FINAL REPORT

NEIWPCC Job Code:	0348-008
Project Code:	S-2022-003
Contractor:	Cornell Cooperative Extension of Suffolk County (CCE)
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Project Period:	03/01/2022 to 03/31/2025
Date Submitted:	September 2025
Date Approved:	November 2025

Utilizing Ribbed Mussel Aquaculture to Improve Water Quality in the Long Island Sound:

Assessment of Bioextraction Potential and Suitability as Animal Feed

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This is a US EPA funded project.

This project has been funded wholly or in part by the United States Environmental Protection Agency (US EPA) under assistance agreement (LI-00A00688) to NEIWPCC in partnership with the Long Island Sound Partnership (LISP) and the New York State Department of Environmental Conservation (NYS DEC). The contents of this document do not necessarily reflect the views and policies of NEIWPCC, LISP, NYS DEC, or the US EPA, nor does NEIWPCC, LISP, NYS DEC, or the US EPA endorse trade names or recommend the use of commercial products mentioned in this document.

ACKNOWLEDGEMENTS

Special thanks to all contributors of this study and reviewers of this report:

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EXECUTIVE SUMMARY

Nitrogen pollution causes critical water quality issues in the Long Island Sound, including harmful algal blooms, hypoxic “dead zones”, and fish die-offs. Although nitrogen reduction targets from wastewater treatment plants have been met, non-point sources and legacy pollutants continue to contribute excess nitrogen into our waterways. Shellfish aquaculture has the potential to reduce nitrogen concentrations in impaired waterbodies because they incorporate nutrients into their tissue and shell as they grow. Harvesting shellfish from the water effectively removes nitrogen from the system, through a process called bioextraction.

The purpose of this project was to evaluate the efficacy of nutrient bioextraction using ribbed mussels (*Geukensia demissa*) as a nutrient management strategy by providing data on nutrient and contaminant removals. Ribbed mussels are a native intertidal shellfish species with a wide geographic range and are resilient to extreme temperature and salinity conditions. Nitrogen-impaired waters may be affected by other water quality impairments like elevated fecal coliform bacterial concentrations, which prohibit harvest of commercially important shellfish species for use as seafood products. Unlike other shellfish on the market, ribbed mussels lack commercial value for human consumption due to their unappealing taste and texture, making them suitable for cultivation in nitrogen-impaired waters where bioextraction is most needed as they will not be harvested for human consumption, and thus do not pose a public health risk.

To encourage growth of a bioextraction industry, a commercial use for ribbed mussels needs to be studied and established. Therefore, this project also aimed to assess the suitability of bioextractive ribbed mussels as animal feed.

Ribbed mussels were deployed at two sites within the Long Island Sound in New York, Huntington Harbor and Northport Harbor, working with Cornell Cooperative Extension of Suffolk County. These sites were representative of those in a future bioextraction industry given their status as nitrogen-impaired and location within an area closed to harvest of shellfish for human consumption. Wild ribbed mussels were collected from a natural salt marsh and deployed in 2022 (Year 1), while aquaculture techniques were tested to produce hatchery-cultured mussels that were deployed in 2023 (Year 2). Water quality data was monitored, and whole mussel samples (shell and tissue) were collected to test for nutrients, micronutrients, feed parameters, and contaminants, which provided data to determine bioextraction potential and animal feed suitability. The remaining cultured mussels were measured for size ranges in their third growing season (Year 3).

Overall, this study demonstrated that ribbed mussel aquaculture is an effective nutrient management strategy to remove excess nitrogen and carbon from impaired embayments. A hypothetical one-acre farm could remove an estimated 54.98 kg of nitrogen and 318.61 kg of carbon at harvest. Although not included in this study, ribbed mussels notably provide other ecosystem services, such as water filtration as they feed, improving water clarity.

Assessment of nutrient and contaminant data demonstrated that ribbed mussels have potential suitability as animal feed. For example, amino acids that are vital for the growth and development of livestock were detected, heavy metals were below maximum allowable levels for animal feed, and other contaminants like pesticides and PCBs were not detected. However, this finding is preliminary with further investigation needed, as the mussels were not dried,

cooked, or pasteurized prior to analysis, unlike commercial animal feed products. The lack of processing was evident in results, such as percent content of moisture and carbohydrates, which did not meet animal feed criteria. Ash content, likely from mussel shells, was too high for animal feed, but could be removed and repurposed for another use. A future study is recommended to separate the whole mussel to test the suitability of processed mussel meat (tissue) as animal feed, and suitability of mussel shells as soil amendment. More data is needed to refine best uses for all parts of the animal and diversify potential commercial uses in order to establish a profitable bioextraction industry as a long-term nutrient management strategy.

Table of Contents

1. PROJECT SYNOPSIS

Nitrogen pollution is a significant problem in the Long Island Sound, with non-point sources of pollution, including onsite wastewater treatment (septic) systems, stormwater, and fertilizer runoff, being major contributors to water quality impairments. Although reduction targets from wastewater treatment plants have been met, these non-point sources, in addition to legacy pollutants that travel in groundwater into coastal embayments, continue to contribute excess nitrogen into waterways in many areas. Common impairments due to excess nitrogen include eutrophication, which fuels harmful algal blooms and creates hypoxic “dead zones” that lead to fish die-offs.

Shellfish cultivation and harvest has the potential to reduce nitrogen concentrations in impaired waterbodies because as shellfish grow, they incorporate nutrients into their tissue and shell. Removing shellfish from the water effectively removes nitrogen from the system, through a process called bioextraction. Shellfish provide other environmental co-benefits, such as filtering water as they feed to remove nutrient-rich organic and inorganic matter from the water column, which improves water clarity for vital habitats like eelgrass beds, and sequestering carbon (CT Department of Agriculture 2025).

The Atlantic ribbed mussel (G*eukensia demissa*) is an intertidal invertebrate shellfish species native to eastern North American salt marshes (Moody and Kreeger 2020). They are known to have a wide geographic range, an efficient ability to filter a wide range of particle sizes, and are a resilient species that can grow in highly impacted environments and under a wide range of extreme temperature and salinity conditions (Galimany et al. 2013; Marine Shellfish – NYS DEC). Previous work in Long Island Sound has estimated that harvesting a fully stocked raft of wild adult ribbed mussels could filter 1.2×10^7 L water daily and sequester 62.6 kg of nitrogen in mussel tissue and shell in a growing season of 6 months from April to October 2012 (Galimany et al. 2017).

Despite the lack of commercial value as a human food product due to their unappealing texture and taste, ribbed mussels are now being considered as a ‘bioextractor’ and an in-water nitrogen mitigation strategy. Nitrogen-impaired waters may be affected by other water quality impairments like elevated fecal coliform bacterial concentrations, which prohibit harvest of commercially important shellfish species for use as seafood products. Unlike other shellfish on the market, ribbed mussels are suitable for cultivation in nitrogen-impaired waters where bioextraction is most needed as they will not be harvested for human consumption, and thus do not pose a public health risk. To encourage the cultivation and harvest of ribbed mussels as a long-term nutrient management strategy, a commercial use needs to be studied and established. Therefore, this study investigated the effectiveness of ribbed mussels grown in nitrogen-impaired Long Island Sound embayments to bioextract nitrogen and carbon, as well as the suitability of the harvested ribbed mussels as animal feed.

Ribbed mussels were deployed at two sites within the Long Island Sound in New York State, Huntington Harbor and Northport Harbor, working with Cornell Cooperative Extension of Suffolk County’s hatchery lab and staff. These sites were chosen as model sites representative of those in a future bioextraction industry given their status as nitrogen-impaired and closed to shellfish harvest meant for human consumption (Suffolk County Department of Health Services 2020).

Wild ribbed mussels were collected from a natural salt marsh and deployed in the first year of the study, while aquaculture techniques were tested to produce hatchery-cultured mussels that were deployed in the second year. In addition to water quality monitoring, whole mussel samples (tissue and shell) were collected to test for nitrogen, carbon, micronutrients, feed parameters, heavy metals, organic contaminants, pesticides, and pathogens. This supplied data to determine bioextraction potential, animal feed suitability, and whether mussels picked up any contaminants that would limit their use for other purposes after harvest.

The purpose of this project was to evaluate the efficacy of nutrient bioextraction using ribbed mussels (*Geukensia demissa*) as a nutrient management strategy by providing data on nutrient and contaminant removals. Because bioextraction is in relatively early stages of development as a usable nitrogen management/mitigation strategy, this type of information is vital in understanding the potential and limitations of using ribbed mussels in such a way. This project also looked at the potential uses of harvested bioextractive ribbed mussels as an animal feed for livestock, including poultry, swine, and farmed fish. If the mussels harvested for bioextraction in our coastal areas could be used for a commercial purpose, that would move bioextraction operations beyond research and restoration/mitigation projects into a self-sustaining and profitable endeavor.

2. TASKS COMPLETED

The following tasks were completed during this project:

Quality Assurance Project Plan Preparation and Approval

Version 1 – This task included the development and finalization of project objectives, experimental design, and sampling methodology with all participants. This task was completed in June 2022, prior to the collection of any data.

Version 1.1 - This task included an update to the QAPP for changes to sample preparation and schedule changes. This task was completed in August 2022.

Version 1.2 - This task included an update to the QAPP for changes to staff and an extension of the timeline schedule to extend to March 2025 to continue monitoring growth of cultured ribbed mussels during their third growing season. This activity was done under previously approved QAPP version 1.1 for their first and second growing season. This task was completed in February 2025.

Ribbed Mussel (*Geukensia demissa*) Aquaculture

Wild Ribbed Mussels – This task included collection of wild adult ribbed mussels from a natural marsh location near Goldstar Battalion Beach at Huntington Harbor to be used for culturing in a hatchery, where they were conditioned and used as broodstock for spawning.

Hatchery-Spawned Cultured Mussels – This task included transferring the hatchery-spawned cultured mussels to mesh bags, where they were raised in a FLUPSY (floating upweller system used for shellfish grow-out) and overwintered. These ribbed mussels were used in Years 2 and 3 of the field study.

Ribbed Mussel (*Geukensia demissa*) Field Study

Field Set-Up – Floating docks were installed at grow-out locations in Huntington Harbor and Northport Harbor. Commercial fish baskets (with perforations to allow for water flow) were placed underneath the floating docks, where ribbed mussels were contained. The fish baskets were used instead of standard aquaculture grow socks from the original project design because they worked better for the purpose of this study, and this change does not affect the intent or quality of the project or data collected.

Field Grow Out – This task included collection of wild ribbed mussels from Huntington Harbor to be used during Year 1 of the field study. These wild ribbed mussels were grown out at the floating docks installed at both grow-out locations. Hatchery-spawned mussels from the aquaculture portion of the study were grown out at the same grow-out locations during Year 2 and 3 of the study at the Gold Star location.

Water Quality Monitoring – This task included discrete water quality monitoring at ribbed mussel grow-out sites. Monitoring began once the QAPP was approved and continued until the end of the second growing season. This task at times coincided with ribbed mussel sampling dates.

Ribbed Mussel Sampling for Lab Analysis (Bioextraction) – A portion of ribbed mussels were sampled (entire animal, including tissue and shell) for analysis of nitrogen and carbon. This was to assess their suitability and effectiveness for use in bioextraction. Sampling was conducted two to three times a season (year).

Ribbed Mussel Size Range Monitoring – Remaining hatchery-cultured ribbed mussels were measured for size ranges in their third growing season during Year 3.

Ribbed Mussel (*Geukensia demissa*) Animal Feed Suitability Assessment

Ribbed Mussel Sampling for Lab Analysis (Animal Feed) – In addition to the lab analyses for the assessment of bioextraction effectiveness, the sampled ribbed mussels were also analyzed for their nutritional value and contaminants, such as heavy metals, pesticides, and pathogens. This was to assess their suitability as animal feed.

3. METHODOLOGY

Ribbed Mussel Aquaculture

The aquaculture portion of this project followed methods established at Rutgers University (Landau, 2014). The spawning and culturing system were monitored for conformance with the procedures established in Landau (2014), but this information will not be analyzed or interpreted, other than to determine if it allowed for the successful survival of mussels to be used in Year 2 of the study. "Success" was based on whether the mussels survived after being cultured, raised during the growing season, and overwintered. This culturing method was indeed successful, so cultured mussels were used in Years 2 and 3 for the grow-out portion of the study. These cultured mussels could not be used for the first year of the grow-out portion of the study in 2022 because the aquaculture process required two years for the animals to be large enough (≥20 mm) to use for nutrient and other lab analyses. For transparency and record-keeping, the aquaculture method will be described here, but the purpose of this study is not to test aspects of the aquaculture process, but rather to analyze the bioextractive capacity of ribbed mussels in coastal waters.

In April 2021, wild ribbed mussels were collected from a natural marsh near Gold Star Battalion Beach at Huntington Harbor, where Cornell Cooperative Extension has collected animals in the past. To limit damage to the marsh, loose mussels were collected along the nearby rocky shoreline rather than removing ones attached to the marsh. The mussels were brought back to the hatchery at Gold Star Beach. The wild ribbed mussels were used as broodstock for breeding purposes to spawn and culture in the hatchery. In preparation for the culturing and spawning process, the ribbed mussels were conditioned for 6-8 weeks using the following protocol. Approximately 40-60 adult mussels were placed in small plastic pots, which allowed for movement during tank cleanings without tearing or damaging the byssal threads and causing stress to the animals. These pots were placed into static tanks at ambient water temperature, which matched the water temperature from where they were collected (Figure 7). Water temperature was increased slowly over the first 1-2 weeks until it reached a temperature of 20°C, which was maintained until they were spawned using the protocol described below. During this time, cultured algae was added to the tank as needed to feed the mussels. Algae species included *Isochrysis galbana*, *Pavlova lutherie*, *Chaetoceros* sp., and *Tetraselmis* sp. The tanks were cleaned regularly on Mondays, Wednesdays, and Fridays by draining out the water, rinsing the plastic pots, cleaning the tanks with oxalic acid, and adding new seawater at the appropriate temperature. Over the course of the conditioning period, subsamples were taken and checked for gonadal maturation, a process which requires shucking the animal to open them for visual inspection.

Spawning of the mussels was done through the Bin-Silo System Method, developed by Brenda J. Landau (Landau, 2014). This method is an alternative to traditional spawning methods that is low-cost, low-labor, requires minimal space, and preserves broodstock, as the spawning animal does not have to be killed and opened, as is required for strip-spawning. There is little evidence that strip-spawning will be a reliable method for ribbed mussels (Landau, 2014). The system included a bucket-like container, called a silo, with a mesh bottom to retain the broodstock mussels. The silo was placed inside a larger bin containing water heated to 28-30°C (Figures 8-10). Once the water reached that temperature, the heat was turned off, and the water was allowed to slowly return to ambient temperature overnight; this slow-cooling process triggers spawning. Water was circulated via an airlift. Gametes and fertilized eggs sank through the mesh to the bottom of the bin because they are slightly denser than seawater. In the morning, the system was drained through several mesh screens stacked on top of one another (120, 74, 44, and 28 µm) to separate fecal matter and debris from the fertilized eggs. Material collected on the 44 µm and 28 µm screens was rinsed with filtered and heated seawater into separate buckets and checked for fertilized eggs and larvae. Once confirmed, the contents were added to conical tanks (tanks with cone-shaped bottoms that are commonly used for rearing shellfish larvae) containing filtered seawater maintained at 24°C and were fed cultured microalgae (Figures 11-12). The larvae were raised in the conical tanks for about two weeks. After the larvae underwent metamorphosis from their free-swimming larval stage to their settled juvenile mussel stage, they were moved to downwellers within the hatchery for 2-3 months, during which the animals were fed with cultured algae (Figure 13). Once the juvenile cultured mussels reached a size of 1-2 mm, they were transferred to mesh bags in July 2021 and raised in a floating upweller system (FLUPSY) on raw seawater throughout the growing season until October 2021, where they reached a size of 5-15 mm (Figure 14). Then they were submerged within the FLUPSY dock to be overwintered until the following spring. As this cohort of mussels was still too small for sampling in Year 1 of the study (2022), they were kept in commercial orange fish baskets that hung beneath locked trap doors at each grow-out site's floating dock at the start of the Year 1 growing season, monitored twice a month and cleaned as needed, but otherwise left undisturbed to allow them to grow until they were at least 15-20 mm for their use in Year 2 of the study (2023).

Ribbed Mussel Field Grow Out

The Suffolk County Nine Element Plan outlines the total nitrogen load in Long Island embayments, including Huntington Harbor and Northport Harbor (Suffolk County Department of Health Services 2020). In this watershed plan, Northport Harbor was ranked first and Huntington Harbor was ranked second out of 4 in priority for nitrogen load reduction, and wastewater infrastructure upgrades alone have not been able to meet nitrogen reduction goals for these embayments. This highlighted the need for an alternative nutrient management strategy through bioextraction to augment nitrogen reduction efforts. Therefore, Huntington and Northport Harbors were chosen as model grow-out sites representative of those in a future bioextraction industry given their status as nitrogen-impaired and closed to shellfish harvest meant for human consumption, and because of ease of access due to their proximity to Cornell Cooperative Extension's hatchery lab.

Year 1 - 2022

Wild ribbed mussels were collected from the rocky shoreline adjacent to the marsh in Huntington Harbor to limit damage to the marsh. They were collected at low tide while their shells were closed, and then were brought to the hatchery at Goldstar Beach, where they were cleaned and placed in running seawater tanks until they were ready to be placed in orange fish baskets at the cultivation site. Personal correspondence with Cornell Cooperative Extension hatchery staff indicated that ribbed mussels can live in these running seawater tanks for months without any adverse outcomes.

Floating docks were installed at both the Huntington Harbor and Northport Harbor sites in early April for use during Year 1 of the study and removed at the end of the season in November (Figures 1-4, 16-17). On the dock, the wild ribbed mussels were placed in the commercial fish baskets and hung beneath locked trap doors at the start of the study, monitored twice a month and cleaned as needed, but otherwise left undisturbed for the project period (Figures 17-18). Water quality was measured once in September and twice in October during Year 1 at both locations (Figure 19), and a temperature logger was installed for the duration of the project.

During Year 1 site visits to conduct water quality monitoring in September and October, ribbed mussel samples for laboratory analysis were also taken (Figure 20). Samples were taken from both locations at each sampling date during Year 1. Seventy-five mussels were collected on each of the sampling dates to be sent to the lab for analysis.

Year 2 – 2023

Hatchery-spawned (cultured) ribbed mussels were used in Year 2 of the study due to success in their survival after they were cultured in 2021, raised during the growing season, overwintered, continued to grow during the 2022 (Year 1) growing season, and overwintered again. The field grow-out methods were otherwise the same as in Year 1 except for minor changes like sampling schedule.

