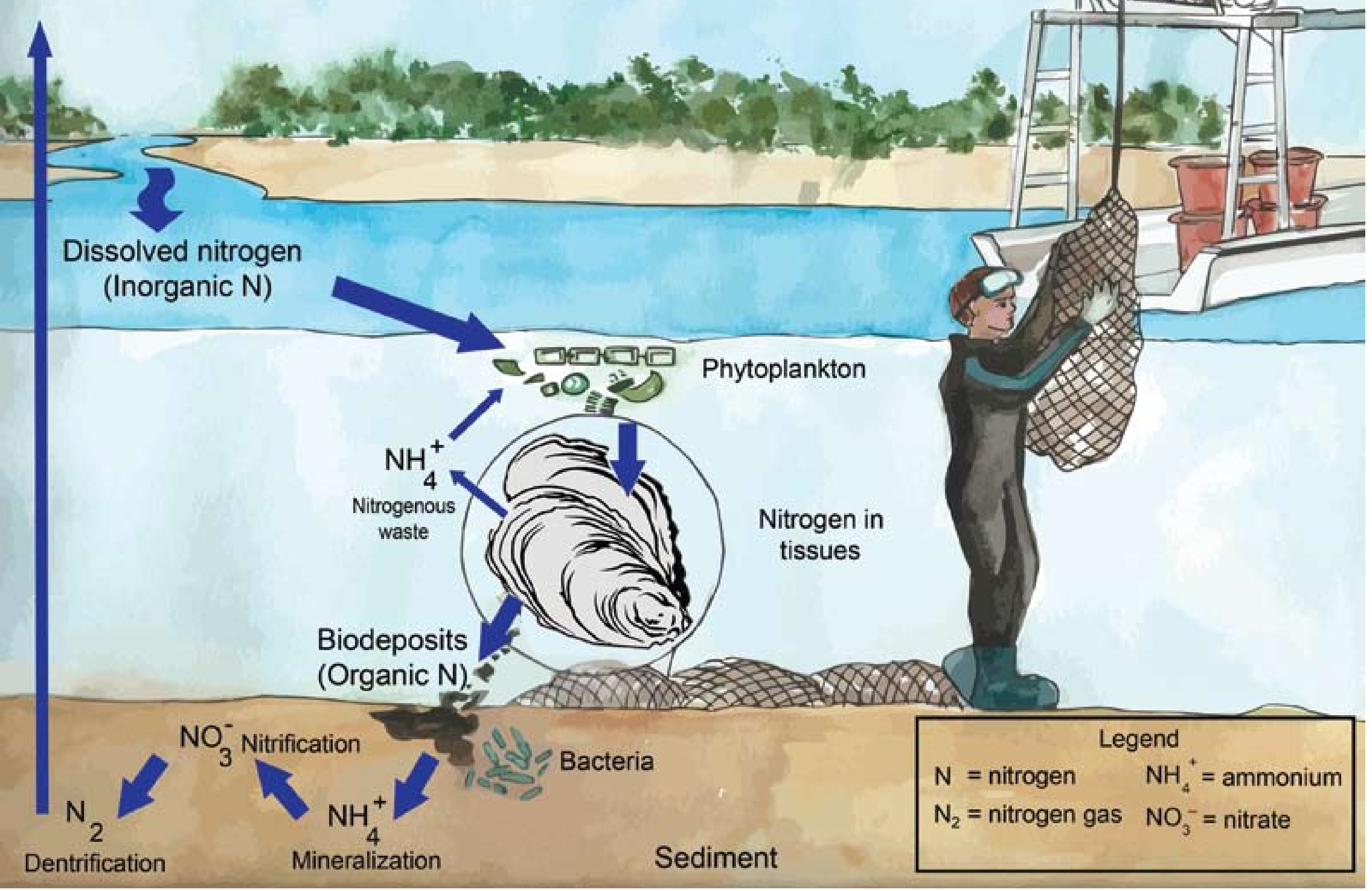


Image adapted from the University of Florida | IFAS Shellfish Aquaculture Research & Extension

Oyster harvest and aquaculture was a significant enterprise and part of the culture of coastal Massachusetts for over 100 years until decimated by disease and overfishing. In recent decades, oysters have again become an important economic resource as new growing methods and disease resistant strains have been developed. Over the past 20 years, as municipalities have been grappling with nitrogen over-enrichment of their salt ponds, bays and estuaries, oysters are being seen for their role as efficient tools for nitrogen mitigation. At present, in addition to the immediate market value of cultured oysters at harvest, oyster aquaculture provides ecosystem service value from the sequestration and removal of excess nitrogen and resultant improvement of water quality.

Why oysters? One oyster can filter about 50 gallons of water per day. This biological filtering power is being looked at by researchers as a potential solution to absorb harmful amounts of nitrogen in coastal waters resulting from inputs of phytoplankton nutrients from septic systems and runoff from agricultural areas. Oysters' ability to improve water quality, reduce phytoplankton (microscopic marine plants), increase water clarity and lower watercolumn TN levels, by filtration is well known, but many questions remain. Such as, does oyster filtration and resulting biodeposition always lead to enhanced nitrogen removal in associated bottom sediments? How much nitrogen is removed by these associated sediments and through harvest, and under what conditions? The nitrogen loads can alter the environment in such a way that new types of phytoplankton that are harmful to aquatic life when they bloom may be present in the water. It can also fuel extra algal growth that causes turbid waters or large mats, which block out the sunlight and kill submerged plants such as eelgrass. When the phytoplankton that makes up these large blooms die and fall to the bottom, animals and microbes in the sediments ramp up oxygen use to decompose this extra organic debris, and in turn cause low oxygen (hypoxic) or no oxygen (anoxic) conditions in the water. Once this happens we see a loss of animals on or in the bottom sediments and even fish kills with the eventual loss of biodiversity and resource value.

How do oysters remove nitrogen from our waters? Oysters are filter feeders; they remove particles from the water by active filtration. These particles contain nitrogen, primarily in algae (phytoplankton), and serve as food for growth of oyster tissues and shells, or if unusable are rejected in loose packets which fall to bottom sediments as biodeposits (pseudofeces). Pseudofeces are a specialized method of expulsion that filter-feeding bivalve mollusks use in order to get rid of suspended particles such as particles of grit or detritus that cannot be used as food, which have been rejected by the animal. Oysters and other benthic bivalves are important in recycling nitrogen (usually in the form of ammonium, NH_4^+) within both subtidal and intertidal systems. Once the nitrogen is in the sediments, microbes may break it down and release nitrogen back in plant available forms or may support denitrification (conversion of inorganic N to nitrogen gas N_2). As nitrogen gas cannot be used by plants directly to support growth, this process effectively removes nitrogen from the estuary. Also, all the nitrogen that is in any oysters that are harvested is removed from the system as well.

So, oysters remove nitrogen in two ways?

Yes! One way in which oysters remove nitrogen is through "bioextraction." That is, as the oyster is growing it takes up nitrogen and holds it in both its shell and tissues. When we harvest this oyster for consumption or sale, we're removing that nitrogen from the system. But while oysters may be filtering and transforming one type of nitrogen (organic N), they're also producing another form of nitrogen via digestion to a waste product — ammonium. This is calculated in the overall nitrogen recycling rate to help calculate how efficient an oyster is at removing nitrogen from the system. The efficiency at which they remove nitrogen is complex due to a number of issues (food quality, amount, environment, etc.). Our study provides important insights to help understand and quantify these processes.

Coastal Ponds of Southeastern Mass and Rhode Island

Some of the most unique and valuable resources in Southeastern New England are the coastal lagoons, embayments, and estuaries that exist at the boundary between land and sea. The salt ponds along the south shore of Rhode Island and Massachusetts are examples of coastal lagoons—shallow and separated from the ocean by a barrier beach. These areas are often protected, shallow, and feature a mix of fresh and salt water, making them a unique habitat distinct from both freshwater and ocean environments.

As coastal development continues, human activity is having increasing impacts on the salt ponds and other coastal embayments . For example, much of the development in the salt ponds region relies on individual septic systems for wastewater treatment and disposal rather than sewers, which transport waste to a wastewater treatment facility that can have significantly more nitrogen removal. Even properly functioning septic systems release nitrogen to the groundwater and improperly maintained systems contribute other contaminants as well (e.g. indicator bacteria) at an even higher cost to water quality.