Floating docks were installed at both the Huntington Harbor and Northport Harbor sites in early April for use during Year 2 of the study and removed at the end of the season in November. On the dock, the cultured mussels were placed in the baskets and hung beneath locked trap doors at the start of the study, monitored twice a month and cleaned as needed, but otherwise left undisturbed for the project period. Water quality was measured in June, August, and October during Year 2, and a temperature logger was installed for the duration of the project.

During Year 2 site visits to conduct water quality monitoring in June, August, and October, ribbed mussel samples for laboratory analysis were also taken. Samples were taken from both locations at each sampling date during Year 2, except for in June when only Huntington was sampled. As the young cultured mussels were much smaller than the wild adult mussels used in Year 1 (~15-40 mm vs ~60-100 mm shell length), 150 to 200 mussels were collected on each of the sampling dates to be sent to the lab for analysis. Furthermore, CCE performed additional ribbed mussel spawns in Year 2 that were cultured as a “backup” should they be needed in this study and to learn more about the grow-out procedures in the floating docks at these sites.

Year 3 - 2024

The remaining cultured ribbed mussels from the 2021 and 2023 hatchery spawnings that survived and were not sampled for lab analysis were kept to continue grow-out late into their third (almost to fourth) growing season. These mussels were measured for growth to collect data on their third (approaching fourth) year for their length (to the nearest mm) using vernier calipers (Figure 14). This is particularly important as we are unaware of cultivated ribbed mussels being held for this long and measured for size. This is of interest not only for their use in bioextraction, but also for habitat restoration projects.

Water Quality Monitoring

Water quality sampling methodology and reporting was conducted in accordance with the Great Cove Citizen Science Monitoring Project QAPP, prepared by Seatuck Environmental Association (effective date: June 1, 2019). While the mussels were in the water, discrete *in situ* water quality monitoring was conducted at a randomized location off the side of the dock at each site location during the field study to provide data on the physical and chemical conditions of the water column. This data may help inform what types of variation exist between the grow-out sites for mussel growth rates, health, and mortality. Parameters included depth, temperature, salinity/conductivity, dissolved oxygen (DO), and pH, which were measured using a YSI EXO1 multiparameter sonde. A continuous water temperature logger was also installed at the sites for the duration of the grow-out period.

Ribbed Mussel Sampling

To conduct sampling for laboratory analysis, ribbed mussels (*Geukensia demissa*) were collected four times at Northport Harbor and five times at Huntington Harbor. Both locations were sampled in September and October 2022 (Year 1) and in August and October 2023 (Year 2). There was an additional sampling event at Huntington Harbor in June 2023 (Year 2).

The Eurofins contract laboratory required a minimum of 1,000 g of sample for all requested analyses for each sampling event. Size measurements were used to estimate mussel weight for the purpose of collecting enough mussels for each sample batch. An additional ribbed mussel was also added to the collected sample batch to ensure that enough tissue was provided. A test was conducted at the start of the experiment to compare size (shell length) and whole mussel weight to inform future sample collections and biomass estimations based on shell length measurements alone, which is more efficient than weighing whole mussels individually (Table 4). Whole mussels (both shell and tissue) were collected from the site, rinsed with ambient seawater, allowed to drain, placed in sterile sample bags, and put on ice for transport from the field site. They were then frozen and ground into a wet sand-like consistency using a coffee grinder and then further ground with a mortar and pestle for any remaining large pieces. The ground up ribbed mussel samples were placed in sterile sampling bags, which were labeled according to the specifications required by the analytical laboratory, and shipped overnight with required documentation to the contract lab in insulated shipping boxes packed with ice packs to keep temperatures low, until they were received and processed (Figure 21).

Mussel samples were shipped to the contract laboratory at Eurofins SF Analytical Laboratories in Wisconsin using appropriate chain-of-custody procedures. Parameters analyzed by the contract laboratory included nutrients and micronutrients (carbon, nitrogen, phosphorus, calcium, copper, iron, potassium, etc.), as well as additional parameters relevant for assessing suitability as animal feed (amino acids, fat, protein, crude fiber, ash, moisture, etc.).

The ribbed mussels were also analyzed by the Eurofins contract laboratory for the following contaminants:

- Pesticides
- Polychlorinated biphenyls (PCBs)
- Polynuclear aromatic hydrocarbons (PAHs)

- Heavy metals
- Pathogens

Statistical Analysis

Data collected from the field and laboratory analyses were compared between Huntington Harbor and Northport Harbor grow-out sites using independent t-test statistical analysis, assuming equal variances. Alpha was set to 0.05 for a 95% confidence interval. A p-value above alpha ($p > 0.05$) indicates that no statistically significant difference was detected between the two sites for a given parameter (both sites are statistically similar). A p-value equal to or below alpha ($p \leq 0.05$) indicates that a statistically significant difference was detected between the two sites for a given parameter. Results for samples below detection limits were substituted for half the method detection limits, as provided by the contract laboratory if available, for statistical analysis purposes only.

4. QUALITY ASSURANCE TASKS COMPLETED

Project Management

Each project partner ensured that staff were trained on the proper protocol and sampling methods. All analytical laboratories ensured that staff were trained on the methods of analysis and met the training/certification requirements specified by their laboratory. The most current copy of the approved Quality Assurance Project Plan (QAPP) was distributed to all project partners in PDF format via email. The QAPP is and was maintained by the NYS DEC Project Lead in electronic format throughout the length of the project. All data was recorded in appropriate data sheets, with sample custody and instrument calibration forms completed and retained. Although mortality data were not collected or were lost, the container to hold the ribbed mussels in the study was changed from grow socks to fish baskets, and the temperature logger installed at both sites malfunctioned in Year 2 of the study, there were no significant changes in the experimental design of the project. The QAPP was amended to update staff changes in 2024 and include an additional task for the contract partner to measure ribbed mussel sizes in their third growing season. All data for this project is being stored on the NYS DEC server.

Data Generation and Acquisition

The sampling schedule planned for this project used a Systematic Random Sampling (SRS) method, which involves taking samples according to a pre-established schedule rather than in relation to particular conditions, such as weather or rainfall, and has been approved by the National Shellfish Sanitation Program (NSSP).

Data collection instruments were prepared in accordance with guidance in EPA’s *Generic Guide to Statistical Aspects of Developing an Environmental Results Program* (Crow et al. 2003), specifically following a checklist, as developed for this project’s Quality Assurance Project Plan. Calibration of the YSI was performed before leaving for the field in accordance with the manufacturer’s instructions, with information recorded in a calibration data sheet. There were no issues identified regarding the instrument, and no data that did not meet the manufacturer-developed acceptance criteria.

Field sampling data sheets were completed by field staff at each sampling date, and were collected and retained by the NYS DEC Project Lead. As guidelines for ribbed mussel collection and handling prior to lab analyses to determine animal feed suitability has not previously been established, project sampling and storage procedures followed protocols in NYS DEC’s *Vibrio parahaemolyticus* (*Vp*) Control Plan, as appropriate, which include time and temperature measures for proper, safe handling of commercial clams and oysters to promote food safety of shellfish intended for human consumption. Whole mussel samples (shell and tissue) were ground and immediately placed into sterile plastic bags under temperature control using gel packs and maintained between 33ºF and 45ºF. All samples were handled using plastic gloves to minimize the risk of contamination. Tags were affixed to the sample bags with the time of harvest and the sampling location, and Chain of Custody forms were completed and used as a control document to track samples from harvest through analysis. Mussel samples were overnight shipped to the Eurofins Food Integrity & Innovation laboratory within their listed hold times, and laboratory staff were notified of the sampling schedule to ensure timely refrigeration/processing of the samples after receipt.

Records and raw data including handwritten field notes, data sheets, field logs, analysis logs and results of instrument calibrations have been scanned into electronic format, with raw data entered into an Excel database. Computer-entered data was cross-referenced with field data and sample analysis results to confirm accuracy.

The following steps were taken to measure/estimate the effect of data errors, consistent with the NYS DEC Division of Water's Quality Management Plan (2016): Duplicate YSI profiles were taken at each sampling location per sampling event, with duplicate readings in conformance with listed YSI sensitivity criteria. For whole mussel analysis, every batch run by the Eurofins Food Integrity & Innovation laboratory had a validated control or a blank spike set with the batch. Data discrepancies or anomalies, if they had occurred, would have been flagged and brought to the attention of the NYS DEC Project Lead. No data points from the laboratory analysis were found to be high or low enough to necessitate re-analysis or re-sampling, nor was it expected that samples could be re-analyzed due to holding times or amounts of biomass submitted to the laboratories. During the project period, laboratory equipment was maintained by Eurofins Food Integrity & Innovation following their laboratory quality manuals. All instruments and equipment used by Eurofins Food Integrity & Innovation were routinely calibrated by laboratory personnel throughout the project period.

Field equipment was inspected prior to use for cleanliness and needed repairs or adjustments. Equipment was rinsed with ambient water at each sampling site prior to use. After use at each sampling site, field equipment was cleaned according to the manufacturer's instructions, and then rinsed with ambient water prior to use at the next site. Water quality instruments were inspected before each use following the manufacturer's recommendations and protocols. The YSI sensor was calibrated prior to each sampling event according to the manufacturer's directions. There were no calibration failures to report during this study.

Project field team members were responsible for coordinating with the NYS DEC Project Lead to ensure maintenance of adequate supplies for mussel cultivation and spawning in the hatchery. The NYS DEC Project Lead was in attendance for most of the sampling dates, with additional supplies in hand. The NYS DEC Project Lead was also responsible for YSI equipment calibration for the sonde used at the Huntington Harbor and Northport Harbor sites. The NYS DEC Project Lead was present at most mussel sampling dates and ensured that sterile sample bags, coolers, and all other sampling supplies were prepared, and also inspected for cleanliness and potential contamination prior to use. All laboratory supplies and materials were provided by Eurofins Food Integrity & Innovation Laboratory with all supplies and materials washed and visually inspected for cleanliness and potential contamination by lab staff prior to use.

Field-collected data were recorded on paper forms in the field, and once sampling events were completed, in cases where the NYS DEC Project Lead was not present, the field team reviewed the data sheets and submitted them to the NYS DEC Project Lead. The NYS DEC Project Lead then scanned all hard copies and stored them electronically and maintained the original data sheets. Raw data was entered into a database by the NYS DEC Project Lead, and computer-entered data was then cross-referenced with field sheets at a later date to ensure accuracy and correction of typos. Laboratory data and results were delivered electronically to NEIWPCC and the NYS DEC Project Lead, and were saved electronically to the NYS DEC server. Raw data from these reports were entered by the NYS DEC Project Lead into an Excel database. Computer-entered data was then cross-referenced with lab reports at a later date to ensure accuracy and correction of typos. The NYS DEC server is backed-up daily, and the data will be available upon the release of this report to other government agencies, researchers, and the general public upon request. Any third-party users will be informed of their restricted rights for using and editing the data.

Assessment and Oversight

Assessment and response actions and reports to management

The NYS DEC Project Lead thoroughly briefed contract partner staff before and after beginning their respective implementation tasks to identify any emerging/unanticipated problems. This was done through virtual meetings, and presence at significant field workdays (water quality monitoring, mussel cleanings and measurements, mussel sampling); identification of potential problems was also done through email correspondence and phone calls. Corrective actions or significant changes to the project were reported to the NEIWPCC QA Program Manager and the EPA Project Officer, and also reported in quarterly reports to the EPA. The problem encountered in this project was that QAPP approval and issues with the lab delayed sampling until September, so only 2 samples were taken in Year 1 instead of the planned 3 samples; the “middle”/mid-season sampling event became the initial sampling event and no early-season sample was taken in Year 1. Meetings were held with the NEIWPCC QA Program Manager and the EPA Project Officer, and after some discussion, these issues were not found to be severe enough to necessitate any QAPP amendments, though changes were noted and acknowledged.

At each sampling date, the NYS DEC Project Lead ensured that sampling occurred as planned, that there was sufficient written commentary and supporting photographs taken, that all necessary forms were properly completed, and that samples were kept under the prescribed conditions through shipment to analytical laboratories. The NYS DEC Project Lead was present at most sampling and monitoring dates, and in cases where they were not present, email updates with photos were sent to the NYS DEC Project Lead by project partners. No issues were encountered that required a suspension of work or any corrective actions.

There was an audit ordered by NEIWPCC in the Fall of 2023 to assess conformance and compliance to the Quality Assurance Project Plan in accordance with the NEIWPCC Quality Management Plan. This field assessment occurred during the monitoring and maintenance of juvenile cultured ribbed mussels at the FLUPSY (floating upweller system) in Huntington Harbor. No compliance issues were found.

The NYS DEC Project Lead prepared quarterly progress reports during the course of the study until February 2025 when the QAPP was amended for the contract partner to prepare quarterly reports. Quarterly progress reports from the project partner were submitted to the NYS DEC Project Lead, NYS DEC Project Manager, and the NEIWPCC Project Manager, and included the current status of ongoing work, accomplishments, and problems encountered.

Data Review and Evaluation

Field data was reviewed to ensure quality, and data was examined for accuracy prior to inclusion in this report. Data verification and validation included checks on existence and completion of all fields on data sheets, completeness of sampling events, and completeness of Quality Control checks.

In addition to the review conducted by Eurofins Food Integrity & Innovation Laboratory staff to verify laboratory data quality, data was examined for accuracy prior to inclusion in this report. This included a review of laboratory-flagged data and outlier evaluation.

Upon review of continuous temperature logger data collected at both sites, it was found that the temperature data logger malfunctioned during Year 2 of the study. To provide supplementary data to fill in this data gap of the study, temperature, salinity, and dissolved oxygen data collected by the Unified Water Study monitoring program is provided in the Appendix section.

5. RESULTS AND DISCUSSION

The tables referenced in this section and included later in the report represent all data collected throughout the project period. Data on site characteristics and water quality were collected in order to characterize the physical and chemical conditions of the water column and to help inform variations that may exist between the grow-out sites. Whole ribbed mussels (shell and tissue) were collected, processed, and analyzed for nutrients and contaminants to understand their effectiveness for use as a bioextraction species.

The lab analysis data was used to quantify estimations of nutrient removal rates based on the estimated total weight of all mussels cultivated and harvested during this pilot study. For example, nitrogen removal rates from the pilot study can be estimated by multiplying nitrogen content determined from the samples sent for lab analysis and the estimated total weight of all mussels cultivated and harvested during this pilot study. The theoretical nutrient removal rates for a scaled-up 1-acre and 5-acre farm were calculated using the number and average weight of adult mussels (based on measurements in the pilot study) that would be theoretically stocked in a ribbed mussel farm. For example, nitrogen removal rates for a theoretical farm can be estimated by multiplying nitrogen content determined from the samples sent for lab analysis, number of mussels stocked in a theoretical farm, and the average weight of the mussels (estimated by average size). Average adult weights were used in calculations to estimate nutrient removals from this pilot study.

The lab analysis data was also used to compare to US Food and Drug Administration (FDA) animal feed action level and tolerance values to determine the suitability of ribbed mussels used for bioextraction as animal feed. The FDA regulates animal feed to ensure that it is safe and high quality by ensuring it is pure and wholesome, produced under clean conditions, free of harmful substances, and labeled appropriately and truthfully. The FDA bases their guidance, action level, or tolerances for heavy metals in animal food on the National Research Council of the National Academies *Mineral Tolerances of Animals* book (NRC MTL), as well as information provided in the Association of American Feed Control Officials *Official Publication* (AAFCO OP) (NRC 2005; AAFCO 2019).

Water Quality and Site Differences

Water quality at both sites was similar across all measured parameters at surface and bottom depths (Tables 2-3), and both sites appeared to have general conditions that would be conducive to ribbed mussel growth. One water quality data point that stood out was dissolved oxygen (mg/L) on 9/6/22 in Northport Harbor, which was < 3 mg/L and classified as hypoxic by the Long Island Sound Partnership: “Severely Hypoxic and Anoxic Areas”. Hypoxic conditions are known to stress biota and would therefore be expected to affect the mussels during this period as well. It should be noted that discrete water quality measurements for certain parameters, such as temperature and dissolved oxygen, may not give the full picture because they vary throughout the day and from day to night. Another water quality monitoring study conducted in the same period collected continuous off-bottom dissolved oxygen measurements with data loggers located near both grow-out sites, which did detect dissolved oxygen levels below 3 mg/L multiple times throughout the study (Figures 24, 27, 29, 31). Both grow-out sites were less than 3 meters (or 10 ft) deep, with Huntington Harbor deeper than the Northport Harbor site by about a meter (Table 1). Based on the overall similarity in water quality data for the two sites, it is assumed that ribbed mussel growth and content were comparably affected.

Comparing ribbed mussels sampled at both grow-out sites, there was no statistically significant difference in nutrients, amino acids, feed quality, PCBs, PAHs, pesticides, or pathogens (Tables 5-7, 9-12, independent t-test, $p > 0.05$). There was also no statistically significant difference in heavy metals, except for lead, which was significantly higher for ribbed mussels sampled in Northport Harbor than in Huntington Harbor (Table 8, independent t-test, $p = 0.048$).

Ribbed Mussel Size and Growth

There was considerable size variation for ribbed mussel shell length data collected from different cohorts spawned in 2021 and 2023 that were grown over three (approaching four) years at both grow-out sites in Huntington and Northport Harbors. A linear regression model yielded an average growth rate of 14.7 mm shell length per year (Figure 6). This data is particularly important as cultured and cultivated ribbed mussels have not previously been held for this length of time and monitored for size. This information would be of interest for future studies for bioextraction, pathogen removal, and habitat restoration projects utilizing cultured ribbed mussels. This information would also be important for potential ribbed mussel farmers to determine peak harvest periods.

Determination of Nutrient Bioextraction Effectiveness

Estimates are provided for determining the amount of nitrogen and carbon removed by harvest (bioextraction) during this pilot study, as well as estimates if this pilot study were scaled up to a one-acre or five-acre farm. The average, minimum, and maximum nitrogen and carbon contents from mussels at each site were used to determine the full potential for nutrient removal rates. Because final mussel survival count was not collected during this study, an estimated total weight of mussels cultivated and harvested was used to calculate nitrogen and carbon removal rates by bioextraction. A minimum of 1,000 g of mussels were harvested during each sampling event, and there were mussels left over to track growth and sizes in their third growing season, so it is estimated that final weights of about 6,000 g or 6 kg of mussels were cultivated and harvested at each site in total. Average fresh weight of each whole wild-collected adult ribbed mussel in this study was about 30 g (0.030 kg/mussel), and this weight will be used in the one-acre and five-acre farm calculations (Table 4). Note that nitrogen and carbon content results were reported on fresh (wet) weight.

To estimate the nitrogen and carbon removal rates if the Huntington Harbor and Northport Harbor data were scaled up to a one-acre and five-acre farm, a mock one-acre farm design set-up was generated (Figure 5). This mock design was used to estimate the total biomass of stocked ribbed mussels since a commercial-scale farm for these species does not yet exist. In another study conducted by Cornell Cooperative Extension of Suffolk County and the CUNY Science and Resilience Institute at Jamaica Bay, 200-250 adult ribbed mussels are stocked in

SEAPA cages typically used for commercial oyster farming (M. Sclafani, pers. comm., March 28, 2025; C. Zarnoch, pers. comm. June 5, 2025). These cages have dimensions of about 26” width, 8.5” length, and 5.5” height, and they can be stacked vertically at multiple depths in the water column to fit 2-3 cages deep, if desired and depending on the depth of the growing area. These cages were used in the mock farm design. This theoretical design for a ribbed mussel farm using off-bottom culture gear such as SEAPA cages is comparable to commercial oyster farms using similar gear that currently operate in New York and other US East Coast states (W. Carden, pers. comm., June 24, 2025). Additional benefits of using SEAPA cages in this theoretical ribbed mussel farm design include that existing oyster farmers may not need to purchase new gear to cultivate ribbed mussels as a way to diversify their production, and new growers (farmers) can easily find and purchase these commercially available cages.

The mock one-acre ribbed mussel farm design is as follows (Figure 5):

It is a one-acre square plot with dimensions of 209 ft x 209 ft. In each row, cages are set 2 ft apart from each other. Rows of cages are coupled together to maximize number of cages placed that can still be accessed by boat, replicating how oyster cages are set up on a commercial farm. Each set of coupled rows is 15 ft apart from each other to allow for boat access to cages between rows. The outermost cages in the plot are at least 8 ft away from the perimeter. There are 24 rows with 37 cages per row, which is a total of 1104 cages per acre. Each cage holds at least 200 adult ribbed mussels for a total of 220,800 stocked ribbed mussels per one-acre farm. It should be noted that this mock design provides a conservative estimate of nutrient removal rates because commercial oyster farms may choose to set their cages closer together in each row and this mock design only uses one layer of cages at the surface without stacking the cages vertically. Assuming linear growth in nutrient uptake, stacking each row 2 or 3 cages deep would potentially double or triple the estimated nutrient rates, respectively.

Nitrogen Removal Rates

Estimate of Nitrogen Removal through Bioextraction: Huntington Harbor

The average, minimum, and maximum nitrogen (N) content measured in ribbed mussels sampled from Huntington Harbor throughout the study was 0.85%, 0.66%, and 1.17%, respectively. Therefore, the estimated total mass of nitrogen sequestered in mussel shell and tissue by all ribbed mussels cultivated during this study and removed from the water at harvest throughout the growing season was:

Average: 6 kg mussels x 0.0085 N = **0.051 kg N (or 0.11 lbs N)**

Minimum: 6 kg mussels x 0.0066 N= **0.0396 kg N (or 0.09 lbs N)**

Maximum: 6 kg mussels x 0.0117 N = **0.0702 kg N (or 0.15 lbs N)**

Nitrogen removal after harvest scaled up for a one-acre farm in Huntington Harbor:

Average: 220,800 mussels x 0.030 kg/mussel x 0.0085 N = **56.30 kg N (or 124.13 lbs N)**

Minimum: 220,800 mussels x 0.030 kg/mussel x 0.0066 N = **43.72 kg N (or 96.38 lbs N)**

Maximum: 220,800 mussels x 0.030 kg/mussel x 0.0117 kg N = **77.50 kg N (or 170.86 lbs N)**

Nitrogen removal after harvest scaled up for a five-acre farm in Huntington Harbor:

Average: 56.30 kg N x 5 = **281.52 kg N (or 620.65 lbs N)**

Minimum: 43.72 kg N x 5 = **218.59 kg N (or 481.91 lbs N)**

Maximum: 77.50 kg N x 5 = **387.50 kg N (or 854.30 lbs N)**

Estimate of Nitrogen Removal through Bioextraction: Northport Harbor

The average, minimum, and maximum nitrogen content measured in ribbed mussels sampled from Northport Harbor throughout the study was 0.81%, 0.67%, and 0.88%, respectively. Therefore, the estimated total mass of nitrogen sequestered in mussel shell and tissue by all ribbed mussels cultivated during this study and removed from the water at harvest throughout the growing season was:

Average: 6 kg mussels x 0.0081 N = **0.0486 kg N (or 0.11 lbs N)**

Minimum: 6 kg mussels x 0.0067 N= **0.0402 kg N (or 0.09 lbs N)**

Maximum: 6 kg mussels x 0.0088 N = **0.0528 kg N (or 0.12 lbs N)**

Nitrogen removal after harvest scaled up for a one-acre farm in Northport Harbor:

Average: 220,800 mussels x 0.030 kg/mussel x 0.0081 N = **53.65 kg N (or 118.29 lbs N)**

Minimum: 220,800 mussels x 0.030 kg/mussel x 0.0067 N = **44.38 kg N (or 97.84 lbs N)**

Maximum: 220,800 mussels x 0.030 kg/mussel x 0.0088 N = **58.29 kg N (or 128.51 lbs N)**

Nitrogen removal after harvest scaled up for a five-acre farm in Northport Harbor:

Average: 53.65 kg N x 5 = **268.27 kg N (or 591.44 lbs N)**

Minimum: 44.38 kg N x 5 = **221.90 kg N (or 489.21 lbs N)**

Maximum: 58.29 kg N x 5 = **291.46 kg N (or 642.55 lbs N)**

Carbon Removal Rates

Estimates of Carbon Removal through Bioextraction: Huntington Harbor

The average, minimum, and maximum carbon (C) content measured in ribbed mussels sampled from Huntington Harbor throughout the study was 4.90%, 3.14%, and 7.24%, respectively. Therefore, the estimated total mass of carbon sequestered in mussel shell and tissue by all ribbed mussels cultivated during this study and removed from the water at harvest throughout the growing season was:

Average: 6 kg mussels x 0.0490 C = **0.294 kg C (or 0.65 lbs C)**

Minimum: 6 kg mussels x 0.0314 C = **0.188 kg C (or 0.42 lbs C)**

Maximum: 6 kg mussels x 0.0724 C = **0.434 kg C (or 0.96 lbs C)**

Carbon removal after harvest scaled up for a one-acre farm in Huntington Harbor:

Average: 220,800 mussels x 0.030 kg/mussel x 0.0490 C = **324.58 kg C (or 715.57 lbs C)**

Minimum: 220,800 mussels x 0.030 kg/mussel x 0.0314 C = **207.99 kg C (or 458.55 lbs C)**

Max: 220,800 mussels x 0.030 kg/mussel x 0.0724 C kg C = **479.58 kg C (or 1,057.29 lbs C)**

Carbon removal after harvest scaled up for a five-acre farm in Huntington Harbor:

Average: 324.58 kg C x 5 = **1,622.88 kg C (or 3,577.84 lbs C)**

Minimum: 207.99 kg C x 5 = **1,039.97 kg C (or 2,292.74 lbs C)**

Maximum: 479.58 kg C x 5 = **2,397.89 kg C (or 5,286.44 lbs C)**

Estimate of Carbon Removal through Bioextraction: Northport Harbor

The average, minimum, and maximum carbon content measured in ribbed mussels sampled from Northport Harbor throughout the study was 4.72%, 3.46%, and 7.28%, respectively. Therefore, the estimated total mass of carbon sequestered in mussel tissue and shell by all ribbed mussels cultivated during this study and removed from the water at harvest throughout the growing season was:

Average: 6 kg mussels x 0.0472 C = **0.283 kg C (or 0.62 lbs C)**

Minimum: 6 kg mussels x 0.0346 C = **0.208 kg C (or 0.46 lbs C)**

Maximum: 6 kg mussels x 0.0728 C = **0.437 kg C (or 0.96 lbs C)**

Carbon removal after harvest scaled up for a one-acre farm in Northport Harbor:

Average: 220,800 mussels x 0.030 kg/mussel x 0.0472 C = **312.65 kg C (or 689.28 lbs C)**

Minimum: 220,800 mussels x 0.030 kg/mussel x 0.0346 C = **229.19 kg C (or 505.28 lbs C)**

Max: 220,800 mussels x 0.030 kg/mussel x 0.0728 C kg C = **482.23 kg C (or 1,063.13 lbs C)**

Carbon removal after harvest scaled up for a five-acre farm in Northport Harbor:

Average: 312.65 kg C x 5 = **1,563.26 kg C (or 3,446.41 lbs C)**

Minimum: 229.19 kg C x 5 = **1,145.95 kg C (or 2,526.39 lbs C)**

Maximum: 482.23 kg C x 5 = **2,411.14 kg C (or 5,315.64 lbs C)**

Total Estimated Nitrogen and Carbon Removal Rates Across Both Sites

Across both sites, an average estimated 0.0996 kg of nitrogen and 0.577 kg of carbon were removed by harvest (bioextraction) in total during the pilot study. This equates to about 0.22 lbs of nitrogen and 1.27 lbs of carbon total.

Scaled up to a one-acre farm at each site, an average estimated 109.96 kg of nitrogen and 637.23 kg of carbon could potentially be removed by harvest (bioextraction) across both sites. This equates to about 242.4 lbs of nitrogen and 1,404.9 lbs of carbon total.

Scaled up to a five-acre farm at each site, an average estimated 549.79 kg of nitrogen and 3,186.14 kg of carbon could be removed by harvest (bioextraction) across both sites. This equates to about 1,212.1 lbs of nitrogen and 7,024.3 lbs of carbon total.

It should be noted that it may take about 3 to 4 years for cultured mussel seeds to reach the 30 gram wild adult weight used for reference in the theoretical farm nutrient removal calculations, and therefore the theoretical farm removal rates would be achieved after at least 3 to 4 years of ribbed mussel cultivation (Table 4, Figure 6).

It should also be noted that aquaculture leasing programs vary in the sizes of their individual land parcels available for shellfish cultivation. In New York, there is currently no commercial leasing program within Long Island Sound, but the Town of Islip and Suffolk County have programs with parcels up to 10-acres available in Great South Bay and Peconic Bays, respectively. In Connecticut, interested applicants can submit competitive leasing bids of 5-acre minimum and up to 200-acre maximum within town underwater lands of Long Island Sound.

Determination of Animal Feed Suitability

Nutrients

Nutrients and micronutrients measured in ribbed mussels sampled at both grow-out sites were generally within animal feed maximum tolerance levels set by the National Research Council *Mineral Tolerances of Animals* book (NRC MTL 2005) (Table 5). The maximum tolerance level (MTL) is the highest "dose" of something that does not cause adverse effects on an animal (Weiss 2008). MTLs are species-specific and while most results were below established MTLs, some samples measured above calcium and iron MTLs for certain species. Excessive calcium consumption can lead to increased urination, decreased appetite, calcification of soft tissues, and interference of mineral absorption, though animals usually tolerate short-term excessive exposure well (NRC MTL 2005).

Ribbed mussel samples exceeded calcium MTLs for growing bird poultry, swine (pigs), and fish (Table 5). For growing bird poultry, calcium exceeded their MTL in one of the 5 Huntington samples during Year 2 (10/23/23) and in one of the 4 Northport samples during Year 1 (9/6/22). For swine with a lower calcium MTL than poultry, an additional sample from Huntington during Year 2 (6/12/23) exceeded their MTL in addition to the 2 previously listed samples. For fish with an even lower calcium MTL than swine, two additional samples (one from Huntington Year 1, one from Northport Year 2) exceeded their MTL in addition to the 3 previously listed samples. In contrast, no samples from the study exceeded the calcium MTL for laying hens, which have a high calcium requirement for eggshell formation of about 3.5% (35,000 mg/kg) and thus have a much higher MTL than other farmed animals. Therefore, for laying hens, ribbed mussel-based feed may help to meet their high calcium requirements, indicating suitability for laying hen feed.

According to the NRC MTL, high concentrations of calcium that exceed MTLs can be tolerated if phosphorus levels are increased sufficiently to maintain an appropriate calcium to phosphorus ratio. Because none of the samples exceeded phosphorus MTLs for all species mentioned, it may be possible to increase supplemental phosphorus in ribbed mussel animal feed to increase relative calcium tolerance. The NRC MTL also notes that oyster shells are a good source of calcium to supplement diets in animal feed; more investigation is needed to determine if ribbed mussels may be a suitable alternative to this.

Iron is required in growing, laying, and lactating animals at between 50-100 mg/kg, and iron content in all ribbed mussel samples met this minimum requirement (Table 5). However, iron was measured above the MTLs for poultry (both growing birds and laying hens) in two of the 4 mussel samples collected in Northport, one from each year of the study (9/6/22 and 8/14/23). Although the source of iron was not determined in sample analyses, the NRC MTL notes that iron oxide is biologically unavailable to animals and will cause few, if any, adverse effects, while sources like iron sulfate and iron chloride are readily available to animals and are the basis of the established iron MTL.

Determination of whether nutrient content in the sampled mussels would meet requirements of animal feed for all farmed animals (pigs, poultry, fish, crustaceans, etc.) would require a thorough comprehensive literature review to compile all respective minimum nutrient requirement values and maximum tolerance values. However, a literature review such as this is beyond the scope of this study. The NRC MTL 2005 did not identify MTLs for crustaceans.

It should be noted that animal feed is typically sold and used in dried form and the sampled ribbed mussels were not dried prior to analysis. This step may influence the nutrient content, so more investigation is needed to determine if nutrient requirements would be met and if MTLs would be exceeded if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products. Additionally, future studies could test for additional nutrients, such as sodium, chlorine, and iodine, as these nutrients are essential in some animal diets like pigs (Crenshaw 2025). Overall, the nutrient and micronutrient content from the sampled mussels demonstrates promising preliminary results as they were generally within established MTLs.

Protein

Swine (pigs) have minimum dietary crude protein requirements ranging from 9.6-26%, depending on their stage of development (Crenshaw 2025). Poultry, specifically broiler chickens and turkeys, have protein requirements ranging from 18-23% and 14-28%, respectively (Applegate and Angel 2008). Farmed aquatic animals like fish and crustaceans have even higher protein needs (20-40%) compared to other livestock (Enviro Care Labs 2024). Protein content for all ribbed mussel samples during the study were below these requirements (Table 7). However, it should be noted that animal feed is typically sold and used in dried form and the sampled ribbed mussels were not dried prior to analysis. This step would likely have increased the percentage of protein content, so there may be potential to meet the high protein requirements of animal feed if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

The average protein results were lower in Year 1 using wild mussels (Huntington: 4.15%; Northport: 4.50%) compared to Year 2 using cultured mussels (Huntington: 6.11%; Northport: 5.30%), but the reason for this is unclear. It may be due to interannual differences in primary productivity in the region or because young mussels aren't spending energy in reproduction and so the young cultured mussels may have more protein in their tissue compared to the older wild mussels, but more investigation is needed to confirm this. It may also be due to differences in wild and cultivated ribbed mussels in general, which is an area in need of more research.

Amino Acids

Amino acids are the building blocks of proteins and are categorized as either essential or non-essential in the context of animal nutrition. Animals cannot synthesize essential amino acids, so they must be supplemented in their diet. Studies have also shown that amino acids in animal feed improve meat flavor and quality, and also prevent diseases in animals (Sefer et al. 2021). If ribbed mussels were to be a viable species for use in animal feed, they would ideally provide essential amino acids required by animals for optimal health.

For example, lysine is an essential amino acid in swine (pig) nutrition, which promotes increase in feed consumption, weight gain, and nitrogen retention (Liao et al. 2015). Pigs also need arginine in their diet, which is important to ensure healthy growth and development for young piglets (Envirocare Labs 2024). Both arginine and lysine are also essential for poultry health to support their growth and reproduction, specifically for feather development, overall growth, and egg production (Envirocare Labs 2024). For farmed aquatic animals (i.e., fish and crustaceans), specific amino acids in feed like histidine and threonine are crucial for their development (Envirocare Labs 2024).

As with nutrients, determination of whether amino acid content in the sampled mussels would meet requirements of animal feed for different animals (pigs, poultry, fish, crustaceans, etc.) would require a thorough literature review to compile all respective minimum amino acid requirement values. However, a literature review such as this is beyond the scope of this study.

Although lysine, arginine, histidine, and threonine were detected in all ribbed mussel samples, they did not meet most amino acid requirements for animal feed (Table 6). For growing pigs, the mussel samples did not meet the dietary lysine requirement range of 0.71-1.7%, and only one mussel sample met the dietary arginine requirement range of 0.32-0.75% (Crenshaw 2025). For poultry, the mussel samples did not meet the lysine or arginine requirement ranges, 0.97-1.36% and 1.04-1.47%, respectively (Applegate 2008). For farmed aquatic animals like fish and crustaceans, the mussel samples did not meet histidine and threonine requirement ranges of approximately 2% and 3.5%, respectively (Xing et al. 2023).

However, it should be noted that animal feed is typically sold and used in dried form and amino acid requirements are typically based on percent dry matter, but the sampled mussels were not dried prior to analysis. More investigation is needed to determine if the addition of this step may increase the percentage of amino acids in mussel samples. Overall, the amino acid content from the sampled mussels demonstrates promising preliminary results because essential amino acids which are vital for the growth and development of pigs, poultry, and aquatic animals were detected in all samples, and there may be potential to meet amino acid requirements of animal feed if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

Crude Fiber

Crude fiber is typically used synonymously with the term “roughage” in animal nutrition, as it refers to the structural carbohydrates made of cellulose, hemicellulose, and lignin, which are poorly digestible or indigestible and insoluble in acids and bases. Fiber also does not contribute to the nutritional value of feed. Therefore, fiber content is viewed negatively for animal feed and lower fiber content is desirable.

Poultry-feed manufacturers and poultry producers generally keep fiber content below 7% in poultry feed because higher fiber content can decrease feed consumption, reproduction, and chicken growth (Varastegani and Dahlan 2014). Typically, crude fiber in poultry feed is between 3-4% and can be up to 5% for laying hens (Varastegani and Dahlan 2014).

For pig feed, fiber content greater than 5-7% is considered excessive without proportional increases in fat to compensate because this would result in decreased weight gain (Crenshaw 2025). For fish feeds, crude fiber content is usually less than 7% to limit the amount of undigested material entering the fish farm system (Gatlin III 2010). Dietary crude fiber requirements for crustaceans were not found.

Crude fiber content in all ribbed mussel samples was very low or not detected; highest crude fiber detection was 1.2% in Northport Harbor on 10/22/22 in Year 1 (Table 7).

However, it should be noted that animal feed is typically sold and used in dried form, but the sampled mussels were not dried prior to analysis. More investigation is needed to determine if the addition of this step may increase the percentage of crude fiber in mussel samples. Overall, the crude fiber content from the sampled mussels demonstrates promising preliminary results as they were low, which is desired for animal feeds.

Ash

Ash content in animal feed is an indicator of feed quality, where low ash content indicates good quality feed and vice versa because it is a measure of total inorganic matter (minerals) devoid of protein, calories, energy, or nutrients (Hoffman 2005). Ash is not digestible by animals and high ash content may dilute nutrient availability for livestock animals. Feeds of animal origin, such as bone and shell, can contribute to ash content. Additionally, higher ash content can indicate contamination of feed with sand or soil (Laube 2023). Therefore, while there are no standards for ash content in animal feeds, minimal ash content is desirable.