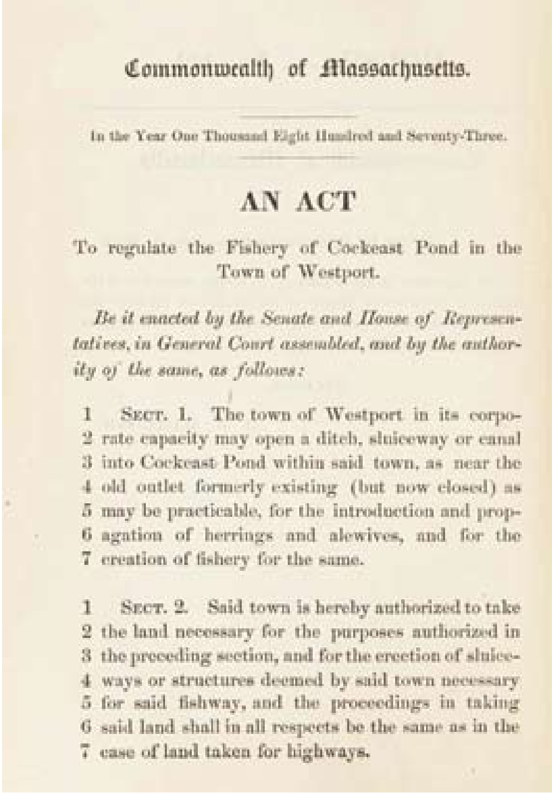
Cockeast Pond's Natural History

Cockeast Pond is a 92 acre salt pond, tributary to the Westport River Estuary (Westport Harbor) at the southern region of the Town of Westport, near the Rhode Island border and Buzzards Bay. The Pond is separated from Buzzards Bay by a barrier beach and exchanges water with the Westport River estuary via a man-made channel and culvert under River Road. The culvert is placed in a manner whereby tidal inflows are significantly restricted and the pond is fresh/brackish (~10 ppt) compared to the adjacent Westport Harbor (25ppt-30ppt), as the inflowing marine waters are diluted with freshwater entering the pond via direct groundwater discharge and a small intermittent stream. Cockeast Pond is the only brackish pond in the Westport River watershed. Past years of nutrient related water quality and macroalgal observations indicate a system that is currently showing clear signs of nutrient related habitat impairment from nitrogen (N) enrichment due to its elevated watershed N loading and its restricted tidal exchange.

- Classified as a Great Pond as it is larger than 10 acres and therefore is a water of the Commonwealth.
- Westport Historical Society's map collection—the 1780 map depicts the Pond as an open embayment connected by a channel to the West Branch of the Westport River Estuary.
- In 1873 the Commonwealth's legislature gave the Town of Westport permission to regulate the pond as a fishery resource.

The importance of Cockeast Pond:

- WRWA has monitored Cockeast Pond water quality since 2008 to create baseline data from which to gauge change. Research found that poor water quality resulted from pollution due to increased nitrogen loading, is a particular concern.
- It provides a unique and diverse habitat for many species of plants and animals including eels, white perch, alewife and river herring.
- It contributes nitrogen to the Westport River, which is also above its healthy limit for that nutrient and has a USEPA/MassDEP issued TMDL under the Clean Water Act. The TMDL sets nitrogen threshold that must be achieved to restore the water and habitat quality of this large estuarine system.



Commonwealth of Massachusetts.

In the Year One Thousand Eight Hundred and Seventy-Three.

AN ACT

To regulate the Fishery of Cockeast Pond in the Town of Westport.

Be it enacted by the Senate and House of Representatives, in General Court assembled, and by the authority of the same, as follows:

SECT. 1. The town of Westport in its corporate capacity may open a ditch, sluiceway or canal into Cockeast Pond within said town, as near the old outlet formerly existing (but now closed) as may be practicable, for the introduction and propagation of herrings and alewives, and for the creation of fishery for the same.

SECT. 2. Said town is hereby authorized to take the land necessary for the purposes authorized in the preceding section, and for the erection of sluiceways or structures deemed by said town necessary for said fishway, and the proceedings in taking said land shall in all respects be the same as in the case of land taken for highways.

Cockeast Pond's Connection to the Westport River

Culvert Under River Road and Repairs

1873— The Town of Westport is given permission to take land and maintain the connection from Cockeast Pond to the Westport River Estuary (Westport Harbor) to regulate the fishery. It is a man-made channel and culvert that passes under River Road.

2005—The Town of Westport completes a herring run restoration project, funded with $10,045 from the Buzzards Bay National Estuaries Municipal Grant Program (BBNEP), with application assistance from the WRWA. The aging metal pipe culvert connecting the River to Cockeast Pond had collapsed, restricting passage of fish into the pond. The funding allowed for a new culvert to be installed under River Road. In addition, BBNEP staff assisted the Town with permitting and wetland delineation. The work was done by the Westport Highway Department. However, the replaced culvert was perched too high due to utilities located within the project area, and the targeted improved flow was only partially achieved.

2010—The Town of Westport Fish Commissioners, WRWA, the former Westport Fishermens Association and a group of concerned individuals raised money to reset the 2005 culvert. The old culvert was set incorrectly and led to Cockeast Pond becoming a freshwater pond during that time. With permits in place, the culvert was removed, the water line reconfigured, and then the culvert reset to a 1% grade. WRWA contributed funds and devoted multiple staff to aid the project. Unfortunately, even with the repairs, the culvert still does not offer an ideal fish passage or water exchange to promote better flushing.

WRWA Seeks Ecological Research To Support Pond Management

Scientific Research on Cockeast Pond

2008—2014—WRWA hired new staff to undertake a Pond Water Quality Monitoring Project. The Coastal Systems Program (CSP) at UMASS Dartmouth School of Marine Science and Technology (SMAST) provided analytical testing and technical services. Sampling occurred four times each summer, establishing baseline information on salinity and nutrient levels in the pond.

2015—WRWA secured private funding to perform an in-depth scientific study to determine the nutrient related health of the pond and factors that may be affecting it.

- WRWA had examined pond water quality for prior 7 years to create baseline data.
- Ecological impact of increased nitrogen loading is of particular concern.
- More and larger algal blooms and increased plant growth degrade the pond's ecosystem and affect its use and resource value.
- The pond contributes nitrogen to the Westport River, which is already above its healthy limit for nitrogen.
- Determine the extent of the pond's change in water chemistry and ecological health.
- The goal was to identify causes of the change and recommend actions for remediating, restoring and maintaining the pond's health.
- This was a cooperative effort between WRWA, UMASS Dartmouth Coastal Systems Program, and stakeholders.

2016—Present—The Coastal Systems Program at UMASS received a USEPA Southeast New England Program (SNEP) Watershed Grant. Past research done with WRWA on the pond contributed to the success of the grant application.

Baseline Research Methods

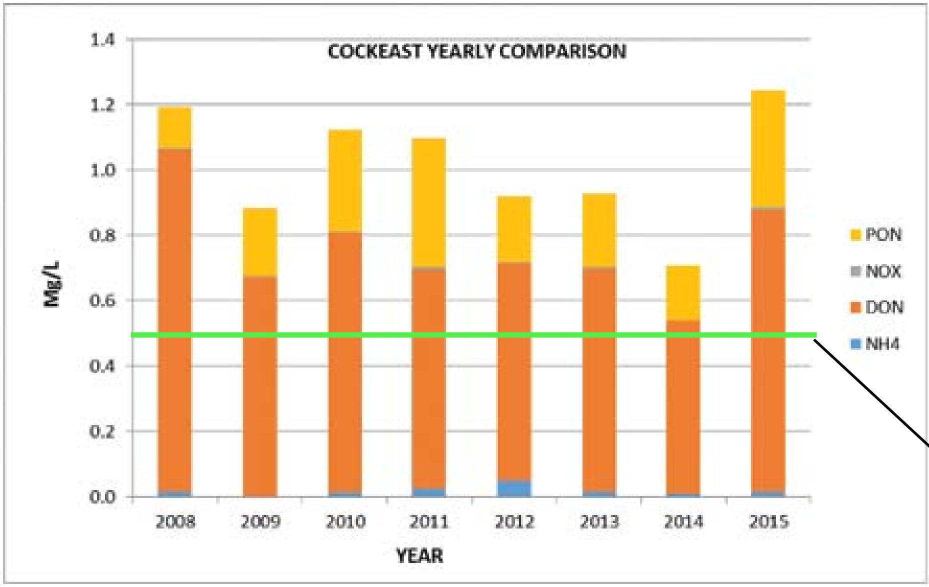
Baseline Data Collected

Data was collected over multiple years to determine water circulation and exchange, pond biology, and nutrient loading.