For both sites, average ash content was lower in mussels sampled during Year 1 (Huntington: 4.68%; Northport: 8.15%) compared to in Year 2 (Huntington: 45.3%; Northport: 38.2%; Table 7). This may be due to differences in using adult wild-harvested mussels in Year 1 versus juvenile cultured ribbed mussels in Year 2 as many more juvenile cultured mussels were sampled to meet the minimum sample weight requirement by the contract laboratory, which may have contributed more ash-containing shells relative to mussel tissue. However, this would require more investigation to confirm.

Overall, the ash content from the Year 1 sampled mussels demonstrates promising preliminary results because low ash is desired as an indicator of higher quality feed. However, ash content from Year 2 sampled mussels was much higher at both locations, which is not desirable for animal feed. In previous studies conducted by the Virginia Institute of Marine Science and NOAA’s Milford Lab, shells of various clams and bay scallops were removed from samples to exclude ash-containing inorganic material like sand and shells before conducting analyses to measure percent organic matter and ash content of eelgrass sediment cores and shellfish tissue, respectively (K. DeGroat, pers. comm., October 28, 2025). Therefore, removing the shells from ribbed mussels would likely decrease ash content to better meet lower ash content desired in animal feeds, but more investigation is needed to confirm.

Fat

Fat is an important high energy component of animal feed as it provides about 2.25 times as much digestible energy as carbohydrates. High or supplemented fat content in animal feed can increase the energy density, improve texture, and reduce the dustiness of feeds, which adds value to the final product (VELP Scientifica 2019). Supplemented fats in animal feed are also carriers of essential fat-soluble vitamins and increase nutrient absorption (Ravindran et al. 2016). While there are no official criteria for fat content in animal feeds, fats are typically included at certain levels to ensure adequate supply of essential fatty acids. For example, a minimum inclusion level of 1% fat has been suggested for poultry diets, though 2-5% is usually added in commercial poultry diets (Ravindran et al. 2016). For swine diets, fats are typically added at 1-5%, depending on the stage of development, with gestating pigs requiring no added fat (Menegat et al. 2019). Inclusion of fats above 4 and 5% in poultry and swine pelleted diets, respectively, lead to inferior pellet quality and should be avoided (Ravindran et al. 2016, Menegat et al. 2019). Farmed fish diets typically comprise about 15% fats, with varying fatty acid requirements between marine and freshwater fish (Craig and Helfrich 2002). Dietary fat requirements for crustaceans were not found.

Average results for fat content in the sampled ribbed mussels were low (Huntington: 0.41%; Northport: 0.38%; Table 7). While animal feed is typically sold and used in dried form, it should be noted that the sampled ribbed mussels were not dried prior to analysis. If this step were to be incorporated, it might have increased the fat content by reducing moisture, but some drying processes also remove fatty acids in feeds (AAFCO 2018), so determining total fat and essential fatty acid content in a dried ribbed mussel animal feed product would require further investigation.

It should also be noted that the energy that fats provide can vary greatly depending on the digestibility and quality of each fat source, which is influenced by many factors like the chain length of fatty acids and free fatty acid content (Menegat et al. 2019). The digestibility of fats in the ribbed mussel samples was not determined in this study, so more investigation is also required to determine if fat digestibility in ribbed mussels is suitable for animal feed.

Overall, the fat content in the sampled ribbed mussels provides promising preliminary results as they were not too high in fat and therefore would not compromise pellet quality in animal feed.

Moisture

The Association of American Feed Controls Officials (AAFCO) defines moisture as water content in animal feed. It is important to determine, optimize, and control moisture in animal feed because it improves nutritional consistency, reduces spoilage, improves shelf-life and stability, and reduces storage requirements (Hydronix 2015). While there are no official criteria for moisture in animal feed, it is recommended that dry feeds contain no more than 12% moisture for safe and long-term storage (Beck et al. 2024).

Average results for moisture content in the sampled ribbed mussels were much higher than the recommended level (Huntington: 77.0%; Northport: 72.8%), though one sample from each site on different dates was below 45% (Table 7). While animal feed is typically sold and used in dried form, it should be noted that the sampled ribbed mussels were not dried prior to analysis. This drying step would have decreased the percentage of moisture content considerably, so there may be potential for the ribbed mussels to fulfill the lower moisture recommendations for dry animal feeds after processing to remove excess moisture. While it is informative to have baseline results for moisture content of cultivated ribbed mussels, future work is needed to test moisture content of dried and processed ribbed mussels to determine suitability for animal feeds and which drying processes work best to retain the nutrients desired within dried mussel product.

Carbohydrates

Carbohydrates make up the majority of animal feed as the primary source of energy in diets for most livestock, about 60-80% of dry matter (USDA 2021, Van Saun 2024). For poultry nutrition, carbohydrates typically make up 60-70% of feed composition (Agriculture Institute 2023). For pigs, energy content in feed is typically measured in the form of calories rather than carbohydrate content. However, corn is the main component of most pig feeds, containing about 65% carbohydrate content (Jagdish 2020).

For fish farmers who use complete diets without supplementation, carbohydrate content is typically 15-20% of feed composition (Craig and Helfrich 2017). While essential for fish health, carbohydrates fed in excessive amounts may harm their immune system (Subramami and Michael 2017). Dietary carbohydrate requirements for crustaceans were not found.

Results for carbohydrates in the sampled ribbed mussels varied greatly throughout the study and were generally very low (Table 7). No carbohydrates were detected in four of the 5 samples from Huntington Harbor; the only sample with detectable carbohydrates was in October of Year 1, which had 2.17% carbohydrate content. Average carbohydrate content from Northport Harbor samples in Year 1 was 1.01% and only one of the two Northport samples in Year 2 had detectable carbohydrates (October sample), and it was notably higher than Year 1 samples from both locations, at 32.7% carb content.

Whether the difference in carbohydrate content between Years 1 and 2 is due to differences of mussels used (wild vs cultured) would require more investigation. Variability in carbohydrate content could potentially be related to seasonal trends, as carbohydrates can be quickly consumed by mature adults in Year 1 after spawning, and the timing of sampling during the study may have affected carbohydrate content due to the timing of ribbed mussel spring/early summer versus late summer/early fall spawns (M. Sclafani, pers. comm., March 28, 2025).

While animal feed is typically sold and used in dried form, it should be noted that the sampled ribbed mussels were not dried prior to analysis. This step would likely have increased the percentage of carbohydrates by removing excess moisture. Based on the results of this study, more investigation is needed to determine if ribbed mussel animal feed may have to be supplemented with carbohydrates from a different source like plant material and grains in order to fulfill adequate energy requirements of livestock feed.

Pesticides

New York State's Agriculture and Markets sets regulations on the manufacture and distribution of commercial feed ("Commercial Feed"). Under Article 8 Section 132 of the State's Agriculture and Markets Law, commercial feed is deemed adulterated if it contains pesticides that are considered unsafe under the Federal Food, Drug, and Cosmetic Act, which authorizes EPA to establish maximum residue levels (MRLs), also known as "tolerances", for pesticide residues that may remain in or on marketed food ("Section 132 – Adulteration"; "About Pesticide Residues"). For example, EPA has established tolerance levels for pesticides, such as insecticides called imidacloprid and spinosad, at 0.05 ppm and 4.0 ppm, respectively, in molluscan shellfish (i.e. mussels) (US EPA 2014). Specific tolerance levels are also established for farmed animals raised for consumption, as well. To analyze the ribbed mussels sampled during this pilot study, the Eurofins contract laboratory used two different analyses to test for the presence of over 300 pesticides ("Quechers Method").

No pesticides were detected in any ribbed mussel sample throughout the study (Table 10). These promising preliminary results demonstrate that ribbed mussels cultivated in both Huntington and Northport Harbors would likely not pose a risk of pesticide contamination when incorporated into animal feed. It should be noted that animal feed is typically sold and used in dried form and the sampled ribbed mussels were not dried prior to analysis. More investigation is needed to determine if pesticides would be detected if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

PCBs

Polychlorinated biphenyls (PCBs) are toxic industrial chemicals and persistent, ubiquitous contaminants in the environment. Because of this, animal feeds that are animal and marine-based typically contain PCBs as unavoidable, environmental contaminants, which are then transmitted to food-producing animals in their meat, milk, and eggs when they consume PCB-contaminated animal feed. The FDA established temporary tolerances for residues of PCBs as 0.2 ppm in finished animal feed and 2 ppm in animal feed components of animal origin, including fishmeal and other by-products of marine origin ("Tolerances for PCBs").

PCBs were not detected in any samples throughout the study (Table 11). These promising preliminary results demonstrate that ribbed mussels cultivated in both Huntington and Northport Harbors would likely not pose a risk of PCB contamination when incorporated into animal feed. It should be noted that animal feed is typically sold and used in dried form and the sampled ribbed mussels were not dried prior to analysis. More investigation is needed to determine if PCBs would be detected if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds found in motor vehicle exhaust; emissions from burning coal, oil, and wood; smoke from industrial and municipal sources; charcoal-cooked food, etc. They can persist in the environment for months or years and can be found in the air, water, and soil. There are hundreds of PAHs, but the US EPA considers 16 of them as “priority pollutants” under the Clean Water Act due to their high toxicity and risks to human health as carcinogens and other health concerns if exposed (“Polycyclic Aromatic Hydrocarbons” Eurofins US 2025; “Priority Pollutant List” US EPA 2014). The Eurofins contract laboratory tested for those 16 “priority” PAHs.

Results for PAHs in the sampled ribbed mussels were variable throughout the study among the 16 PAHs tested (Table 12). Four of the 16 PAHs tested were not detected in any of the samples from either grow-out location throughout the study. Eight of 16 PAHs tested were detected in at least one sample across both grow-out locations throughout the study. One PAH of the 16 tested was not detected in any samples from Huntington Harbor but was detected in at least one sample from Northport Harbor. Three of the 16 PAHs tested were detected in all samples at both grow-out locations throughout the study.

The US federal government has set regulatory standards and guidelines for PAHs in air and drinking water. The FDA has not introduced PAH regulations for food or animal feed (Zelinkova and Wenzl 2015). To compare the results of this study to an existing standard in order to get a general sense of whether the ribbed mussels would be safe for use as animal feed in terms of PAH content, we looked to the maximum contaminant level (MCL) set by EPA for benzo(a)pyrene in drinking water, which is 0.2 ppb (“National Primary Drinking Water Regulations”). In 2 out of the 9 ribbed mussel samples collected throughout the study, benzo(a)pyrene was higher than 0.2 ppb in one sample from each site and different dates in Year 2 (Table 12). The other 7 samples had no PAHs detected, but the detection limit was 0.5 ppb, so it is difficult to determine whether those samples were below 0.2 ppb, or in fact above 0.2 ppb but lower than the detection limit.

Without established regulations for PAHs in food and animal feed though, it’s not currently possible to determine whether PAH content in the sampled mussels would be considered safe for incorporation in animal feed. It should be noted that animal feed is typically sold and used in dried form and the sampled ribbed mussels were not dried prior to analysis. More investigation is needed to determine if PAH content would be affected if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

Heavy Metals

Heavy metals like arsenic, lead, cadmium, and mercury are found in certain animal foods. While high levels of these heavy metals can be toxic, it's not always possible to eliminate them from animal feeds completely because they’re found in the air, water, and soil. The FDA Center for Veterinary Medicine (CVM) has not established guidance, action levels, or tolerances for heavy metals in animal food, but the FDA takes action based on information provided by the National Research Council of the National Academies *Mineral Tolerance of Animals* book (NRC MTL) and the Association of American Feed Control Officials *Official Publication* (AAFCO OP) (Deemy and Benjamin 2019).

Heavy metals in the sampled ribbed mussels were all below the maximum tolerance levels established for arsenic, cadmium, chromium, mercury, lead, and nickel in complete feed, according to the NRC MTL and AAFCO OP (Table 8, Table 13). These promising preliminary results demonstrate that ribbed mussels cultivated in both Huntington and Northport Harbors would likely not pose a risk of heavy metal contamination when incorporated into animal feed. It should be noted that animal feed is typically sold and used in dried form and the sampled ribbed mussels were not dried prior to analysis. More investigation is needed to determine if heavy metals would remain below the maximum tolerance levels if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

Pathogens

The ribbed mussels in this study were cultivated in waters that are closed for shellfish harvest designated for human consumption due to pathogen contamination that pose public health concerns. Therefore, it was important to test the ribbed mussel samples for pathogenic bacteria to determine if there are pathogenic contamination concerns if used as animal feed. The Eurofins contract laboratory tested the samples for aerobic plate count, total coliforms, Enterobacteriaceae, *E. coli* O157:H7, fecal coliforms, non-O157 Shiga toxin-producing *E. coli* (STEC), *Salmonella*, *Shigella*, and *Vibrio*.

Results for pathogens in the sampled ribbed mussels were variable throughout the study among the 9 parameters tested (Table 9). Three of the 9 parameters tested were not detected in any of the samples from either grow-out location throughout the study. Two of the 9 parameters tested were detected in at least one sample across both grow-out locations throughout the study. Two of the 9 parameters tested were detected in most samples from Huntington Harbor and for all samples from Northport Harbor. Non-O157 Shiga toxin-producing *E. coli* (STEC) was only detected once in Huntington Harbor, though detection was found with a different method for this sample than for all other samples, including Northport Harbor's sample from the same day. Aerobic plate count was high in most samples at both grow-out locations throughout the study. It should be noted that coliform plate counts can be highly variable and at times even produce unreliable counts (e.g. when compared with flow cytometry), and bacteria levels may vary seasonally and during high precipitation events (M. Sclafani, pers. comm., March 28, 2025).

It should also be noted that animal feed is typically pasteurized/cooked and dried to eliminate harmful bacteria and extend shelf-life, and the sampled ribbed mussels did not undergo this treatment process before analysis. Therefore, pathogen contamination in the ribbed mussels would likely be lower if used as animal feed because it would undergo the pasteurization/cooking treatment process.

While the US federal government has set regulatory standards and guidelines to protect people from eating and consuming pathogens in food products like dairy, produce, shellfish, and seafood ("Office of Microbiological Food Safety"), pathogen guidance is more complicated for animal feed (Center for Veterinary Medicine 2022). For example, one of the tested pathogens, *Salmonella* spp., is the bacterium responsible for salmonellosis (Salmonella poisoning) in humans and animals, but each animal species only develops diseases to certain strains of *Salmonella*. For example, poultry can develop diseases if they consume feed contaminated with Salmonella strains Pullorum, Gallinarum, and Enteritidis, which are different from strains that affect other livestock.

Although there are no US guidelines for *Vibrio* in animal feed, a WHO/FAO (2005) Risk Assessment indicated that a *Vibrio vulnificus* concentration of <30 units per gram in raw oysters is a negligible health risk. In the UK, another common species of *Vibrio* in shellfish, *V. parahaemolyticus*, is considered a low health risk if concentrations are <20 cfu/g (UK Health Protection Agency 2009). Although *Vibrio* spp. were detected in most mussel samples, the analysis was performed as a detect/non-detect basis and the detection limit was 1 unit/gram, so it is unclear whether counts were above or below the 30 units/gram target and would thus pose a potential health risk or not. While freezing does not kill off *Vibrio*, most heat treatments do (UK Health Protection Agency 2009), so a cooking treatment process would likely remove *Vibrio* contamination in ribbed mussel animal feed.

Determination of whether pathogen results in the sampled mussels would meet requirements of animal feed for different animals (pigs, poultry, fish, crustaceans, etc.) would require a thorough literature review to compile all respective acceptance limits and criteria as this information is not readily available and there is little official guidance or regulations on this topic (D. Legan, pers. comm., April 7, 2025). However, a literature review such as this is beyond the scope of this study.

Overall, the pathogen results from the sampled mussels are promising because pathogens like *Salmonella* spp. and *E. coli* O157:H7 were not detected in any samples throughout the study, and though other pathogens like *Vibrio* spp. were detected in most samples throughout the study, contamination in the ribbed mussels would likely be lower if used as animal feed because they would undergo a pasteurization/cooking treatment process to remove pathogens.

6. CONCLUSIONS

This pilot study provided data to assess the effectiveness of using ribbed mussels (*Geukensia demissa*) as a nutrient management strategy via bioextraction, as well as the suitability of bioextractive ribbed mussels as animal feed. This data contributes to the critical data needs of an understudied shellfish species that is key to the Bioextraction Initiative's goal of establishing a bioextraction industry with a commercial use for the harvested biomass by supporting relevant research and communicating findings to regulators, growers, researchers, stakeholders, and the public.

Determination of Nutrient Bioextraction Effectiveness using Ribbed Mussels

Nutrient bioextraction effectiveness of ribbed mussels was determined by the nutrient content data, which was used to calculate estimated nutrient removal rates. The results from the study demonstrated that ribbed mussel farming would be an effective nutrient management strategy to remove excess nitrogen and carbon. In a hypothetical one-acre farm stocked with 220,800 ribbed mussels in commercial cages used by oyster farmers, an estimated average of 54.98 kg of nitrogen and 318.61 kg of carbon would be removed at harvest via bioextraction. This equates to removal of 121.2 lbs of nitrogen and 702.42 lbs of carbon per acre each harvest. It should be noted that it may take about 3 to 4 years for cultured mussel seeds to reach the 30 g wild adult weight used for reference in the nutrient removal calculations, and therefore the estimated removal rates would be achieved after at least 3 to 4 years of ribbed mussel cultivation. For reference, it takes 2 to 4 years for oyster seeds to grow to market size before they're ready for harvest. Farmers would need to consider this if interested in pursuing ribbed mussel aquaculture commercially.

These nutrient removal estimates are conservative as a commercial farmer may set up their farm differently than the mock farm design. For example, a farmer may choose to set the cages closer together to fit more cages per row, set their rows of cages closer together to add more rows, or stack cages vertically in the water column 2 to 3 cages deep. These estimates also do not account for additional benefits achieved by filtration as the mussels feed on algae. A previous ribbed mussel filtration study found that a fully stocked raft of 337,500 mussels could filter on average 12 million liters of water daily (Galimany et al. 2017). This ecosystem service provided by ribbed mussels, though not studied in this particular project, improves water quality and clarity and further enhances nutrient removal that is achieved through harvest of the mussel tissue and shell, suggesting much higher total nutrient removal rates than the calculated estimates achieved through bioextraction alone. Assuming the same filtration rate as the Galimany et al. 2017 study, a one-acre farm stocked with 220,800 ribbed mussels could filter about 7.85 million liters of water daily. This strengthens the finding that ribbed mussel aquaculture is an effective nutrient management strategy.