- **Tide gauges**—multiple deployments over three years to support estimates of tidal exchange and importance of wind in pond circulation.
- **Tidal Flux**—direct measurements of tidal inflow and outflow through the herring ditch connecting Cockeast Pond to the lower portion of the Westport River estuary were taken. This provided direct measurements of tidal volume exchange as well as an estimate of the residence time of water in the pond based on the pond volume calculated from the measured bathymetry (underwater pond depth).

- **Benthic animals**—sampling of sediments throughout the pond was conducted to determine the species of animals colonizing the bottom sediments and the populations of inhabitants, which is an indicator of ecological health.
- **Land use data**—determine site-specific land uses and the associated nitrogen loads using geographic information programs and site surveys.
- **Nitrogen input** through surface water, stream flows and other sources over 3 years.
- **Habitat assessment**—determine the health and diversity of flora (including macroalgae) of the pond ecosystem.
- **Time-series water column oxygen and chlorophyll-a measurements** —determine oxygen levels, critical to ecosystem health. Chlorophyll- a is a proxy for phytoplankton biomass
- **Benthic nitrogen regeneration in bottom sediments**—determine extent of recycling sinks of nitrogen and complete a nutrient mass balance for the pond.

Parcels within the Cockeast Pond watershed area - data from the Town of Westport Assessors Office



Healthy Level of Nitrogen determined by the Massachusetts Estuaries Report for the West Branch.

Comparison of water column Nitrogen concentrations from 2008-2015

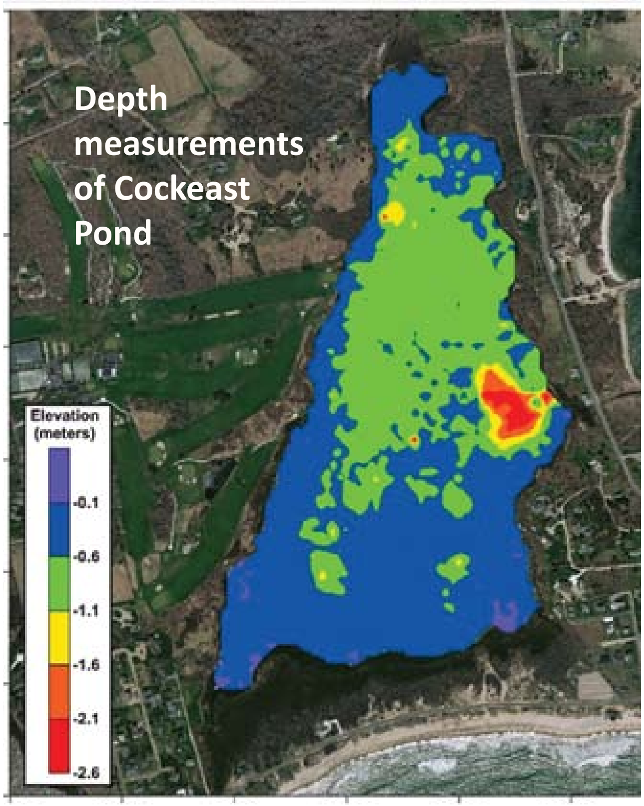
Baseline Results

Comparison of Data with Previously Collected Water Quality Results

Total nitrogen values have been variable in Cockeast Pond over the sampling years, and there is no clear trend in summer Total Nitrogen (TN) levels. Instead, it appears that the variation results in part from periodic changes in tidal exchange at the culvert. Over this 8-year period, 2015 has the highest TN concentration (1.23 mg/L). For all 8 years, organic forms of nitrogen dominate the total nitrogen pool, with dissolved inorganic nitrogen (DIN) contributing only a small fraction. The high TN levels (>0.7 mg N/L) are indicative of a nitrogen impaired estuarine water body.

Bathymetric surveying results

Critical to the completion of a detailed assessment of the nutrient and habitat characteristics of Cockeast Pond is having an accurate measure of the volume of water in Cockeast Pond, as well as the rate of tidal exchange between the pond and Westport Harbor and freshwater inflows. This information combined with water quality characteristics of water in the pond allows for the calculation of residence time (time to exchange pond volume) of that water and the mass of nutrients available in the pond for stimulating plant productivity. Based on depth range and bathymetry, volume was calculated for each depth interval and summed to determine the total volume of Cockeast Pond (210,046 m^3). More than half the pond volume is represented by area that is in marginal shallows, 0.0 to 0.5 meter depth range.



Tidal Flux Experiments:

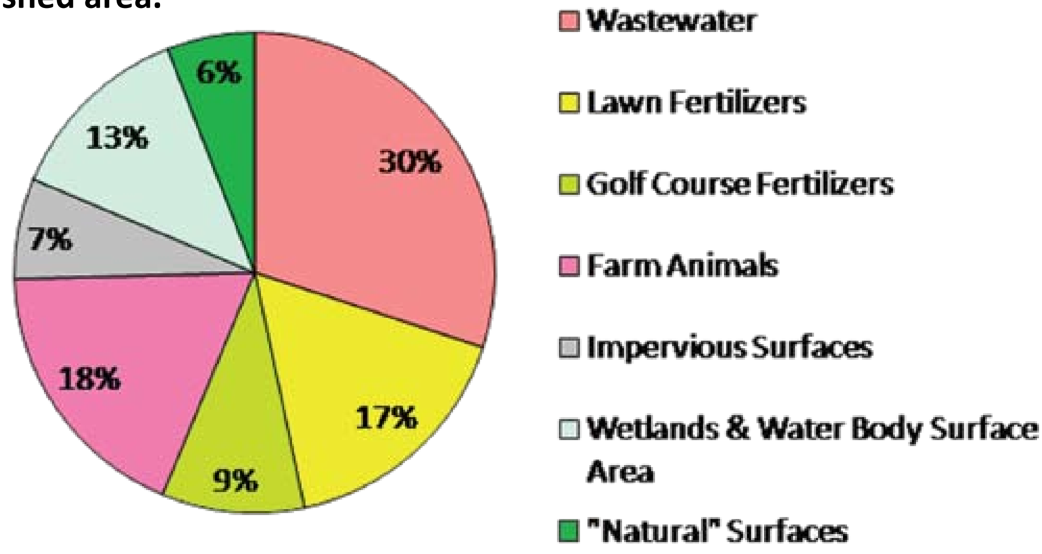
Measurements of tidal inflow and outflow through the channel and culvert connecting Cockeast Pond to Westport Harbor (the lower portion of the Westport River estuary) was undertaken to provide direct measurements of tidal volume and nutrient exchange as well as to verify the residence time of water in the pond given the pond volume calculated from the bathymetry data. The tidal flux experiments were also undertaken to determine the degree to which Cockeast Pond is actually influenced by tidal changes in Westport Harbor. A total of three tidal nutrient flux samplings (includes determination of freshwater flow and salt water flow) were conducted in the summer 2015. SMAST scientists planned the study to observe the degree of tidal exchange under both maximum and minimum tidal forcing conditions (exclusive of storm events).

It should be noted that even while a clear tidal signal was measured in Cockeast Pond during the third tidal flux sampling, the overall change in water level in the pond was a mere 0.10 meters, only 7% of the ~1.4 meter change in water level measured by the "offshore" gauge in Westport Harbor. Over the three tidal flux samplings, the change in Cockeast Pond water level ranged from 0.10 m to 0.30 m. This is important as it indicates only a low exchange of water between the harbor and the pond, a critical consideration for controlling the water quality in Cockeast Pond.

Results show that Cockeast Pond generally functions as an exporter of freshwater and nutrient load to the larger Westport Harbor system. There may be times during the year when very specific conditions exist, allowing more flow to enter Cockeast Pond from the harbor than leaves on the ebb tide, thereby reducing the amount of nutrient load leaving the Pond. However, long-term recording shows that this occurs infrequently.

Benthic Infaunal Analysis:
The existing benthic animal community is consistent with a nitrogen enriched stressed brackish habitat. The community has very low diversity, generally low evenness and low productivity. While the species were generally similar from the shallow north to the deeper south basin, the number of individuals in the north basin was very low, less than 1/10th of the southern basin. This difference appears to be related to the spatial distribution of macroalgal accumulations, based on a pond-wide underwater video survey. Restoration of benthic habitat will require a lowering of the current level of nitrogen enrichment throughout the pond waters and likely an increase in salinity/tidal flushing.

Inital Study Determined - Sources of Nitrogen and Percent Load in the Cockeast Pond watershed area.



Oyster Research (SNEP)—The Experiments

Primary Project Goals:

- Determine the effect of oyster aquaculture on water column nitrogen concentrations.
- Assess the total mass of nitrogen removed from Cockeast Pond through oyster aquaculture and subsequent oyster harvest based on varying water quality parameters and oyster growth rates.
- Determine the extent of enhanced denitrification and rates of biodeposition in this brackish pond associated with oyster aquaculture.

As communities across Southeast New England seek new approaches to lessen the impact and impairment from watershed nitrogen enrichment, oyster aquaculture is a gaining momentum as a nitrogen mitigation tool across the region. While the plans to use aquaculture continue to grow, there has been almost no quantification of the effectiveness of the approach.

To address this gap, Cockeast Pond —a saltwater pond with a high level of nitrogen enrichment—was used as a natural laboratory. Which had established baseline conditions from years of monitoring. Oysters were deployed and the resulting habitat and water quality were monitored for changes. This project will assess and quantify the ability of aquaculture as a method of nitrogen reduction.

The pond has been selected for study due to its high level of nitrogen enrichment, its physical structure, its suitability for oyster culture and appropriateness for measuring nitrogen removal rates. The results are aimed at restoring this specific salt pond, but also it providing quantitative information to the numerous towns throughout southeastern Massachusetts that are seeking new nitrogen removal approaches for their estuaries and salt ponds, and are considering the use of shellfish for nitrogen remediation.

UMASS Students and WRWA volunteers sorting oysters and cleaning bags

Hundreds of young oysters counted and sorted through a 9 mm mesh.

Research Methods

Task 1: Oyster Deployments in Cockeast Pond

Approximately 1 million seed oysters were deployed as either singles or remote sets. The oysters were deployed in floating surface bags. SMAST graduate students and interns worked to tend to the floating oyster arrays with supervision by scientific staff of CSP and WRWA scientists. Field support and technical assistance was also provided by the Town of Westport Shellfish Department.

Task 2: Water Quality Sampling for Pond with Oysters

Sampling stations were established inside and outside the oyster aquaculture area in a pattern to assess near and far field effects and built on previous sampling locations in order to relate new water quality data to historical data collected by WRWA in collaboration with CSP. Sampling was undertaken biweekly during the summer growing season (May-September) with an additional sampling taking place in April before the growing season and again in October/November as the growing season was ramping down. Seven to fourteen sampling events were undertaken in each year (2016-2020) dependent on the timing of oyster deployment and overwintering.

Task 3: Dissolved Oxygen and Chlorophyll-a Measurements

YSI-6600 autonomous sensors were deployed in Cockeast Pond to measure dissolved oxygen (D0), salinity, temperature and chlorophyll-a (via fluorescence) every 15 minutes within the oyster deployment area and at a far field station to determine background levels. The moorings were maintained and calibrated bi-weekly by CSP scientists for the duration of the deployment, which focused on the portion of the growing season when DO concentrations typically reach a minimum and phytoplankton are most productive (e.g. July and August).

Task 4: Oyster Biodeposition Rates and Biodeposit Impact Areas

CSP scientists quantified particulate capture and deposition from oysters within oyster aquaculture areas using particle traps attached under the oyster bags. Traps were deployed through the growing season over a range of water column particulate concentrations. Data collected from particle traps was used to track the amount of particulate organic nitrogen and carbon deposited by oysters held in grow-out bags and from individual oysters in separate collectors. An upward looking acoustic doppler current profiler (ADCP) was placed in the deployment area to determine the direction and speed of water transport typical during the oyster-growing season. The area of sediment surface influenced by the oyster biodeposition was a modeled from measured biodeposit settling rates and water flow rate using video and acoustic velocity measurement techniques refined by CSP scientists in other oyster aquaculture studies. The relationship of water column particulate levels and biodeposition rates were determined over the range of oyster sizes, time and deployment approaches to develop algorithms for predicting biodeposition rates.

Task 5: Enhanced Nitrogen Removal by Denitrification in Sediments Resulting from Biodeposition

Intact sediment cores (10 to 12) were collected by SCUBA diver over the oyster growing season and incubated at the CSP laboratory at SMAST in order to quantify sediment oxygen uptake (carbon turnover) and nutrient fluxes both within the oyster aquaculture area and outside of the area potentially influenced by the oysters. Most critically, CSP scientists directly measured denitrification rates to quantify the degree to which intensive oyster aquaculture can change sediment nutrient flux rates through enhancement of denitrification. Denitrification is routinely measured in estuarine and fresh pond sediments by Isotope Ratio Mass Spectrometry (IRMS) in the SMAST Stable Isotope Facility (M. Altabet). This method allow the nitrogen gas (N_2) produced by denitrification to be quantified against the large background of atmospheric N_2 by analysis of its ratio with the atmospheric inert gas Argon.

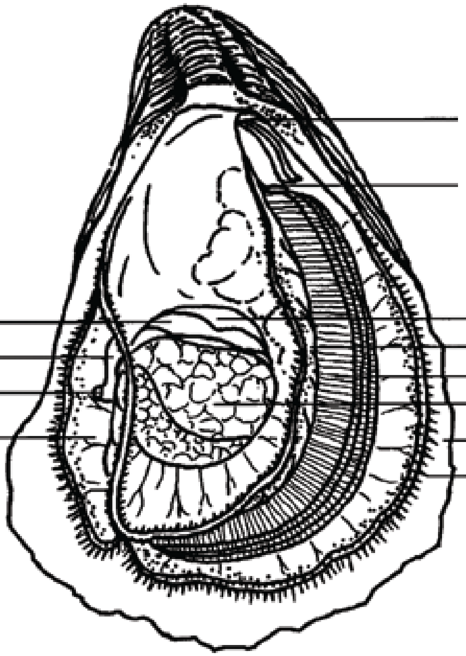
Task 6: Potential of Nitrogen Removal through Bioextraction

Oysters were sub-sampled monthly for mortality and growth (increase in shell length). A sub-sample of oysters was also collected to determine whole oyster, soft tissue, and shell weights, as well as, carbon and nitrogen content. Dry weights were determined for the soft tissue and shell samples. These samples were separately ground using a mortar and pestle. Carbon and nitrogen content of the ground sample were determined using a Perkin Elmer 2400 Series II CHN Elemental Analyzer for particulate nitrogen and carbon.

Results from Full Oyster Deployment

Task 1 Results: Oysters survived and grew in Cockeast Pond incorporating nitrogen from the water column.

Adult oysters can tolerate a salinity range of 5 to 30 PSU (practical salinity units), but are most successful in saline waters ranging from 10 to 28 PSU. Oyster growth slows significantly at 7 PSU and ceases at 5 PSU. However, an oyster's ability to tolerate low salinities depends on temperature. Oyster can better tolerate cooler low salinity water than warmer low salinity water. Minimum salinity measurements were recorded in early June 2018 (4.9 PSU); however, water temperatures were low enough (17.2 °C) preventing a noticeable mortality event. The average summer salinity of Cockeast Pond was 11.2 PSU (Table 1). These low salinity conditions may lead to sub-optimal filtration and growth rates. However, oyster drills and predatory starfish are generally absent being restricted to higher salinity waters (>20 PSU). Decreased mortality attributable to a lack of predators may be a desirable trade-off for cultured oysters. Furthermore, low salinities may lead to greater oyster nitrogen contents (i.e. more nitrogen removed upon oyster harvest; unpublished data), which could balance or outweigh slow growth rates.



The anatomy of an eastern oyster, *Crassostrea virginica*

Cockeast Pond avgerage long term results	**Temperature (°C)**	**Salinity (optimal)**	**Particulate Organic Carbon - POC (µM)**	**Particulate Organic Nitrogen -PON (µM)**	**Total Pigments (µg/l)**
	8.3 – 27.0	11.2 ± 4.2	152.4 ± 74.2	19.0 ± 8.8	12.2 ± 5.9

Table 1. Time weighted average water quality measurements associated with the oyster growing season (April – November). Seven sampling events occurred July-September, 2016; 13 June-November, 2017; and 14 May-November, 2018. Surface grab samples were collected mid-morning independent of tide stage. Surface temperature measurements are expressed as a range (minimum-maximum); salinity, POC, PON, and total pigment measurements are expressed as the mean and 1 standard deviation (mean ± SD).