Determination of Animal Feed Suitability using Ribbed Mussels

Overall, the nutrient and micronutrient data demonstrated promising results for animal feed suitability as they were generally within established maximum tolerance levels (MTLs) for poultry, pig, and fish feeds. In a few samples, calcium and iron were measured above their respective MTLs, though promisingly, calcium that exceeded MTLs for some farmed animals met the high calcium requirement for others, such as egg-laying hens. While protein content in the mussels were below the requirements for poultry, pigs, and farmed aquatic animals like fish and crustaceans, there is potential for these requirements to be met if the mussels were processed and dried to remove excess moisture and increase protein percent content. Additionally, the amino acid content from the ribbed mussels demonstrate promising preliminary results as arginine, lysine, histidine, and threonine were detected in all samples, as these amino acids are vital for the growth and development of poultry, pigs, and farmed aquatic animals like fish and crustaceans. Like with protein, more investigation is needed to determine if the addition of a drying and processing step would help meet amino acid requirements for respective animal feeds by removing excess moisture.

Additional feed analysis results included moisture, crude fiber, fat, carbohydrates, and ash. As previously mentioned, the ribbed mussels were not dried prior to analysis, so it was unsurprising to find that moisture in most samples were high, making up about 75% of mussel content, and above the recommended moisture standard for animal feed. Due to the high percentage of moisture present in the samples, all other feed analysis values were naturally very low. While the other feed analysis parameters were assessed as-is, it should be noted that they are not reflective of final determination of animal feed suitability since an animal feed product would be processed into a dry form.

Crude fiber content was very low or not detected in the mussels, which is typically considered desirable as this may be an indicator of high energy content in feed. However, fat and carbohydrate contents make up the components of energy in feed, and both these results were very low in the ribbed mussels. Low fat in feed is generally desired to prevent production of low-quality feed pellets, though fat inclusion is also desired at a minimum to ensure absorption of fat-soluble vitamins and nutrients. On the other hand, low carbohydrate content in most animal feeds is undesirable as carbohydrates make up the majority of animal feed to provide the necessary energy for poultry and pigs. More investigation is needed to determine if dried and processed ribbed mussels would meet the carbohydrate requirement of various animal feeds, or if dried ribbed mussel feed would need to be supplemented with additional sources of carbohydrates to fulfill the energy requirements of livestock feed. In terms of crude fiber and fat contents, the mussels would be considered suitable for use in animal feed.

In addition, ash content data was variable as they were low in Year 1 adult wild mussels and very high in Year 2 cultured young mussels. This may be due to increased younger cultured mussels sampled to meet the minimum contract laboratory requirement, which may have introduced more shell that is higher in ash content relative to mussel tissue. High ash content is undesirable because it is an indicator of poor feed quality given that ash does not provide nutritional value and may dilute nutrient availability for livestock animals. As shells contribute to ash content, a recommendation to reduce ash content would be to remove the mussel shells before the animal is processed into animal feed. A sustainable, bioextraction-focused Swedish food-tech company that processes blue mussels into products like animal feed and seasonings has developed an energy-efficient process to separate the shells from the mussel meat (tissue) (Musselfeed 2021). While the mussel meat is used for their products, they have found alternative uses for the shells, such as acidified soils that need to be supplemented with lime that is rich in calcium and magnesium. A soil amendment such as this could be a great alternative use for the ribbed mussel shells as the calcium content was found at times to be too high for animal feed.

Based on the contaminant data, the mussels would be considered generally safe for use as animal feed because there was no presence of pesticides, PCBs, *E. coli*, *Salmonella*, or *Shigella*, and heavy metal contents were all below the respective maximum tolerance levels.

While some pathogens were detected in at least one sample, such as fecal coliforms and *Vibrio*, more investigation is needed to determine if these pathogens would persist in the samples after cooking/pasteurization, which is an important processing step to reduce pathogenic bacteria in feed. In addition, PAHs have not been introduced into human food or animal feed regulations, so it’s not currently possible to determine the safety of using ribbed mussels in animal feed with this parameter. As noted in the results, more investigation is needed to determine if these contaminants would be detected or meet animal feed standards if the ribbed mussels were processed and dried to remove excess moisture, as is done for traditional animal feed products.

The suitability of the cultivated and harvested wild and cultured ribbed mussels as animal feed was determined by the results for nutrients, micronutrients, feed analysis, amino acids, and contaminant data. A thorough literature review to compile animal feed criteria for all common livestock animals and specific requirements for each stage of development would be necessary to provide a definitive assessment, though a review such as this is beyond the scope of this study. Therefore, this assessment should be considered a preliminary and general overview based on criteria found through internet searches that can be accessed without paywalls. While livestock feed is typically pasteurized and dried to remove bacteria and moisture, extend shelf-life, and improve long-term quality, the ribbed mussels in this study were frozen and ground prior to analysis without the pasteurization or drying process. The exclusion of a pasteurization or drying step became apparent in the results, so it is important to consider this when assessing suitability as animal feed.

Future Studies Needed

Overall, the findings from this study showed success in effectiveness of using ribbed mussels to bioextract nutrients from embayments, as well as preliminary data that demonstrated the bioextracted mussels were generally safe and suitable for use as animal feed. To better understand the bioextraction effectiveness of ribbed mussels, an analysis of theoretical nitrogen and carbon removal relative to the total nitrogen and carbon of each site would help contextualize the impact of a ribbed mussel farm as a nutrient management strategy.
The preliminary animal feed data also informs future work using ribbed mussels that could be done to determine animal feed suitability and safety with mussels that have undergone additional processing steps before analysis, such as shell-removal, pasteurization, and drying, so the samples reflect a higher quality, finished animal feed product that could be sold to market. Future work is also needed to identify best drying processes to retain the nutrients desired within dried ribbed mussel feed product.

A post-study discussion with the contract laboratory company revealed that in addition to removing pathogenic bacteria, pasteurization would help the palatability of the mussels in animal feed, as livestock animals would typically not eat raw, unprocessed mussels. A refined study such as this would contribute additional data needed to establish a new market in the bioextraction industry. Furthermore, Dr. Michael Rust, a marine fish nutrition expert at NOAA, stated that while soybeans are an inexpensive source of protein and energy for fish feeds, mussels have potential as a flavor enhancer for fish feed pellets. This is because most predatory fish reject the flavor of soybeans and prefer feeds that mimic their natural sources of food (G. Wikfors, pers. comm., September 2, 2025). This may be promising for potential live animal feed trials using ribbed mussel animal feed in the future.

The study identified further investigation needed to confirm its preliminary findings, such as a thorough comprehensive review by animal nutritionists. The study also identified data gaps for future work to investigate, such as testing ribbed mussels for additional parameters like sodium, chlorine, and iodine, as these nutrients are essential in some animal diets like swine.

Future work utilizing bioextracted ribbed mussels can also test animal feed suitability using mussel meat only and test soil amendment suitability using mussel shells repurposed for this use instead. Additional work could also investigate if ribbed mussel shells would be a suitable alternative to oyster shells that are used as a calcium supplement for farmed animals. Refining the best uses for both parts of the animal will diversify the potential commercial products in a bioextraction industry. These recommended studies would provide more data to support an emerging industry that will remove nutrient pollution to improve coastal water quality.

Because ribbed mussels are not yet considered a commercial species, they are not produced in hatcheries at a commercial scale. Therefore, the cultured mussels in this study were considered a novel success and more data is needed to understand cultured ribbed mussels in general. Future work with cultured ribbed mussels could include a bioextraction comparative study to determine differences between wild and cultured mussels, and a bioextraction comparative study to determine differences in bioextraction performance between different ages of cultured mussels. In addition, more work is needed to refine ribbed mussel aquaculture techniques so they can be sourced sustainably at commercial scale for use in a bioextraction industry, as well as other large-scale uses for environmental remediation, such as pathogen removal and living shoreline restoration.

Additional Considerations for Site Selection & Timing, and Efficiency of Bioextraction

It is worth noting that mussel farm site selection has been shown to impact biomass yield and, therefore, nutrient removal through bioaccumulation of nitrogen and carbon (Visch et al. 2020). Additionally, the nutrient mitigation capacity of mussel farms can be affected by the timing of harvest due to seasonal variability in nutrient uptake by the animals (Visch et al. 2020). Bivalves typically contain more tissue, and therefore more nitrogen and carbon, during the autumn months, driven by metabolic requirements associated with the reproductive cycle, so removal of the mussels during this period of higher biomass would enhance bioextraction of these nutrients (Jansen et al. 2019).

It is also important to note that other factors must be considered in the site selection process aside from just those needed to maximize nutrient extraction. For example, site selection should incorporate considerations of potential negative ecological impacts of mussel farming, including the possibility of increasing the organic load and decreasing oxygen availability in the water column due to the sudden addition of a large quantity of mussels that may occur with the establishment of a mussel farm (Zhang et al. 2009; Visch et al. 2020). For these reasons, the sites of any future large-scale mussel farms in Huntington and Northport Harbors will be carefully assessed during the planning stages of the project in order to maximize biomass and excess nutrient extraction, while also minimizing any deleterious environmental impacts.

Once removed from the farm, the final application of the mussel tissue has the greatest impact on whether they can be considered an effective long-term carbon sink once removed from the marine environment, and more studies such as this should be conducted to determine whether extractive aquaculture can be considered a useful nutrient mitigation tool (Visch et al. 2020).

It should also be noted that commercial-scale bioextraction through ribbed mussel and/or macroalgae (seaweed) cultivation is not yet a reality in New York State, but pilot-scale bioextraction projects using ribbed mussels and macroalgae have been completed or are underway.

7. TABLES

Site Characteristics and Water Quality Data

Table 1. Site characteristics for ribbed mussel grow-out locations on docks located in Huntington Harbor and Northport Harbor.

Site Characteristic	Huntington Harbor	Northport Harbor
Latitude	40.8979	40.8982
Longitude	-73.4350	-73.3532
Average depth on sampling dates	2.6 m	1.7 m

Table 2. Water quality measurements taken 0.5 m from surface.

		Year 1			Year 2			
Parameter	**Site**	**9/6/2022**	**10/3/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**	**p-value**
Time of measurement	Huntington	2:30 PM	2:30 PM	10:10 AM	10:30 AM	11:45 AM	1:00 PM	N/A
	Northport	3:00 PM	11:00 AM	11:00 AM	11:10 AM	11:00 AM	2:00 PM	
Temperature (°C)	Huntington	24.40	15.57	14.51	19.63	24.59	15.32	0.973
	Northport	24.64	14.68	14.35	19.81	25.37	14.58	
Salinity (ppt)	Huntington	26.81	28.42	28.56	26.55	27.18	25.14	0.535
	Northport	27.93	26.65	27.85	26.39	26.66	24.30	
Conductivity (mS/cm)	Huntington	41.05	36.05	35.36	37.11	41.98	32.10	0.834
	Northport	43.06	33.35	34.44	37.04	41.93	30.60	
Sp. Conductance (µS/cm)	Huntington	41803	44000	44208	41380	42312	39.372	0.430
	Northport	43360	41530	43207	41127	41703	38197	
Dissolved Oxygen (%)	Huntington	86.3	95.4	103.2	95.7	92.5	148.1	0.565
	Northport	41.3	84.4	105.8	92.1	79.2	154.9	
Dissolved Oxygen (mg/L)	Huntington	6.22	7.99	8.83	7.49	6.60	12.73	0.711
	Northport	2.93	7.47	9.12	7.17	5.59	13.58	
pH	Huntington	7.57	7.77	7.90	7.65	7.65	7.65	0.258
	Northport	7.28	7.47	7.96	7.59	7.47	7.66	

Results were compared between both sites using t-test (alpha = 0.05).

Table 3. Water quality measurements taken 0.5 m from bottom depth.

		Year 1			**Year 2**			
Parameter	**Site**	**9/6/2022**	**10/3/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**	**p-value**
Time of measurement	Huntington	2:30 PM	2:30 PM	10:10 AM	10:30 AM	11:45 AM	1:00 PM	N/A
	Northport	3:00 PM	11:00 AM	11:00 AM	11:10 AM	11:00 AM	2:00 PM	
Temperature (°C)	Huntington	24.67	15.57	14.45	19.11	24.24	15.25	0.987
	Northport	24.62	14.85	14.43	19.57	25.24	14.30	
Salinity (ppt)	Huntington	28.88	28.43	28.67	26.76	27.27	25.30	0.933
	Northport	33.34	26.74	28.0	26.53	27.01	24.39	
Conductivity (mS/cm)	Huntington	43.74	36.09	35.43	36.93	41.82	32.23	0.786
	Northport	43.62	33.55	34.67	37.02	42.30	30.51	
Sp. Conductance (µS/cm)	Huntington	44002	44008	44366	41630	42434	39581	0.333
	Northport	43940	41683	43463	41307	42103	38.331	
Dissolved Oxygen (%)	Huntington	76.3	95.8	107.6	90.2	84.8	154.9	0.522
	Northport	34.1	82.0	104.7	85.5	82.4	146.1	
Dissolved Oxygen (mg/L)	Huntington	5.39	8.01	9.20	7.13	6.08	13.30	0.647
	Northport	2.41	7.02	8.99	6.79	5.82	12.88	
pH	Huntington	7.54	7.76	7.91	7.62	7.64	7.69	0.256
	Northport	7.26	7.45	7.96	7.56	7.49	7.65	

Results were compared between both sites using t-test (alpha = 0.05).

Ribbed Mussel Size Data

Table 4. Adult wild-collected ribbed mussels were measured for shell length and total weight before and after shucking. This information was used to estimate the number of sampled mussels necessary to meet the analytical laboratory minimum weight requirements and to estimate total final weight of mussels for nitrogen and carbon removal calculations.

Sample #	Shell Length (mm)	Total Weight Before Shucking (g)	Tissue + Shell Weight (g)	Tissue Weight (g)	Shell Weight (g)
1	98		36	16	20
2	63	16	14	8	6
3	74	30	24	12	12
4	93	58	50	24	26
5	77	30	20	8	12
6	63	18	16	8	8
7	85	46	38	18	20
8	73	26	20	10	10
9	60	16	16	10	6
Average	**76.2**	**30.0**	**26.0**	**12.7**	**13.3**

Ribbed Mussel Analysis Data

Table 5. Ribbed mussel samples analyzed for nutrients to determine effectiveness in bioextraction and suitability as animal feed.

			Year 1		Year 2				Maximum Tolerance Levels (MTLs) for feed in:		
Parameter	**Unit**	**Site**	**9/6/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**	**p-value**	**Poultry**	**Swine**	**Fish**
Nitrogen (N)	%	Huntington	0.67	0.66	1.17	0.97	0.77	0.727	-	-	-
		Northport	0.67	0.85	-	0.88	0.82				
Carbon (C)	%	Huntington	3.14	3.42	7.24	5.07	5.61	0.882	-	-	-
		Northport	4.11	3.46	-	7.28	4.03				
Phosphorus (P)	mg/kg	Huntington	513.7	494.1	452.3	847.1	600.6	0.835	10,000 (growing birds) 8,000 (laying hens)	10,000	1,000
		Northport	598.4	217.5	-	903.8	478.1				
Boron (B)	mg/kg	Huntington	4.37	5.92	4.84	3.67	5.4	0.925	150	150	150
		Northport	4.67	5.8	-	3.36	5.28				
Calcium (Ca)	mg/kg	Huntington	9,974	5,352	14,447.5	4,875.1	35,401.2	0.676	15,000 (growing birds) 50,000 (laying hens)	10,000	9,000
		Northport	23,130	2,667	-	7,254.6	9,976.1				
Copper (Cu)	mg/kg	Huntington	4.246	2.76	3	4.2	4.1	0.815	250	250	100
		Northport	4.53	1.75	-	5.9	3.3				
Iron (Fe)	mg/kg	Huntington	491	219	86.8	463	278.3	0.282	500	3,000	-
		Northport	593.1	223.4	-	720.3	316.5				
Magnesium (Mg)	mg/kg	Huntington	897.3	901.3	648.1	836.2	676.8	0.405	5,000 (growing birds) 7,500 (laying hens)	2,400	3,000
		Northport	864.3	414	-	836.2	663.8				
Manganese (Mn)	mg/kg	Huntington	145.3	81.28	43.9	177.1	113.4	0.147	2,000	1,000	2,000
		Northport	58.1	30.28	-	102.7	64.7				
Potassium (K)	mg/kg	Huntington	1,104	1,179	1,197.1	1,379.1	1,125.1	0.409	10,000	10,000	-
		Northport	1,155	501.2	-	1,457.1	1,029.1				
Sulphur (S)*	mg/kg	Huntington	1,280	2,370	1,800	1,610	483	0.709	4,000	4,000	-
		Northport	ND	2,090	-	1,900	1,160				
Zinc (Zn)	mg/kg	Huntington	11.67	8.914	9.0	12.8	14.9	0.846	500	1,000	250
		Northport	10.72	6.044	-	14.2	13.2				

Results were compared between both sites using t-test (alpha = 0.05). Cells highlighted in green are below the maximum tolerance levels for all examined livestock animals (poultry, swine, fish). Cells highlighted in orange are above at least one of the examined livestock animal's maximum tolerance level. ND = not detected.

* Detection limit for sulfur = 95.1 mg/kg.

Table 6. Ribbed mussel samples analyzed for amino acids to determine their suitability for use as animal feed.

			Year 1		Year 2			
Parameter	**Unit**	**Site**	**9/6/22**	**10/31/22**	**6/12/23**	**8/14/23**	**10/23/23**	**p-value**
Alanine	%	Huntington	0.19	0.21	0.28	0.28	0.37	0.361
		Northport	0.22	0.21	-	0.25	0.24	
Arginine	%	Huntington	0.20	0.17	0.30	0.24	0.41	0.674
		Northport	0.24	0.16	-	0.30	0.26	
Aspartic Acid	%	Huntington	0.35	0.28	0.50	0.45	0.66	0.561
		Northport	0.37	0.26	-	0.49	0.46	
Cystine	%	Huntington	0.05	0.05	0.07	0.05	0.10	0.837
		Northport	0.05	0.04	-	0.08	0.10	
Glutamic Acid	%	Huntington	0.44	0.33	0.61	0.50	0.81	0.623
		Northport	0.49	0.27	-	0.59	0.57	
Glycine	%	Huntington	0.22	0.28	0.47	0.56	0.71	0.441
		Northport	0.33	0.32	-	0.44	0.36	
Histidine	%	Huntington	0.07	0.06	0.10	0.08	0.14	0.382
		Northport	0.08	0.04	-	0.09	0.08	
Isoleucine	%	Huntington	0.13	0.11	0.22	0.18	0.26	0.744
		Northport	0.16	0.11	-	0.21	0.19	
Leucine	%	Huntington	0.20	0.18	0.32	0.27	0.40	0.659
		Northport	0.25	0.17	-	0.30	0.28	
Lysine (total)	%	Huntington	0.21	0.17	0.31	0.26	0.42	0.704
		Northport	0.24	0.14	-	0.32	0.30	
Methionine	%	Huntington	0.06	0.05	0.09	0.07	0.15	0.780
		Northport	0.07	0.05	-	0.09	0.10	
Phenylalanine	%	Huntington	0.12	0.11	0.19	0.18	0.26	0.799
		Northport	0.15	0.11	-	0.21	0.18	
Proline	%	Huntington	0.14	0.10	0.23	0.19	0.36	0.469
		Northport	0.18	0.10	-	0.20	0.17	
Serine	%	Huntington	0.13	0.11	0.23	0.23	0.34	0.519
		Northport	0.15	0.11	-	0.23	0.20	
Threonine	%	Huntington	0.14	0.12	0.22	0.19	0.31	0.651
		Northport	0.18	0.10	-	0.22	0.20	
Tryptophan	%	Huntington	0.05	0.05	0.08	0.07	0.08	0.857
		Northport	0.07	0.06	-	0.07	0.07	
Valine	%	Huntington	0.16	0.13	0.22	0.20	0.28	0.587
		Northport	0.18	0.11	-	0.22	0.20	

Results were compared between both sites using t-test (alpha = 0.05).