Results from Full Oyster Deployment

Survival of Year 1 (Y1) and Year 2 (Y2) oysters found in Table 2 suggest that the Cockeast Pond oysters are most vulnerable during their first year of growth. Survival of the Y1 cohort during the 2018 growing season was 39%, whereas, survival of the Y2 cohort during 2018 was 94%. The Y2 cohort experienced similar high mortality during its first year of growth (2017; data not shown); the Y2 survival measurement (94%) reflects survival during the second year of growth only.

Year Class	Length of Deployment (days)	Mean Stocking Density (oysters /bag)	Initial shell length (mm), whole weight(g)	Final shell length (mm) & whole weight(g)	Final shell length (mm) & whole weight(g)
Y1	138	2000 (4 mm*) 500 (9 mm*)	8.6, 0.1	33.9, 4.9	39
Y2	222	500	21.0, 1.2	50.2, 12.9	94

Table 2. 2018 full oyster deployment information. Year 1 (Y1) oysters were first deployed in 4 mm mesh bags, then size-sorted and redeployed in 9 mm mesh bags once large enough.

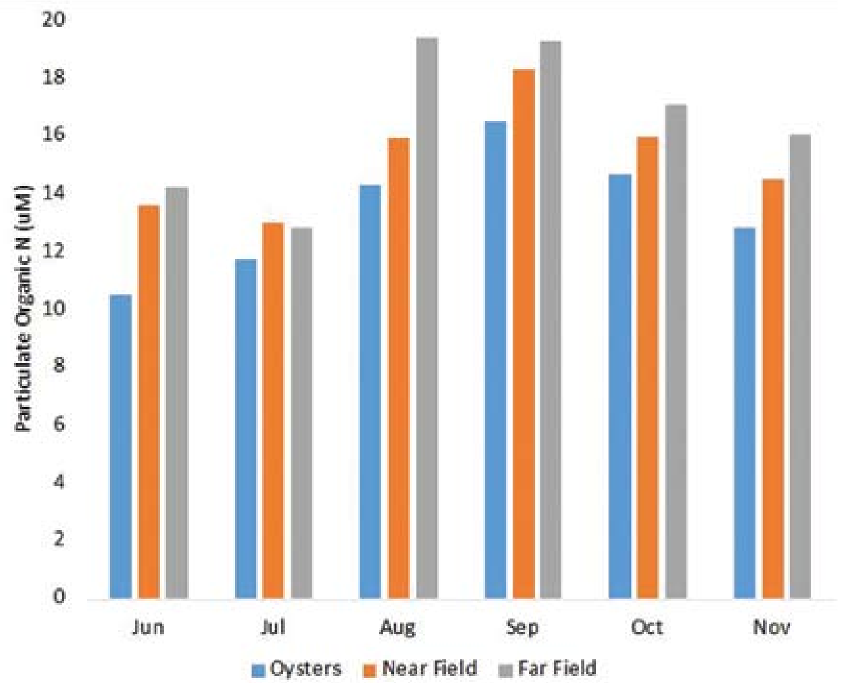
The primary cause of Y1 oyster mortality was presumably an inability to capture sufficient food for maintenance and growth of their soft tissue and shell. Subsampled mortalities did not explain actual mortality rates; therefore, it is likely that many of the smallest oysters died and their shells broke apart within the first few months of deployment resulting in an underestimate of Y1 mortality. However, the potential nitrogen release from the breakdown of dead Y1 oysters is insignificant compared to nitrogen removed upon harvest.

Because oysters are sessile (not free to move about), they are unable to move toward food supplies and the smallest oysters may not be able to outcompete larger neighboring oysters for access to food in high-density deployments. In whole, low food replenishment (flow rate through the bag mesh), warm temperatures, low salinity, and potentially poor food quality may all contribute to low survival of Y1 oysters deployed in July in Cockeast Pond.

Water Quality Results

Task 2 Results: Oyster reduced nitrogen levels in Cockeast Pond.
Scientists found that oyster mediated particulate organic nitrogen (PON) reduction occurred throughout all deployments but was least efficient in July. PON is an important component of oyster food and a measure of overall food availability and one indicator of water quality along with levels of total pigment and dissolved oxygen. Oyster filtration rate, the volume of water filtered per unit time, is largely a function of temperature and salinity. In July 2018, the average salinity was 7.8 PSU and the average temperature was 26 °C. Low salinity and warm water can cause physiological stress and reduced filtration rates, which appeared to be the case here.

Cockeast Pond is a well-mixed estuary with no horizontal gradients in water quality. However, during 2018, historical water quality sites (CP1, northern basin; and CP2, southern basin) showed greater PON concentrations compared to PON measurements within the aquaculture area. Additionally, in 2018, scientists found a 10-33% reduction in PON between CP2 and the aquaculture area (July-November), and a 13- 36% reduction between CP1 and the aquaculture area for the same period. Furthermore, inter-annual comparisons of POC, PON, and total pigment (phytoplankton biomass) measurements collected at CP2 during July-September show reductions of all three water quality markers from 2016 (pre-oyster) to 2018 (full scale deployment). While suggestive, further analysis is needed to determine whether this reduction is the product of oyster filtration or inter-annual variability.



2018 monthly averaged water column PON concentrations within the aquaculture area and at distances away from the aquaculture area: Near field (5m) and Far Field (> 5m). Averaging over the growing season (June to November), PON was reduced 18% between the far field and aquaculture site.

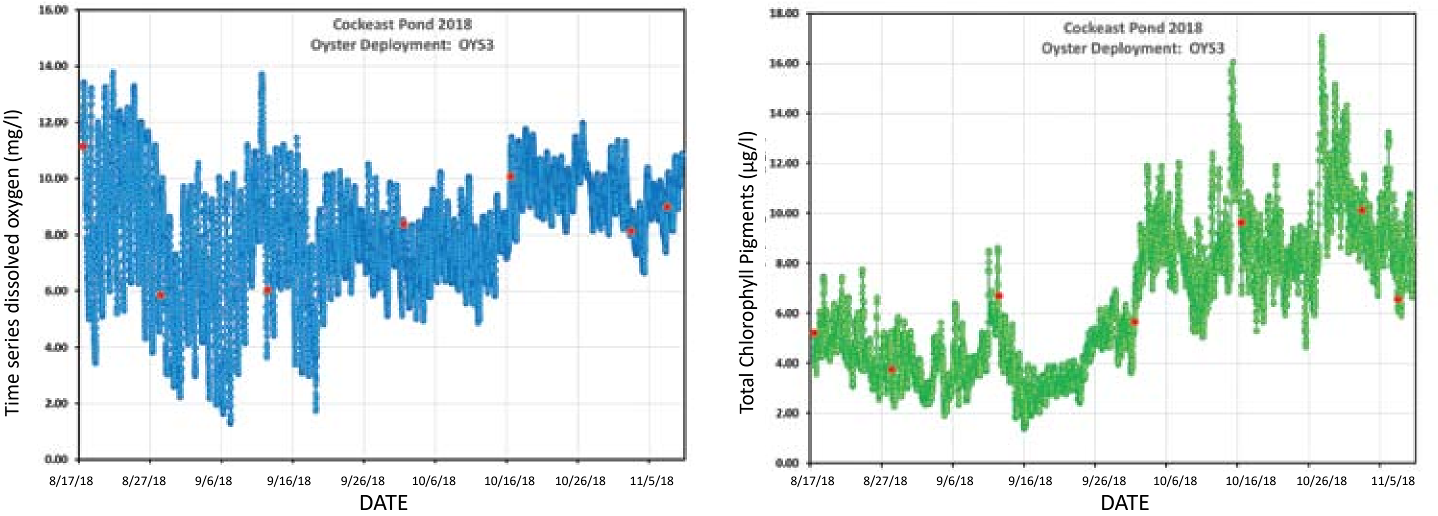
Task 3 Results: Time-series Dissolved Oxygen (DO)/Chlorophyll-a Moorings

Phytoplankton (measured by chlorophyll-a) is filtered from the water column by oysters for energy and growth. Some of the nitrogen in the phytoplankton is sequestered in oyster tissue, thereby lowering the amount of nitrogen within the surrounding waters particularly as PON. Critics of oyster aquaculture warn that only a fraction of the phytoplankton filtered is sequestered, while much of the phytoplankton PON is released as feces and pseudofeces and accumulates in bottom sediments resulting in higher sediment oxygen demand and sometimes even local declines in bottom water oxygen concentrations. Both phytoplankton and dissolved oxygen concentrations can change rapidly in a matter of minutes to hours from changes in light or mixing or in the case of phytoplankton, oyster filtration, (see Plots 1 and 2) thus requiring autonomous instruments to capture short term events.

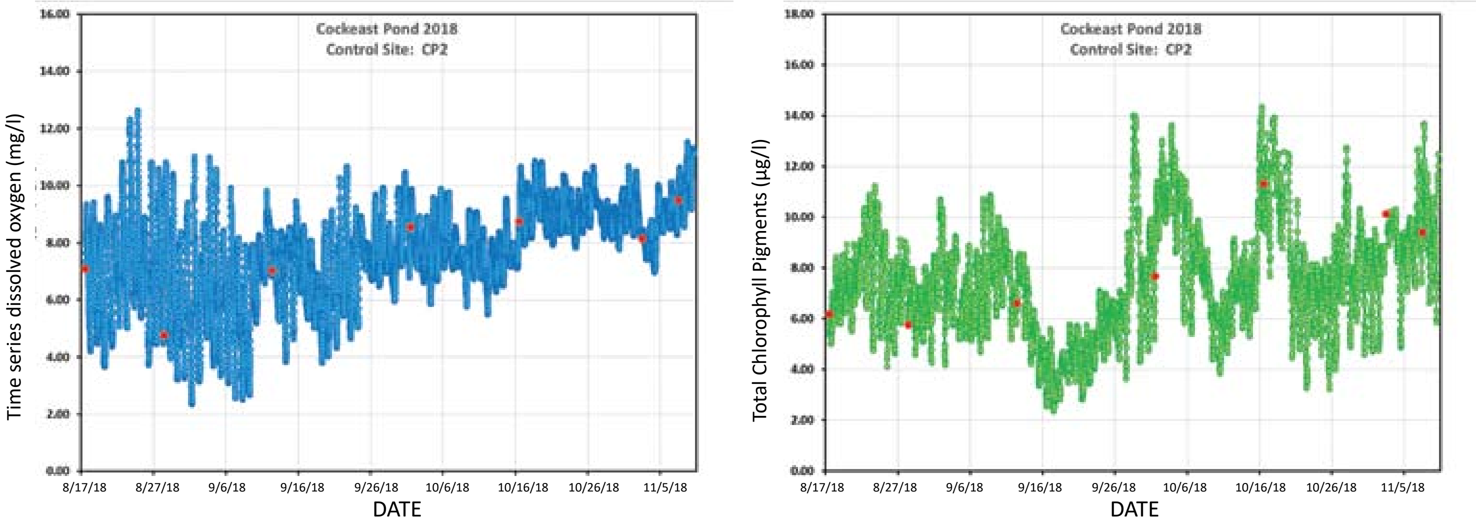
Comparing the oxygen record at the control site with the record from under the oysters showed an overall similar pattern over time, but with consistently larger diurnal oxygen excursions under the oyster arrays and lower oxygen minima (Aug. 27-Sept. 20). Oxygen concentrations under the oyster arrays fell below 2 mg/L on 4 separate occasions; oxygen concentrations at the control site never fell below 2 mg/L, but were only slightly above 2 mg/L during the same time period. Oxygen concentrations appeared not to be affected by the oyster aquaculture. The strong diurnal excursions during the same time period imply that the oxygen deficits observed under the oysters were most likely a result of macrophytes, which cause a diurnal cycle in oxygen levels. In contrast, changes in oxygen from organic inputs from feces and pseudofeces which cause lowered oxygen concentrations without a diurnal component. However, it is likely that the oysters did raise the overall baseline level of oxygen uptake upon which the oxygen exchanges associated with the macrophytes were operating.

Chlorophyll concentrations at the control site were generally higher than at the oyster site during the first 5 weeks, implying that phytoplankton was being removed from the water column by oyster filtration. During the latter part of the record a phytoplankton bloom occurred causing chlorophyll concentrations at both sites to exceed 10ug/L. During the same period chlorophyll concentrations at the oyster site were often higher than the control site. We expected higher filtration rates by the oysters and lower chlorophyll concentrations once the concentrations exceeded 10ug/L, as was seen under similar conditions in Mashpee River and Bournes Pond where a 30-60% decrease in chlorophyll concentration was observed in the oyster areas. Unlike in the Mashpee River and Bournes Pond, however, there is very little tidal current in Cockeast Pond. The lack of significant water movement in Cockeast Pond may limit access to the phytoplankton and the filtration efficiency of the oysters compared to those tidally influenced sites. Growing oysters in mesh bags requires sufficient waterflow to replace the water and plankton faster than the filtration rate, otherwise particle removal can be reduced.

In general, the time series data indicates slightly lower water quality beneath the oyster arrays, but does not represent a significant decline. The oxygen record suggests that the trapping of macrophytes within the deployment gear was most likely responsible for the low oxygen observed, and only partially the result of increased sediment oxygen demand created by localized deposition of feces and pseudofeces. The relatively low flow environment of Cockeast Pond makes the quantification of phytoplankton uptake by the oysters extremely difficult, but during the first half of the time series there was a clear removal of chlorophyll and an increase in water clarity, attributable to the oysters.



Plot 1 - The time series dissolved oxygen (left) and chlorophyll (right) from beneath the floating oyster bags, summer 2018. Calibration samples, collected in situ, are represented by red dots. Low summer phytoplankton levels are consistent with the observed oyster growth rates, which increased during the fall bloom period.



Plot 2. Time series dissolved oxygen (left) and chlorophyll (right) from control site located northeast of oyster propagation area. Calibration samples, collected in situ, are represented by red dots.

Task 4 Results: Biodeposition Rates and Biodeposit Impact Areas

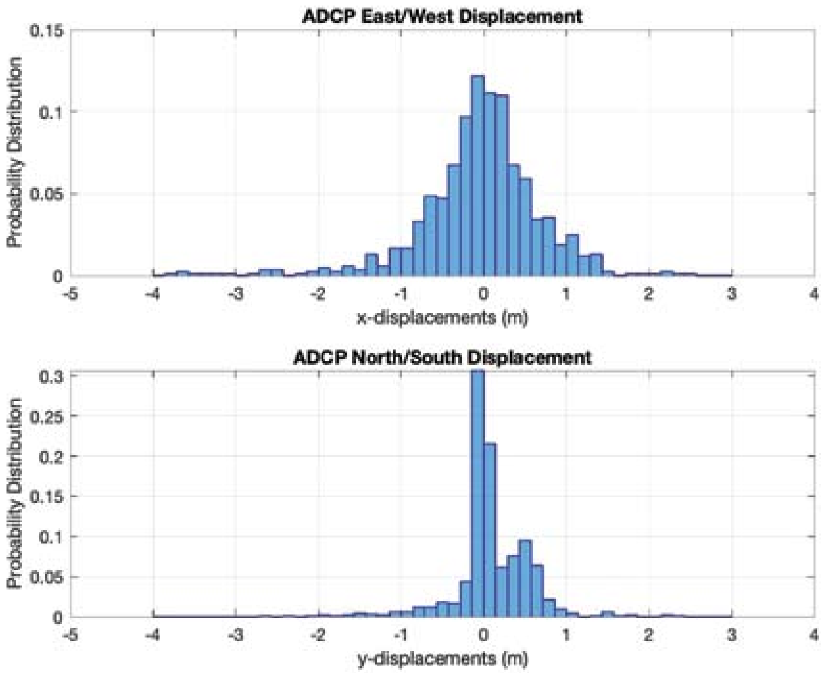
Biodeposition rates can be explained by temperature, salinity, and food availability. Generally, biodeposition increases with increasing water temperature, salinity, and food availability up to some maximum value for each parameter. Biodeposition rates were greatest in June, which suggests that temperature and salinity were not determining factors because salinity typically increases throughout the growing season in Cockeast Pond and the temperature is comparatively warmer in July and August. Furthermore, the average water temperature (2016-2018) was 22.8 °C in June and 21.8 °C in September; however, salinity was more than two times greater in September compared to June, but size normalized biodeposition rates were nearly three times lower in September than in June. Therefore, it is likely that food quantity and quality affected biodeposition rates. Food concentrations were adequate throughout the growing season, but it is possible that food size and replenishment rate (flow through the bag mesh) was most favorable in June.