Table 7. Ribbed mussel samples analyzed for feed analysis to determine their suitability for use as animal feed.

			Year 1		Year 2			
Parameter	**Unit**	**Site**	**9/6/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**	**p-value**
Crude Fiber*	%	Huntington	ND	0.4	ND	0.6	0.2	0.731
		Northport	ND	1.2	-	ND	ND	
Ash	%	Huntington	5.96	3.40	57.4	27.7	50.7	0.716
		Northport	10.8	5.49	-	51.2	25.2	
Fat**	%	Huntington	0.32	0.520	0.334	0.377	0.500	0.847
		Northport	ND	0.800	-	0.203	0.454	
Moisture	%	Huntington	89.9	89.8	44.5	87.3	73.3	0.783
		Northport	82.9	89.0	-	82.8	36.5	
Protein	%	Huntington	4.19	4.11	5.00	7.30	6.04	0.571
		Northport	4.79	4.20	-	5.49	5.11	
Carbohydrates***	%	Huntington	ND	2.17	ND	ND	ND	0.281
		Northport	1.51	0.510	-	ND	32.7	

Results were compared between both sites using t-test (alpha = 0.05). ND = not detected.

* Detection limit for Crude Fiber was 0.2%.

** Detection limit for Fat was 0.128%.

*** Detection limit for Carbohydrates was 0.01%.

Table 8. Ribbed mussel samples analyzed for heavy metals.

			Year 1		Year 2			
Parameter	**Unit**	**Site**	**9/6/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**	**p-value**
Arsenic (As)	mg/kg	Huntington	0.145	0.566	0.384	0.638	0.717	0.429
		Northport	0.202	0.747	-	0.941	0.674	
Cadmium (Cd)*	mg/kg	Huntington	ND	0.048	0.022	0.025	0.035	0.671
		Northport	ND	0.054	-	0.031	0.033	
Chromium (Cr)	mg/kg	Huntington	0.324	0.460	1.17	0.904	1.84	0.699
		Northport	0.25	1.48	-	1.55	1.13	
Lead (Pb)	mg/kg	Huntington	0.604	0.49	0.272	0.922	0.789	***0.048***
		Northport	0.747	1.55	-	1.63	0.84	
Mercury (Hg)**	mg/kg	Huntington	ND	ND	ND	ND	ND	N/A
		Northport	ND	ND	-	ND	ND	
Nickel (Ni)	mg/kg	Huntington	0.205	0.349	0.730	0.521	0.942	0.951
		Northport	0.173	0.730	-	0.751	0.592	

Results were compared between both sites using t-test (alpha = 0.05). Significant difference between sites highlighted in bold and italicized p-value. ND = not detected.

* Detection limit for Cadmium was 0.03 mg/kg and 0.02 mg/kg in years 2022 and 2023, respectively.

** Detection limit for Mercury was 0.044 and 0.04 in years 2022 and 2023, respectively.

Cells highlighted in green are below the maximum tolerance level (see Table 13).

Table 9. Ribbed mussel samples analyzed for pathogens.

				Year 1		Year 2			
Parameter	**Unit**	**Detection Limit**	**Site**	**9/6/22**	**10/31/22**	**6/12/23**	**8/14/23**	**10/23/23**	**p-value**
Aerobic Plate Count	cfu/g	100*	Huntington	6000	71000*	100*	16000	2700	0.865
			Northport	8300	9500	-	68000	5000	
Total Coliforms	cfu/g	10	Huntington	220	430	ND	240	20*	0.319
			Northport	50*	200	-	40*	30*	
Enterobacteriaceae	cfu/g	20*	Huntington	440	550	20*	510	ND	0.314
			Northport	220*	220*	-	140	20*	
***E. coli* O157:H7**	/25g	1	Huntington	ND	ND	ND	ND	ND	N/A
			Northport	ND	ND	-	ND	ND	
Fecal coliforms	MPN/g	3	Huntington	240	93	ND	ND	ND	0.321
			Northport	23	15	-	4	ND	
Non-O157 Shiga toxin-producing *E. coli* (STEC)**	/g or /25g	1	Huntington	Detected	ND	ND	ND	ND	N/A
			Northport	ND	ND	-	ND	ND	
***Salmonella* spp.**	/25g	1	Huntington	ND	ND	ND	ND	ND	N/A
			Northport	ND	ND	-	ND	ND	
***Shigella* spp.**	/25g	1	Huntington	ND	ND	ND	ND	ND	N/A
			Northport	ND	ND	-	ND	ND	
***Vibrio* spp.**	/g	1	Huntington	Detected	Detected	Detected	ND	Detected	N/A
			Northport	Detected	Detected	-	ND	Detected	

Results were compared between both sites using t-test (alpha = 0.05). ND = not detected. Cells highlighted in green were not detected and therefore show absence of that pathogen.

* Results estimated

** At the discretion of the contract laboratory, a different analysis method was used for the Huntington 9/6/22 sample (method reference AOAC-RI 031002; units in /g) than the rest of the samples (method reference BAX ® System Real-Time PCR STEC Suite; units in /25g).

Table 10. Ribbed mussel samples analyzed for pesticides using two different screening methods.

		Year 1		Year 2		
Parameter	**Site**	**9/6/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**
Screened pesticides (GC-MS)	Huntington	ND	ND	ND	ND	ND
	Northport	ND	ND	-	ND	ND
Screened pesticides (LC-MS/MS)	Huntington	ND	ND	ND	ND	ND
	Northport	ND	ND	-	ND	ND

Samples were analyzed for presence or absence of pesticides. Cells highlighted in green were not detected and therefore show absence of pesticides.

Table 11. Ribbed mussel samples analyzed for polychlorinated biphenyls (PCBs).

		Year 1		Year 2		
Parameter, mg/kg*	**Site**	**9/6/2022**	**10/31/2022**	**6/12/2023**	**8/14/2023**	**10/23/2023**
PCB 1	Huntington	ND	ND	ND	ND	ND
PCB 101	Northport	ND	ND	-	ND	ND
PCB 104	Huntington	ND	ND	ND	ND	ND
PCB 105	Northport	ND	ND	-	ND	ND
PCB 118	Huntington	ND	ND	ND	ND	ND
PCB 126	Northport	ND	ND	-	ND	ND
PCB 128	Huntington	ND	ND	ND	ND	ND
PCB 138	Northport	ND	ND	-	ND	ND
PCB 153	Huntington	ND	ND	ND	ND	ND
PCB 170	Northport	ND	ND	-	ND	ND
PCB 18	Huntington	ND	ND	ND	ND	ND
PCB 180	Northport	ND	ND	-	ND	ND
PCB 187	Huntington	ND	ND	ND	ND	ND
PCB 188	Northport	ND	ND	-	ND	ND
PCB 195	Huntington	ND	ND	ND	ND	ND
PCB 201	Northport	ND	ND	-	ND	ND
PCB 206	Huntington	ND	ND	ND	ND	ND
PCB 209	Northport	ND	ND	-	ND	ND
PCB 28	Huntington	ND	ND	ND	ND	ND
PCB 29	Northport	ND	ND	-	ND	ND
PCB 44	Huntington	ND	ND	ND	ND	ND
PCB 52	Northport	ND	ND	-	ND	ND
PCB 66	Huntington	ND	ND	ND	ND	ND
PCB 77	Northport	ND	ND	-	ND	ND
PCB 8	Huntington	ND	ND	ND	ND	ND
PCB 87	Northport	ND	ND	-	ND	ND

* Detection limit for all PCBs is 0.01 mg/kg. ND = not detected.

Cells highlighted in green are below the detection limit.

Table 12. Ribbed mussel samples analyzed for polycyclic aromatic hydrocarbons (PAHs).

			Year 1		Year 2			
Parameter, ug/kg	**Detection Limit**	**Site**	**9/6/22**	**10/31/22**	**6/12/23**	**8/14/23**	**10/23/23**	**p-value**
Acenaphthene	1.0	Huntington	3.3	8.3	ND	9.5	17	0.734
		Northport	17	ND	-	ND	21	
Acenaphthylene	2.0	Huntington	3.1	4.5	ND	5.6	5.4	0.927
		Northport	5.0	ND	-	ND	8.0	
Anthracene (Ant)	2.0	Huntington	ND	ND	ND	ND	ND	0.098
		Northport	2.8	ND	-	ND	3.6	
Benz(a)anthracene (BaA)	0.5	Huntington	ND	ND	0.95	1.0	ND	0.949
		Northport	ND	ND		ND	1.5	
Benzo(a)pyrene (BaP)	0.5	Huntington	ND	ND	ND	0.87	ND	0.845
		Northport	ND	ND	-	ND	0.91	
Benzo(b)fluoranthene (BbF)	0.5	Huntington	ND	ND	2.0	1.5	ND	0.669
		Northport	ND	ND	-	ND	1.7	
Benzo(ghi)perylene	2.0	Huntington	ND	ND	ND	ND	ND	N/A
		Northport	ND	ND	-	ND	ND	
Benzo(k)fluoranthene (BkF)	3.0	Huntington	ND	ND	ND	ND	ND	N/A
		Northport	ND	ND	-	ND	ND	
Chrysene (Chrysene)	0.5	Huntington	ND	ND	1.8	2.1	1.5	0.977
		Northport	2.0	ND	-	ND	2.3	
Dibenz(a,h)anthracene (DbA)	3.0	Huntington	ND	ND	ND	ND	ND	N/A
		Northport	ND	ND	-	ND	ND	
Fluoranthene (Flu)	1.0	Huntington	3.1	4.8	2.2	11	4.4	0.924
		Northport	6.0	2.3	-	5.1	7.8	
Fluorene (Flr)	1.0	Huntington	3.1	3.1	ND	7.3	8.9	0.590
		Northport	8.6	ND	-	1.4	16	
Indeno(1,2,3-cd)pyrene (IcdP)	2.0	Huntington	ND	ND	ND	ND	ND	N/A
		Northport	ND	ND	-	ND	ND	
Naphthalene (Np)	5.0	Huntington	24	56	ND	24	61	0.385
		Northport	23	20	-	ND	37	
Phenanthrene (Phn)	2.0	Huntington	8.1	10	4.4	21	22	0.273
		Northport	24	7.6	-	18	31	
Pyrene (Pyr)	1.0	Huntington	3	4.8	3.5	10	6.7	0.598
		Northport	7.8	2.1	-	6.3	11	

Results were compared between both sites using t-test (alpha = 0.05). ND = not detected.

Cells highlighted in green are below the respective detection limit.

Table 13. Heavy metals in ribbed mussels compared to maximum tolerance level values for arsenic, cadmium, mercury, and lead in complete animal feed, according to the NRC MTL and AAFCO OP.

	Arsenic (ppm)	**Cadmium (ppm)**	**Chromium (ppm)**	**Mercury (ppm)**	**Lead (ppm)**	**Nickel (ppm)**
NRC MTL in complete feed	**30**	**10**	**100**	**0.2**	**10**	**100**
AAFCO OP in complete feed	**50**	**0.5**	**-**	**2**	**30**	**-**
Huntington 9/6/22	0.145	<0.03	0.324	<0.044	0.604	0.205
Northport 9/6/22	0.202	<0.03	0.25	<0.044	0.747	0.173
Huntington 10/31/22	0.566	0.048	0.460	<0.044	0.49	0.349
Northport 10/31/22	0.747	0.054	1.48	<0.044	1.55	0.730
Huntington 6/12/23	0.384	0.022	1.17	<0.04	0.272	0.730
Huntington 8/14/23	0.638	0.025	0.904	<0.04	0.922	0.521
Northport 8/14/23	0.941	0.031	1.55	<0.04	1.63	0.751
Huntington 10/23/23	0.717	0.035	1.84	<0.04	0.789	0.942
Northport 10/23/23	0.674	0.033	1.13	<0.04	0.84	0.592

Cells highlighted in green to show they are below the maximum tolerance levels for these heavy metals.

8. FIGURES

Maps

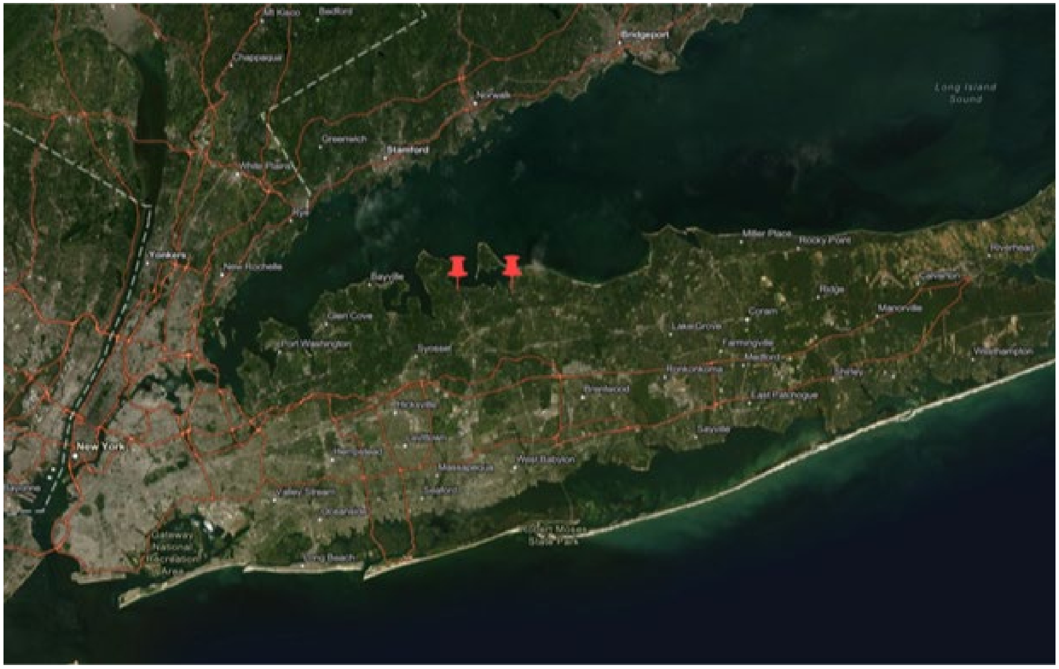
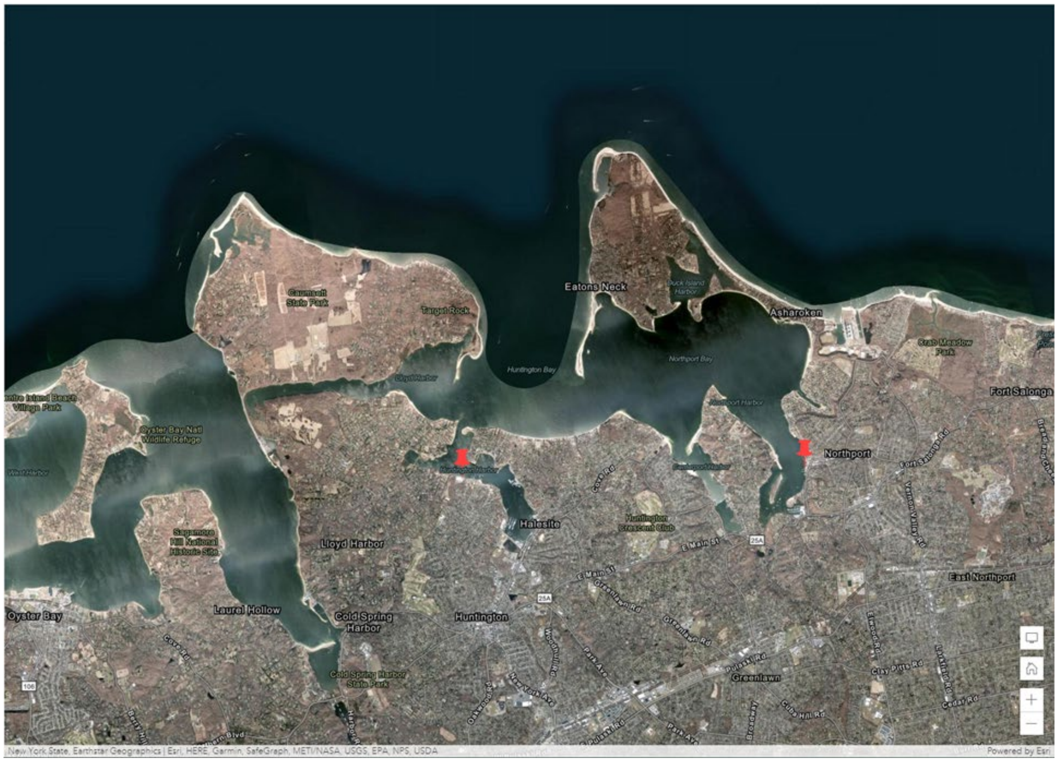


Figure 1. Red pins indicate ribbed mussel grow-out locations in Huntington (left) and Northport (right).



New York State, Earthstar Geographics | Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

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Figure 2. Project area. Red pins indicate grow-out locations in Huntington (left) and Northport (right).

Figure 3. Huntington Harbor ribbed mussel grow-out site.

Figure 4. Northport Harbor ribbed mussel grow-out site.