Water column velocities, total depth, and biodeposit settling rates were used to determine the area of sediment influenced by biodeposit settling from the surface bags. The area of sediments influenced by biodeposits is needed to determine the potential spatial distribution of enhanced denitrification. Here, the area of influence is described as the directional distance from biodeposit source, i.e., the bag from which it is released. The majority of biodeposits settle directly below the bags, but some biodeposits are dispersed by currents as they settle.

The extension of the biodeposition area is predominantly towards the north with approximately equal displacements in the east and west directions. The majority (>95%) of biodeposits will settle within one meter of the source bag in all directions. Therefore, the biodeposition area in Cockeast Pond extends about 1.0 m beyond the perimeter of the area with the floating bags.

Month	Stocking Density (oysters/bag)	Biodeposits (dry weight)	
		g/bag/day	mg/g DTW/hour
June	300	7.96 ± ND	1.89 ± 0.84
August	300	0.36 ± 0.04	0.11 ± 0.01
September	300	2.94 ± 1.38	0.66 ± 0.12
October	250	0.74 ± 0.03	0.44 ± 0.01

Table 3. Measured mean (± standard error) daily and hourly biodeposition rates. Biodeposit rates are reported as the mass of dried biodeposits collected per bag per day. Biodeposit rates are also reported as the mass of dried biodeposits per gram of dried oyster tissue weight (DTW) per hour, in this case, the rates are normalized to a standard oyster size.



Probability distribution of biodeposits from the source location (oyster) from an August 2018 Acoustic Doppler Current Profiler deployment.

Task 5 Results: Sediment Core Incubations and Analysis of Denitrification and Particulate Organic Nitrogen (PON) Cycle

Intact sediment cores were collected and incubated under in situ conditions to quantify sediment oxygen uptake (carbon turnover) and nutrient fluxes including denitrification. These cores were taken within the oyster aquaculture area as well as outside of the area potentially influenced by the oysters.

Background (control) denitrification rates were similar between the September and October benthic fluxes. However, sediment oxygen demand (SOD), NH4+, and denitrification rates in the biodeposit affected sediments were significantly larger during the October benthic flux. Since the bottom water oxygen concentrations were greater in October than September, which increased the depth of aerobic sediment, it is likely that coupled nitrification-denitrification was enhanced. The increase in denitrification was also likely supported by PON (food) having higher nitrogen content in October as seen by its lower C:N ratio. Oysters preferentially select nutritious particles (lower C:N), which in turn, affects the chemical composition of the biodeposits. Release of nitrogen rich biodeposits could enhance sediment nitrification and ultimately, denitrification. Lastly, Cockeast Pond has dense submerged aquatic vegetation, which starts to die off at the end of summer. The accumulation and breakdown of dead plant matter can also affect nutrient cycling by increasing the mass of organic matter in the surficial sediments.

		SOD	NH_4^+	NO_3^-	N_2-N	
		(mMoles/m²/d)	(uMoles/m²/d)	(uMoles/m²/d)	(uMoles/m²/d)	(mg/m²/d)
Sep-18	Control	53.46	127.42	-42.87	589.66	8.3
	Treatment	67.27	4820.90	-50.22	955.05	12.4
Oct-18	Control	51.42	290.23	-72.52	403.28	5.7
	Treatment	109.11	9753.01	-34.84	1676.81	23.5

Table 4. Summary of September and October 2018 benthic flux rates of sediment oxygen demand (SOD), ammonium (NH_4^+), nitrite+nitrate (NO_3^-), and nitrogen gas production (N_2-N); a negative rate indicates that the flux was into the sediment. Control rates are from cores with sediments not influenced by oyster biodeposits. Treatment rates are from cores collected directly below oyster bags where the majority of biodeposits settle.

Task 6 Results: Nitrogen Removal through Bioextraction

Oyster growth rates varied by month and oyster size. These differences are likely attributable to changes in water quality throughout the growing season. As stated above, salinity and temperature can affect oyster growth. In Figure 1 the lowest salinities corresponded with slowest growth rates (June and July). Once salinity increased past 10 PSU, growth rate increases. It is likely that oyster growth in Cockeast Pond is a function of salinity, as well as, food quality and quantity.

At the beginning of the 2019 growing season, the full-scale grow-out array was dismantled and replaced with four experimental plots containing 20 bags each with stocking densities ranging from 100 oysters/bag to 400 oysters/bag. The excess oysters from the full-scale deployment were transplanted to a permitted relay site in the Westport River in a separate attempt to re-establish a natural population. Between 6/3/19 and 6/7/19 an estimated 241,500 oysters including approximately 15,000 dead (shells) were transplanted. Theses oysters were from both the 2017 and 2018 cohorts and had a total mass of about 2100 kg containing 6.7 kg of nitrogen. On 12/2/19, an additional 131.5 kg of oysters containing 0.5 kg nitrogen were removed from Cockeast Pond resulting in a total nitrogen mass removal by harvest of 7.2 kg N in 2019.

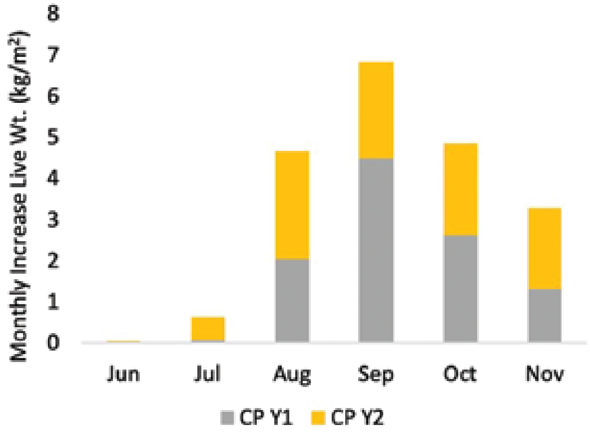


Figure 1. Monthly gains in live oyster weight (corrected for mortality) and monthly averaged temperature and salinity (T/S)

Oyster Population	Live Oyster N (% lw)	Net Live Wt. Gain (kg/m^2)	N Removed via Harvest (kg/m^2)
Y1	0.40	11	0.044
Y2	0.37	10	0.038

Table 5. 2018 field season live weight increase and potential for N removal upon harvest for each age class. The year one (Y1) cohort was deployed in July 2018 as 11 mm seed; the year two cohort (Y2) was deployed in late June 2017 as 9 mm seed. Nitrogen content is reported as percent nitrogen in a live oyster (% lw)

Project Conclusions and Summary

Between 2017 and 2018, more than one million oysters were deployed in floating bags in Cockeast Pond to determine and quantify the effect of oyster aquaculture on nitrogen cycling. Scientists reported that the full-scale deployment of year one (Y1) and year two (Y2) oysters appeared to produce reductions in water column particulate organic nitrogen (PON) when compared to two historical sites located in the north and south basins. Oyster mediated reduction in water column particulates is the result of oyster filtration (capture and removal of food particles from the water column) and subsequent biodeposition. Scientists found that biodeposit loading to the sediments significantly affected nitrogen cycling in the sediments, increasing both the rate of remineralization, release of ammonium and the mass of nitrogen removed through denitrification. Ammonium release was 34 and 38 times greater in biodeposit areas than control areas during the September and October fluxes, respectively. Scientists note that greater sediment oxygen demand (SOD) and ammonium release rates are expected as a result of increased organic matter loading to the sediments; however, this is not an indication that oyster aquaculture negatively affects the sediment system. Low bottom water oxygen is a concern in nitrogen enriched basins, Low bottom water dissolved oxygen and even anoxic surface sediments have been reported in Cockeast Pond, including many locations not associated with oyster aquaculture. One goal of the project is to lower pond nitrogen levels, ultimately resulting in improved bottom water oxygen levels and habitat quality.

The comparatively large rates of ammonium release are likely attributable to slow moving water, which results in a smaller area of accumulated biodeposits, and the pond's long residence time, which favors greater rates of nutrient cycling. It is important to note that the ammonium nitrogen released is not new nitrogen, but rather nitrogen that had entered the pond waters previously which was taken up by phytoplankton, consumed by oysters, deposited and returned to inorganic nitrogen (thus recycled). However, despite high rates of ammonium release, scientists also found enhanced nitrogen loss through denitrification.

N_2 production by denitrification in sediments suggests that in addition to nitrogen removal through oyster harvest an additional 4.1 and 17.8 mg N/m^2/day were permanently removed via denitrification above background rates in September and October, respectively. Therefore, it is likely that **oyster aquaculture supports permanent nitrogen removal by creating conditions that increase nitrification and denitrification**. Lastly, oyster growth in Cockeast Pond was slow with the lowest growth rates occurring between June and July. This is unique to Cockeast Pond and should be taken into account if future aquaculture deployments are planned. Specifically, oysters deployed in early spring or late summer might benefit from increased food quality and quantity not necessarily available during late June through July. Although the nitrogen content of oysters remained relatively consistent between Y1 and Y2, the slow growth rates mean that oysters require 2-3 growing seasons to reach 2.5 inches (maximum size allowed in Cockeast Pond) rather than 1-2 years seen in more saline eutrophic estuaries in the region. For example the scientists report that oysters grown at experimental sites in Falmouth and Orleans, MA at >25 PSU reached 2.5 inches within 1-2 growing seasons (data not shown).

Multiple Benefits of Project

UMASS Students Graduate Research

Many students participated in the project as part of their graduate degree program.

Ranjoy Barua—The numerical modeling work used for the Cockeast Pond study was completed in partial fulfillment of the University of Massachusetts-Dartmouth Master's Degree thesis (January 2018) titled "Assessing Water Quality Improvement Strategies for Cockeast Pond, Westport, MA Using RMA2/RMA4" . All the modeling work undertaken in completing the thesis was under the supervision of Dr. Miles Sundermeyer (Director, Ocean Mixing and Stirring Laboratory, UMD-SMAST) and Dr. Brian Howes (Director, Coastal Systems Program, UMD-SMAST).

Micheline Labrie– PhD – Assessment of nitrogen cycling relative to floating oyster aquaculture was completed in partial fulfillment of the University of Massachusetts-Dartmouth Doctorate program dissertation (expected January 2021). Data collection, analysis, and interpretation for the purposes of the Cockeast Pond project and Micheline's dissertation were supervised by Dr. Miles Sundermeyer (Director, Ocean Mixing and Stirring Laboratory, UMD-SMAST) and Dr. Brian Howes (Director, Coastal Systems Program, UMD-SMAST).

Elizabeth Ells – PhD – Oyster incubation experiments were completed as preliminary research towards the University of Massachusetts-Dartmouth Doctorate program dissertation. Measurements of denitrification relative to individual oysters were conducted to determine the potential for nitrogen removal pathways not captured by sediment core collection and benthic flux measurements. These incubations were conducted in addition to tasks outlined in the SNEP grant; significant results will be reported in the SNEP grant final report. Oyster incubation experiments were undertaken under the supervision of Dr. Brian Howes (Director, Coastal Systems Program, UMD-SMAST).

UMASS Marine Science Graduate Course Developed From Project

An added benefit of this project was that Coastal Systems Program at SMAST was able to leverage other efforts of the project to support parallel University undergraduate and graduate teaching and research. Cockeast Pond was selected for the Marine Science Graduate Case Studies course (MAR-620), which continues to be performed as the project progresses. This not only enhances environmental education, but also trains young scientists on the implementation and testing of new nitrogen removal approaches for years to come. The information collected for the project is also being used for public education and training, filling a critical need for Massachusetts and bringing additional resources to the effort.

Community Benefits - Volunteers at WRWA Build Equipment

Through this grant partnership hours of in-kind work supported the project. WRWA Interns, Commonwealth Corps Environmental Educators and volunteers helped to build more than 600 oyster cages. Each bag took at least 30 minutes to construct properly. Two different mesh size bags were needed during the course of the experiments.

Presentations

Labrie, M.S., D.R. Schlezinger, M.A. Sundermeyer, and B.L. Howes. "Evaluation Of The Potential For Oyster Mediated Nitrogen Reduction In A Coastal Salt Pond: Year Three Findings" focusing on our comparison project in Lonnies Pond (Orleans, MA). 112th meeting of the National Shellfisheries Association. March 30 – April 2, 2020. Baltimore, Maryland. Abstract submitted.

Labrie, M., R. Samimy, and B. Howes. Oyster Aquaculture for Restoration of Water Quality in Two Southeastern MA Salt Ponds: Environmental Controls on Growth Rates and Nitrogen Removal. SNEP EPA Share-A-Thon. October 25, 2019. Providence, Rhode Island. Poster presentation.

Labrie, M.S., D.R. Schlezinger, M.A. Sundermeyer, and B.L. Howes. Quantifying the Potential for Nitrogen Removal Through the Harvest of Aquaculture Oysters from Southeastern Massachusetts Embayments. Poster presentation. Sigma Xi Annual Research Exhibit, April 17 & 18, 2019, Dartmouth, MA.

Labrie, M.S., D.R. Schlezinger, M.A. Sundermeyer, and B.L. Howes. Evaluation of the Potential for Oyster Mediated Nitrogen Reduction in a Coastal Salt Pond: Year Two Findings. Oral presentation. New England Estuarine Research Society Spring Meeting, April 27, 2018. Portsmouth, NH.

Howes, B.L., D.R. Schlezinger, M.S. Labrie, R.I. Samimy, J. Benson, S.J. Sampieri, A.D. Unruh, and P.J. Mancuso. Oyster Demonstration Project: Lonnies Pond Effect on Water Quality and Nitrogen Cycling. Oral Presentation. Town of Orleans Shellfish Working Group, February 6, 2017 .

Benefit to the Town of Westport and Westport Marine Services

The Marine Service Department from the Town of Westport was a critical partner in the project. They assisted in permitting the experimental activities in the pond with the Commonwealth's Division of Marine Fisheries. Because Cockeast Pond is classified as a prohibited area for shellfishing the oysters from the project could not be harvested and consumed. However the oysters could be relayed to another area (after testing for diseases) for further grow-out and oyster stock replenishment. The Town's Director of Marine Services, Christopher Leonard, was an active partner in helping to transfer oysters from the experiment to the Westport River, East Branch and ensuring regulatory compliance.

In total **over 238,000 oysters were transferred from the experiment and donated to the Town.**









Special Thanks

Ketcham Supply – All gear for the deployment of oysters in Cockeast Pond was purchased from Ketcham Supply. Thank you for your support and assistance in completing these tasks.

Riptide Oyster – provided 1,000 adult oysters for bottom deployment during the 2016 site selection phase. Additionally, 500,000 seed were purchased from Riptide Oyster in 2018.

Nicholas Uline – Designed and constructed a manual oyster tumbler used to size-sort the growing oysters, and constructed large biodeposition traps designed to capture biodeposits from a whole floating bag.

Roxanna Smolowitz, D.V.M. Associate Professor and Director, Aquatic Diagnostic Laboratory, Roger Williams University – performed pathology testing on Cockeast Pond oysters prior to relay to the Westport River.

Betsy White, Alan Austin, and Elizabeth Ells – conducted water quality sampling and monitoring of deployed gauges.

WRWA

The Westport River Watershed Alliance (WRWA) is a nonprofit, 501(c3), environmental organization established in 1976 to protect the natural resources of the 100-square mile Westport River Watershed. Located at the entrance to Buzzards Bay in Southeastern Massachusetts, the watershed encompasses parts of Dartmouth, Fall River, Freetown, and Westport in Massachusetts and Little Compton and Tiverton in Rhode Island.

WRWA has been working for over 40 years to educate watershed residents about sound environmental practices to protect our natural resources. Our education programs reach over 2,000 public school students during each academic year through in-class lessons and field studies. Our outdoor summer programs and outreach activities enrich the lives of more than 100 children.

Through our scientific efforts, we continue multiple collaborative programs of measuring water quality. We analyze, document, and communicate the results about the condition of the River and watershed to residents. WRWA has instituted numerous local scientific research efforts. We advocate for responsible solutions and best management practices with local, state and federal regulators who are making critical decisions for our environment. WRWA staff and volunteers assist and serve on relevant Town boards and committees.

Our purpose is first and foremost to understand and respond to the issues that affect or have the potential to degrade the watershed. WRWA reaches out to provide its resources to any and all. We work with municipal leaders and watershed residents to protect and preserve the Westport River Watershed now and for future generations.

Westport River Watershed Alliance

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Tel (508) 636-3016 • info@wrwa.com • www.westportwatershed.org

OUR MISSION—
Working together to protect and preserve the Westport River Watershed now and for future generations.

OUR VISION—
A healthy watershed where people, wildlife and the River thrive.

WRWA