One-Acre Ribbed Mussel Farm Layout

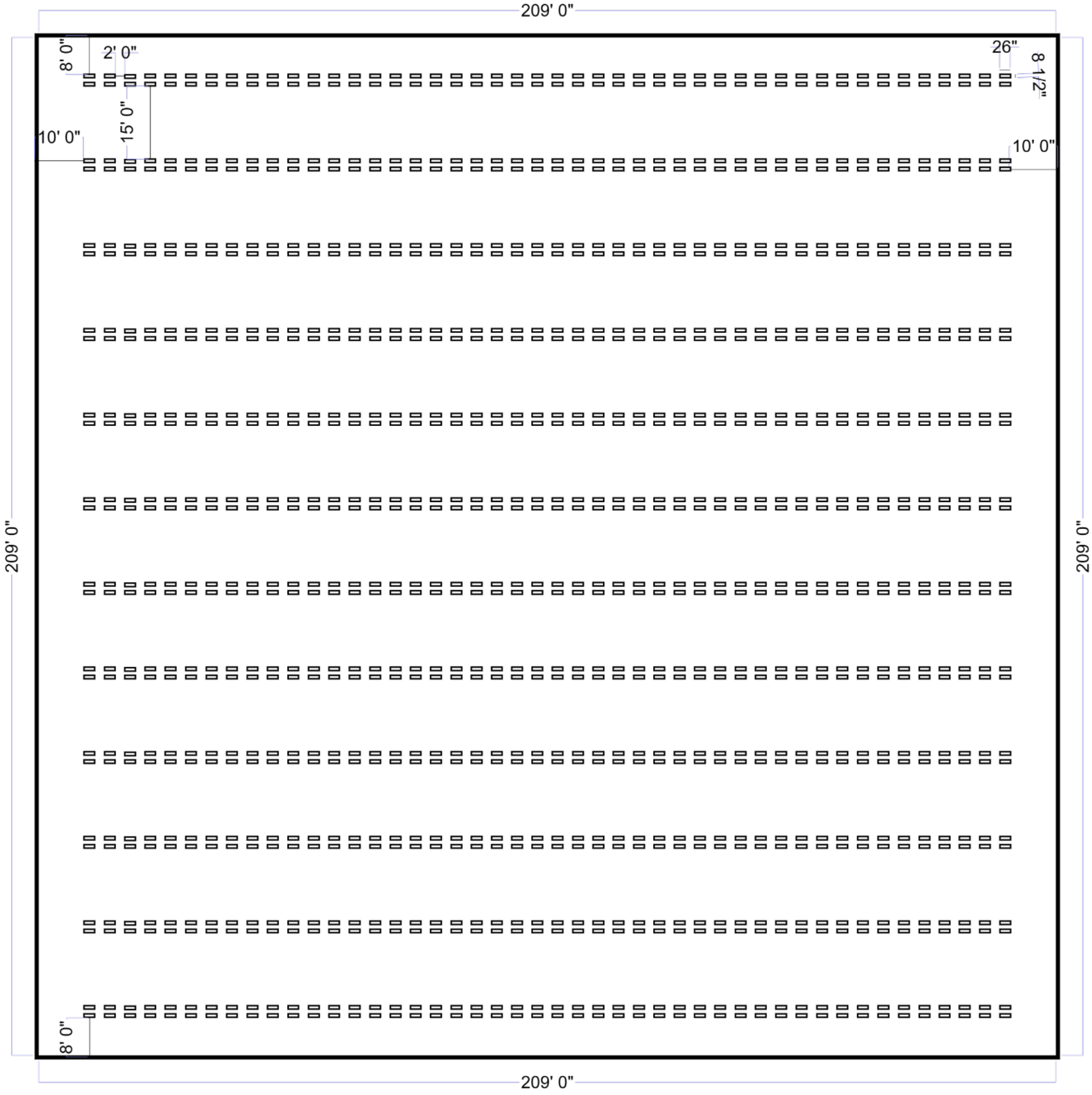

Figure 5. Example layout of a one-acre ribbed mussel farm. Perimeter of the farm is 209 ft x 209 ft. The ribbed mussels would be cultivated in SEAPA commercial cages or other commonly used oyster aquaculture cages. Each cage is 26 in x 8.5 in and placed 2 ft from each other in each row. Rows are coupled together similar to oyster cages on commercial farms. Each set of coupled rows is 15 ft apart from each other to allow for boat access to cages. The outermost cages are at least 8 ft away from the perimeter. Total number of cages = 46 per row by 24 rows = 1,104 cages total. Each cage holds at least 200 adult ribbed mussels = 220,800 ribbed mussels per one-acre farm.

Ribbed Mussel Size Data

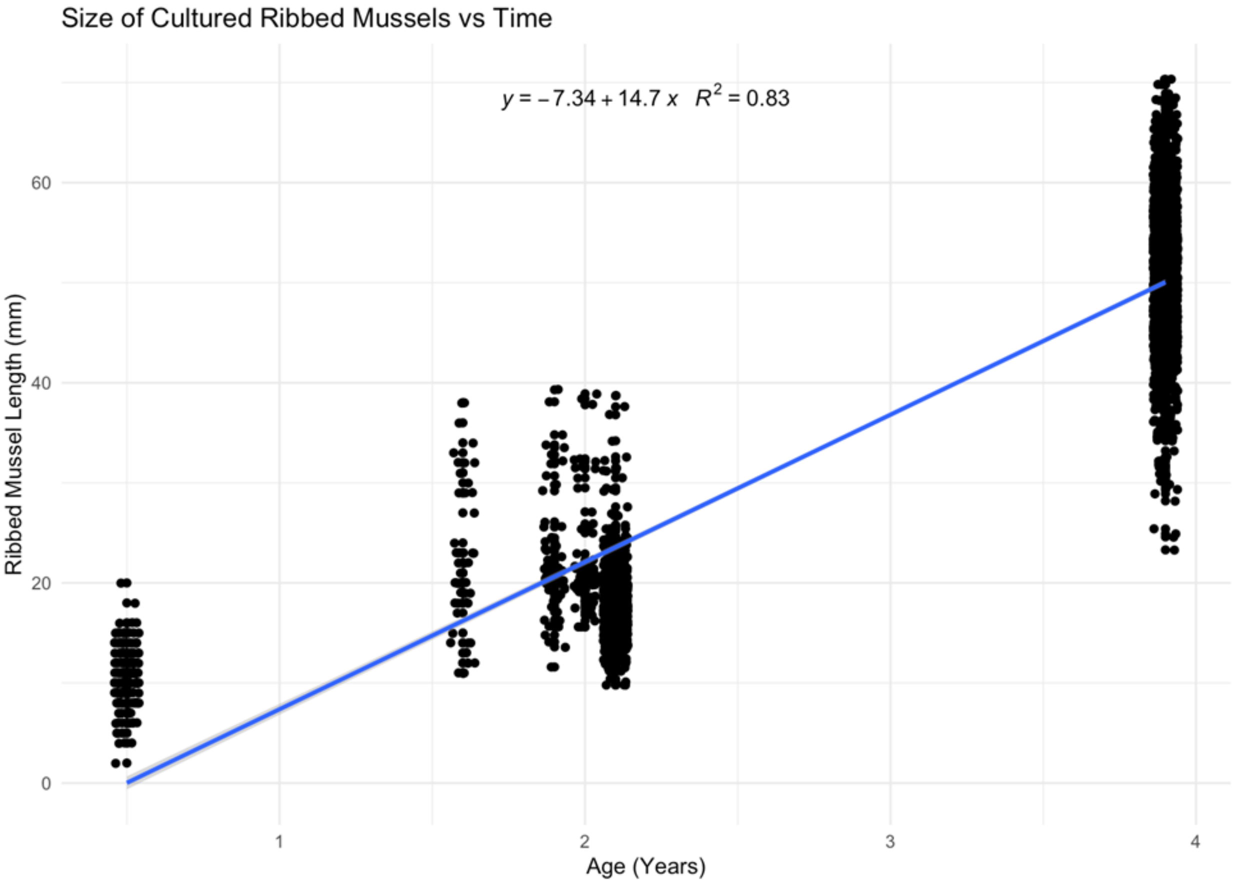

Figure 6. Change in size (shell length, mm) of aquacultured ribbed mussels that were spawned in 2021 and 2023 and grown over several years at the Huntington Harbor and Northport Harbor sites. While there was considerable size variation within each sampling interval, a linear regression model (blue line) yielded an average growth rate of 14.7 mm per year. Note: overlapping data points collected on the same date are slightly spread out (jittered) to show patterns of clustered data points.

9. REFERENCES

Agriculture Institute. November 2, 2023. Poultry Feeds and Feeding: Understanding Essential Nutrients in Poultry Feed. Accessed September 9, 2025.

Association of American Feed Control Officials (AAFCO). January 23, 2018. Recommendations and Critical Factors in Determining Moisture in Animal Feeds. AAFCO's Laboratory Methods and Services Committee, Moisture Best Practices Working Group. Moisture_paper_final.pdf.

Association of American Feed Control Officials. 2019. 2019 AAFCO Official Publication. Champaign, IL: FASS Inc. Retrieved from http://www.aafco.org/Publications.

"About Pesticide Tolerances". US Environmental Protection Agency. September 9, 2024. www.epa.gov/pesticide-tolerances/about-pesticide-tolerances. Accessed March 2025.

Applegate T.J., Angel R. 2008. Protein and Amino Acid Requirements for Poultry. Purdue University Cooperative Extension. AS-584-W.pdf.

Beck P, Lalman D, Moehlenpah A. March 2024. "Nutritive Value of Feeds". Oklahoma State University Cooperative Extension. Nutritive Values of Feeds ANSI 3018

Center for Veterinary Medicine. July 2022. Hazard Analysis and Risk-Based Preventative Controls for Food for Animals. US Department of Health and Human Services. Food and Drug Administration. www.fda.gov/media/110477/download. Accessed March 2025.

"Commercial Feed". New York State Department of Agriculture and Markets. www.agriculture.ny.gov/food-safety/commercial-feed. Accessed March 2025.

Craig, S., Helfrich, L.A. 2002. Understanding Fish Nutrition, Feeds, and Feeding. Virginia Cooperative Extension. Publication 420-256.

Crenshaw 2025. "Nutritional Requirements of Pigs". MSD Manual Veterinary Manual. Nutritional Requirements of Pigs - Management and Nutrition - MSD Veterinary Manual. Accessed August 2025.

Crow, Michael et al. *Generic Guide to Statistical Aspects of Developing an Environmental Results Program.* United States Environmental Protection Agency OPEI, 2003.

"Environmental Benefits of Shellfish". Connecticut Department of Agriculture. https://portal.ct.gov/doag/aquaculture1/aquaculture/environmental-benefits-of-shellfish-aquaculture. Accessed on May 27, 2025.

Envirocare Labs. 2024. "The Vital Role of Amino Acids in Animal Nutrition: Enhancing Growth, Health, and Sustainability". Accessed March 2025. https://envirocarelabs.com/the-vital-role-of-amino-acids-in-animal-nutrition/#specific-amino-acid-requirements-for-different-livestock.

The Food and Agriculture Organization (FAO) and The World Health Organization (WHO). Risk assessment of Vibrio vulnificus in raw oysters: Interpretative summary and technical report. 2005. Rome, Italy, FAO. Microbiological Risk Assessment Series No. 8.

Galimany, E., J.M. Rose, M.S. Dixon, and G.H. Wikfors. 2013. Quantifying feeding behavior of ribbed mussels (Geukensia demissa) in two urban sites (Long Island Sound, USA) with different seston characteristics. Estuaries and Coasts, 36, pp.1265- 1273.

Galimany, E., G.H. Wikfors, M.S. Dixon. C.R. Newell, S.L. Meseck. D. Henning, Y. Li, and J.M. Rose. 2017. Cultivation of the Ribbed Mussel (Geukensia demissa) for Nutrient Bioextraction in an Urban Estuary. Environmental Science and Technology, 51, pp.13311-13318.

Gatlin III, D.M. Principles of Fish Nutrition. 2010. Southern Regional Aquaculture Center.

Hoffman PC. 2005. “Ash Content of Forages”. University of Wisconsin Extension. https://fyi.extension.wisc.edu/forage/files/2014/01/ASH05-FOF.pdf.

Jagdish. 2020. Pig Feed Formulation; Types of Pig Feed – A Full Guide. Agrifarming.

Jansen, H.M., Strand, Ø., Van Broekhoven, W., Strohmeier, T., Verdegem, M.C., Smaal, A.C., 2019. Feedbacks from filter feeders: review on the role of mussels in cycling and storage of nutrients in oligo-meso-and eutrophic cultivation areas. Goods and Services of Marine Bivalves. Springer, pp. 143–177.

Kan C.A., Meijer G.A.L. February 2007. The risk of contamination of food with toxic substances present in animal feed. Animal Feed Science and Technology, 133:1-2, pp.84-108.

Lalman D and Holder A. 2024. Nutrient Requirements of Beed Cattle: E-974. Oklahoma State University Cooperative Extension. https://extension.okstate.edu/fact-sheets/print-publications/e/nutrient-requirements-of-beef-cattle-e-974-a.pdf.

Landau, B.J., 2014. The Bin-Silo system: a simple spawning method for bivalve shellfish. World Aquaculture, 45(1), pp.58-61.

Liao SF, Wang T, Regmi N. Lysine nutrition in swine and the related monogastric animals: muscle protein biosynthesis and beyond. Springerplus. 2015 Mar 27;4:147. doi: 10.1186/s40064-015-0927-5. PMID: 25830085; PMCID: PMC4377136.

“Marine Shellfish”. NYS Department of Environmental Conservation. Accessed on April 25, 2025. Marine Shellfish - NYSDEC

Menegat, Mariana B., Robert D. Goodband, Joel M. DeRouchey, Mike D. Tokach, Jason C. Woodworth, and Steve S. Dritz. 2019. Kansas State University Swine Nutrition Guide: Energy Sources for Swine Diets: Fats and Oils.

“Moisture Control in Animal Feed Production”. March 13, 2025. Hydronix. Moisture Control in Animal Feed Production - Hydronix. Accessed April 2025.

Moody, J. and D. Kreeger, 2020. Ribbed mussel (Geukensia demissa) filtration services are driven by seasonal temperature and site-specific seston variability. Journal of Experimental Marine Biology and Ecology, Vol. 522, 151237.

“Musselfeed”. 2021. Musselfeed AB. Accessed on April 24, 2025. Enabling Sustainable Aquatic Protein Extraction – Enabling Sustainable Aquatic Protein Extraction.

National Academies of Sciences, Engineering, and Medicine; Division on Earth and Life Studies; Board on Agriculture and Natural Resources; Committee on Nutrient Requirements of Dairy Cattle. Nutrient Requirements of Dairy Cattle: Eighth Revised Edition. Washington (DC): National Academies Press (US); 2021 Aug 30. 5, Carbohydrates. Available from: https://www.ncbi.nlm.nih.gov/books/NBK600592/

"National Primary Drinking Water Regulations". US Environmental Protection Agency. www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#Organics. Accessed March 2025.

National Research Council of the National Academies. (2005). Mineral Tolerance of Animals (Second Revised ed.). Washington, D.C.: The National Academies Press.

"Office of Microbiological Food Safety". US Food and Drug Administration. www.fda.gov/about-fda/human-foods-program/office-microbiological-food-safety. Accessed March 2025.

"Polycyclic Aromatic Hydrocarbons". Eurofins US. www.eurofinsus.com/environment-testing/built-environment/subservices/polycyclic-aromatic-hydrocarbons/. Accessed March 2025.

"Priority Pollutant List". United States Environmental Protection Agency. December 2014. www.epa.gov/sites/default/files/2015-09/documents/priority-pollutant-list-epa.pdf

"QuEChERS Method for Pesticide Residue Analysis". Sigma-Aldrich Millipore Sigma. www.sigmaaldrich.com/US/en/technical-documents/protocol/analytical-chemistry/quechers/quechers-method-pesticide-residue-analysis. Accessed March 2025.

Ravindran, V., Tancharoenrat, P., Zaefarian, F., Ravindran, G. (2016). Fats in poultry nutrition: digestive physiology and factors influencing their utilization. Animal Feed Science and Technology, 213, pp. 1-21. https://doi.org/10.1016/j.anifeedsci.2016.01.012.

"Section 132 – Adulteration". New York State Senate Legislation. Agriculture and Markets (AGM) CHapter 69, Article 8. September 22, 2014. www.nysenate.gov/legislation/laws/AGM/132. Accessed March 2025.

Sefer M., Petronijevic R.B., Trbovic D., Baltic T., Parunovic N., Djordjevic V. (2021). Amino acids in animal feed: significance and determination techniques. IOP Conference Series: Earth Environmental Science. 854 012082. doi: 10.1088/1755-1315/854/1/012082.

"Severely Hypoxic and Anoxic Areas". Long Island Sound Partnership. https://lispartnership.org/ecosystem-target-indicators/area-of-hypoxia/. Accessed March 2025.

Smith J. September 2024. "Nutrient Requirements of Beef Cattle". Merck Veterinary Manual. Nutrient Requirements of Beef Cattle - Management and Nutrition - Merck Veterinary Manual

Subramami, P.A., Michael, R.D. 2017. Prophylactic and prevention methods against diseases in aquaculture. Fish Diseases: Prevention and Control Strategies, pp. 81-117. https://doi.org/10.1016/B978-0-12-804564-0.00004-1.

Suffolk County Department of Health Services. 2020. *Suffolk County Subwatersheds Wastewater Plan*. Suffolk County Government. SWP FINAL July 2020.pdf

"Tolerances for Polychlorinated Biphenylls (PCBs)". Code of Federal Regulations National Achives. Title 21 (Food and Drugs), Chapter I, Subchapter B, Part 109, Subpart B, Section 109.30. February 25, 2025. www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-109/subpart-B/section-109.30. Accessed March 2025.

UK Health Protection Agency. Guidelines for Assessing the Microbiological Safety of Ready-to-Eat Foods. London: Health Protection Agency, November 2009.

US Department of Agriculture (USDA). March 2021. Nutrient Management Technical Note No. 190-NM-8. Animal Diets and Feed Management. 190-TN-NM-8, Animal Diets and Feed Management

US Environmental Protection Agency (EPA). July 1, 2014. "Tolerances and Exemptions for Pesticide Chemical Residues in Food". Gov Info Code of Federal Regulations. www.govinfo.gov/content/pkg/CFR-2014-title40-vol24/xml/CFR-2014-title40-vol24-part180.xml#seqnum180.3. Accessed March 2025.

Van Saun RJ. September 2024. "Nutritional Requirements of Dairy Cattle". MSD Veterinary Manual. Nutritional Requirements of Dairy Cattle - Management and Nutrition - MSD Veterinary Manual

VELP Scientifica. 2019. "Crude Fat Determination in Feed according to the Randall method". crude-fat-determination-in-feed-206519.pdf

Visch, W., Bergström, P., Nylund, G. M., Peterson, M., Pavia, H., & Lindegarth, M. (2020). Spatial differences in growth rate and nutrient mitigation of two co-cultivated, extractive species: The blue mussel (Mytilus edulis) and the kelp (Saccharina latissima). Estuarine, Coastal and Shelf Science, 246, 107019.

Weiss W. 2008. Mineral Tolerances of Animals. Ohio State University. Ohio Agricultural Research and Development Center. Department of Animal Sciences. Tri-State Dairy Nutrition Conference.

"What Does Crude Fiber Tell Me about a Feed?". Beef Cattle Extension. September 2019. www.beef-cattle.extension.org/what-does-crude-fiber-tell-me-about-a-feed/.

Xing, S., Xiaofang, L., Zhang, X., Oliva-Teles, A., Peres, H., Wang, H., Mai, K., Kaushik, S.J., Xue, M. 2023. Essential amino acid requirements of fish and crustaceans, a meta-analysis. Reviews in Aquaculture, 16:3, pp. 1069-1086. https://doi.org/10.1111/raq.12886

Zhang, J., Hansen, P.K., Fang, J., Wang, W., Jiang, Z., 2009. Assessment of the local environmental impact of intensive marine shellfish and seaweed farming—application of the MOM system in the Sungo Bay, China. Aquaculture 287, 304–310.

Zelinkova Z, Wenzl T. The Occurrence of 16 EPA PAHs in Food - A Review. Polycycl Aromat Compd. 2015 Mar 15;35(2-4):248-284. doi: 10.1080/10406638.2014.918550. Epub 2015 Nov 16. PMID: 26681897; PMCID: PMC4673601.

10. PHOTOS

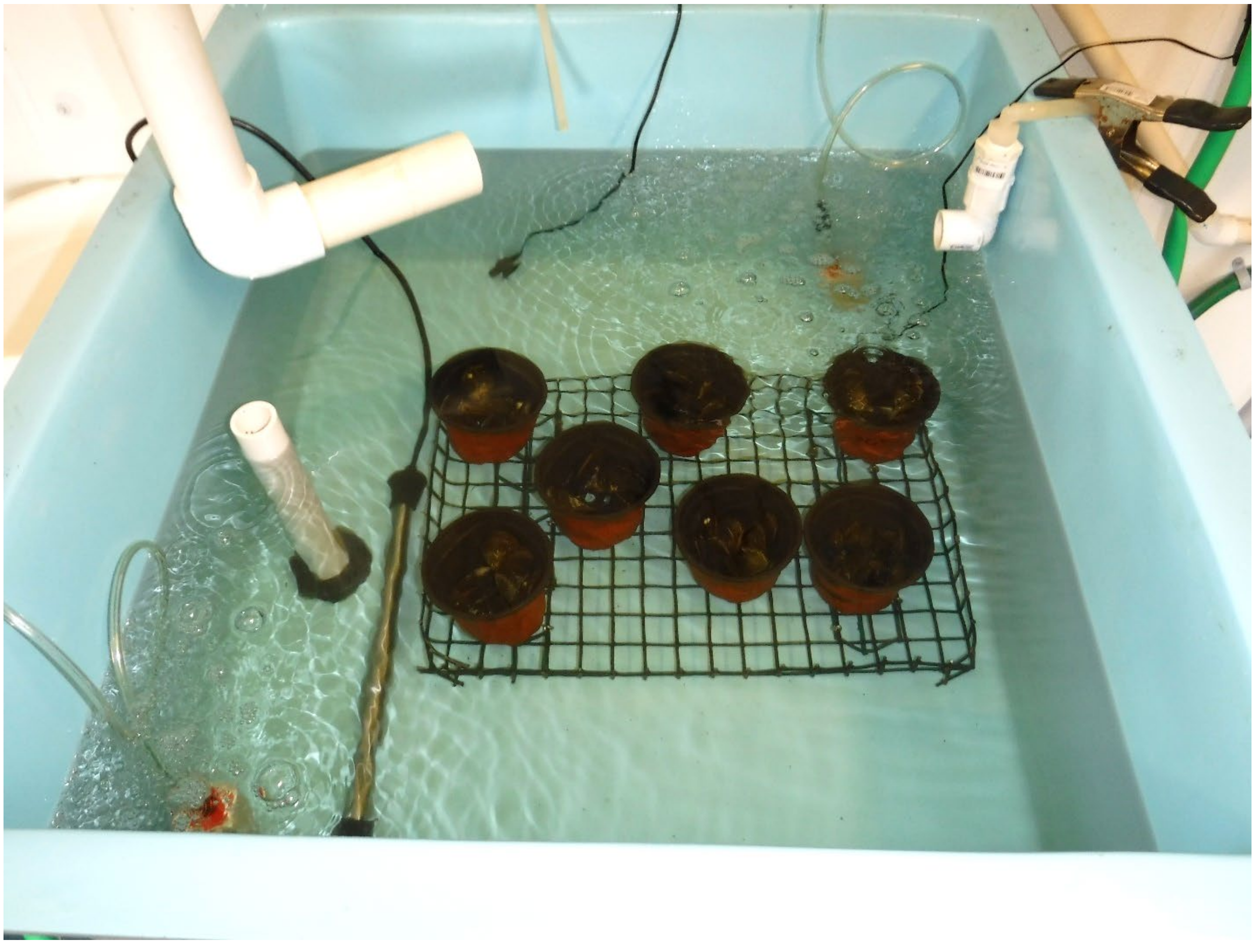

Figure 7. Tanks used to condition wild-collected ribbed mussels in preparation for spawning. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 8. Loose adult wild mussels collected along the rocky shoreline of Gold Star Battalion Beach and placed inside a silo container with a mesh bottom. Using culturing methods developed by Rutgers University, these mussels spawned gametes that developed into juvenile cultured mussels that were used in Year 2 of the project at the Cornell Cooperative Extension Gold Star Beach hatchery. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

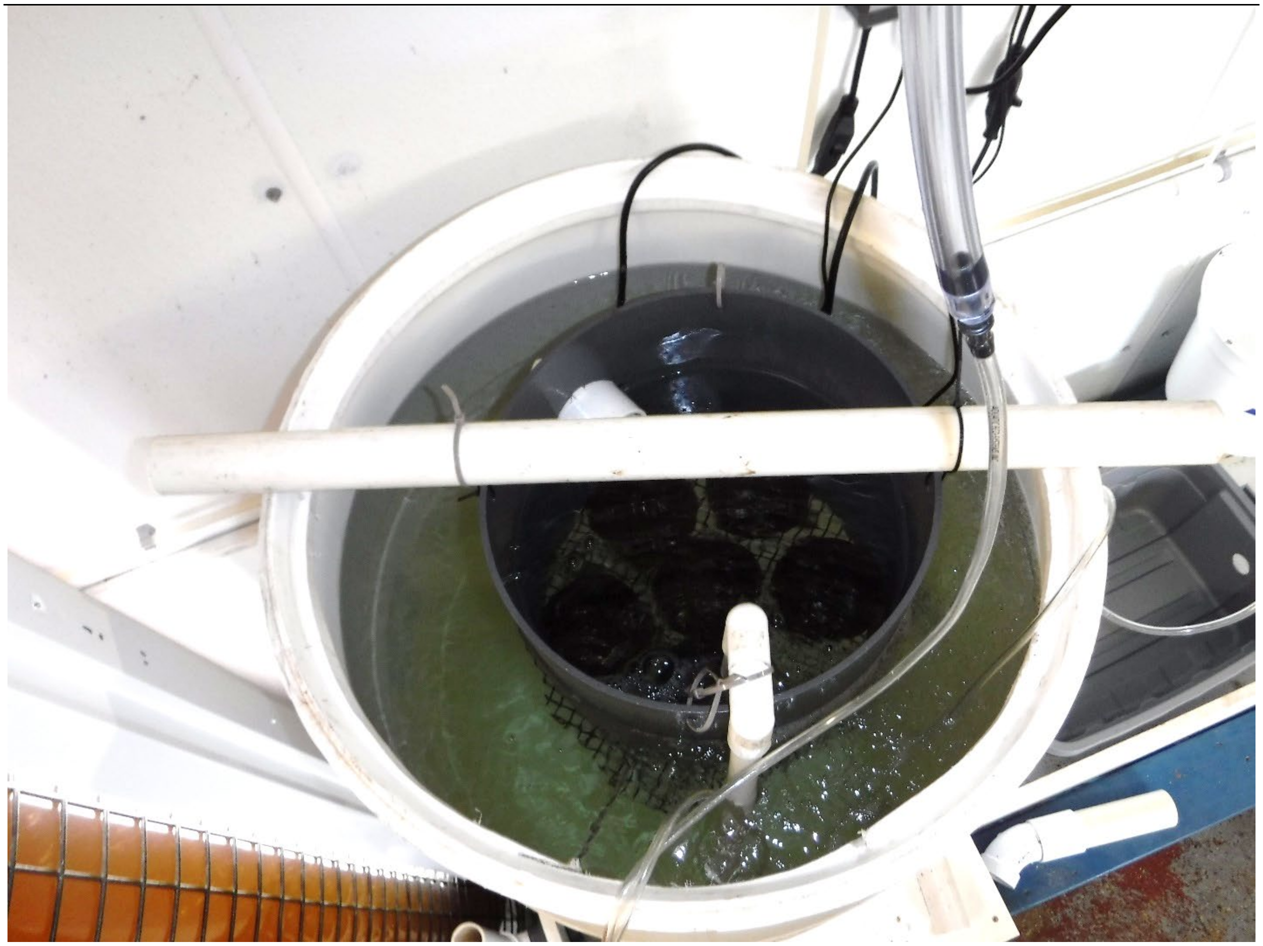

Figure 9. Adult wild-collected mussels inside a silo with a mesh bottom, which is placed within a larger bin in the hatchery. These mussels undergo a mild temperature shock to trigger spawning using the Bin-Silo method developed at Rutgers University. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 10. The bin containing the mesh-bottom silo and adult wild-collected ribbed mussels. This set up was used for spawning gametes using the Bin-Silo method developed at Rutgers University. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 11. Conical tanks containing filtered seawater, fertilized eggs, and mussel larvae. Next to the conical tanks are bags filled with different species of cultured algae used to feed mussel larvae. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 12. Conical tanks containing filtered seawater, fertilized eggs, and mussel larvae. The seawater is maintained at a constant temperature and the mussel larvae are fed cultured algae. This stage of the hatchery culturing process is about 2 weeks. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

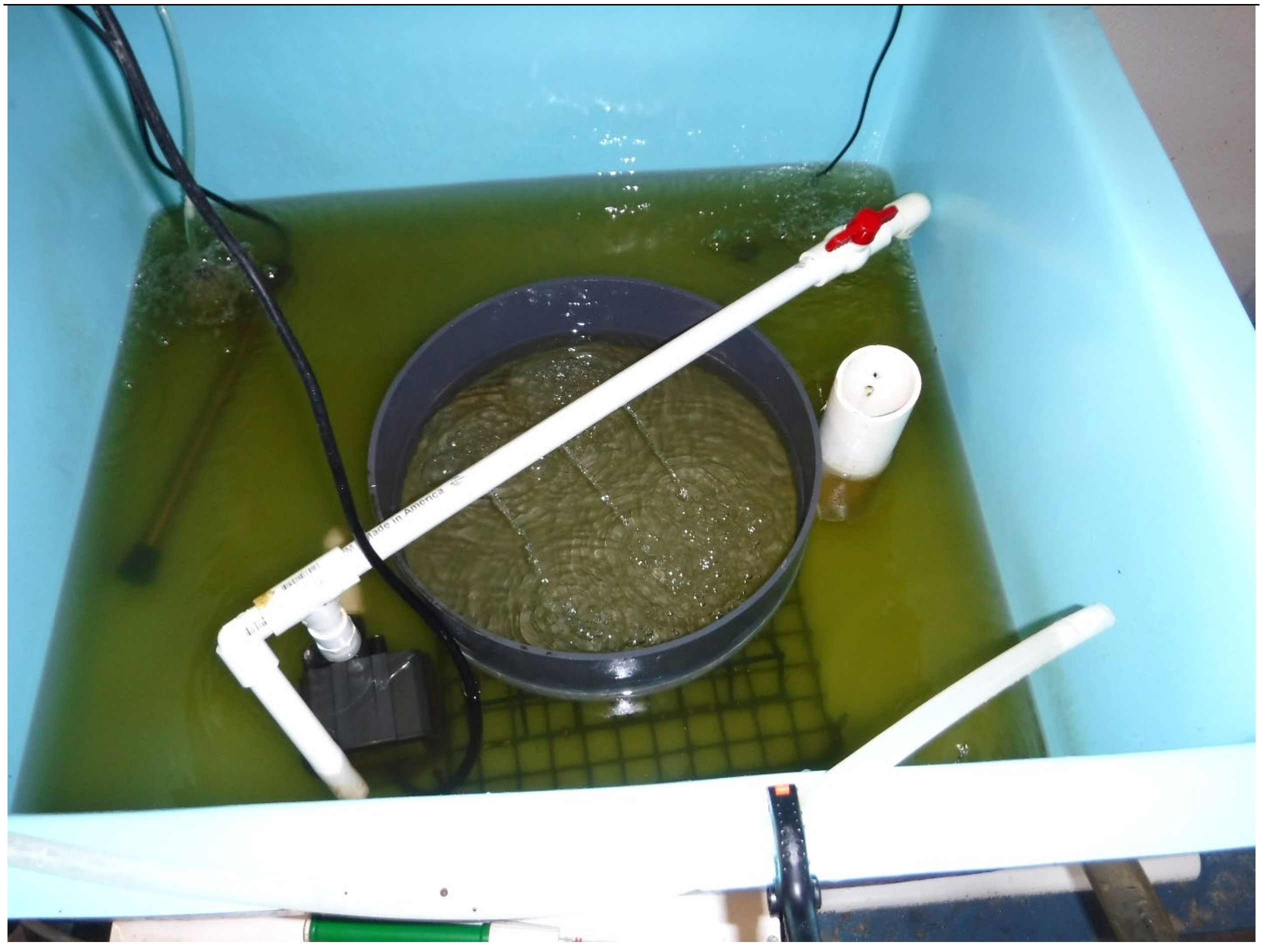

Figure 13. After mussel larvae underwent metamorphosis in the conical tanks from their free-swimming larval stage to their settled juvenile mussel stage, they were moved to downwellers (seen here) within the hatchery for 2-3 months and fed with cultured algae. They were kept in this set-up until they reached a size of 1-2 mm and were then moved to be raised in a floating upweller system (FLUPSY). Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 14. Once the juvenile cultured mussels reached a size of 1-2 mm in the downwellers, they were transferred to mesh bags in July 2021 and raised in a floating upweller system (FLUPSY) on raw seawater throughout the growing season until October 2021, where they reached a size of 5-15 mm. Coins added for scale. They were then submerged within the FLUPSY dock to be overwintered until the following spring (not shown). As this cohort of mussels was still too small for sampling in Year 1 of the study (2022), they were kept in commercial orange fish baskets that hung beneath locked trap doors at each grow-out site's floating dock at the start of the Year 1 growing season, monitored twice a month and cleaned as needed, but otherwise left undisturbed to allow them to grow until they were at least 15-20 mm for their use in Year 2 of the study (2023). Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 15. Huntington Harbor grow-out location where floating docks were installed. Photo courtesy of Kristin Kraseski, former Nutrient Bioextraction Coordinator.

Figure 16. Huntington Harbor grow-out location where ribbed mussels were deployed. Photo courtesy of Kristin Kraseski, former Nutrient Bioextraction Coordinator.

Figure 17. Field grow-out set-up. Floating docks were installed at both the Huntington Harbor and Northport Harbor sites in early April for use during Year 1 of the study and removed at the end of the season in November. On the dock, the wild-collected adult ribbed mussels were placed in orange fish baskets and hung beneath locked trap doors at the start of the study, monitored twice a month and cleaned as needed, but otherwise left undisturbed for the project period. This set up was repeated in Year 2 with hatchery-cultured juvenile mussels. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 18. Field grow-out set-up. Wild-collected adult ribbed mussels placed in orange fish baskets and hung beneath trap doors at the installed floating docks in Huntington Harbor and Northport Harbor. This set-up was repeated in Year 2 with hatchery-cultured juvenile mussels. Photo courtesy of Barry Udelson, formerly at Cornell Cooperative Extension and currently at NY Sea Grant.

Figure 19. Water quality measurements, such as temperature, salinity, and pH, were taken at each site using a multiparameter sonde. Photo courtesy of Johanna Mazer, former Nutrient Bioextraction Coordinator Assistant.

Figure 20. Cornell Cooperative Extension staff sampling ribbed mussels for lab analysis. Photo courtesy of Kristin Kraseski, former Nutrient Bioextraction Coordinator.

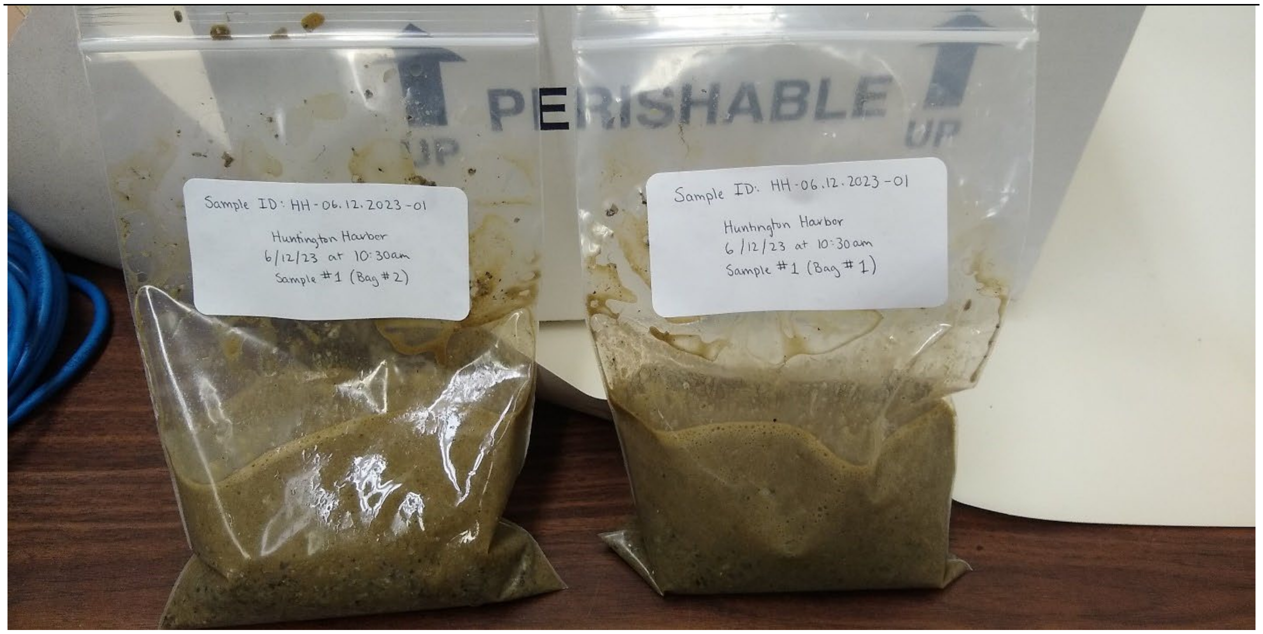

Figure 21. Sampled ribbed mussels were ground and frozen prior to shipping overnight for lab analysis. Photo courtesy of Kristin Kraseski, former Nutrient Bioextraction Coordinator.

11. APPENDIX

Grow-Out Site Water Quality Data Collected By Unified Water Study Monitoring Program

2022 - Huntington Harbor

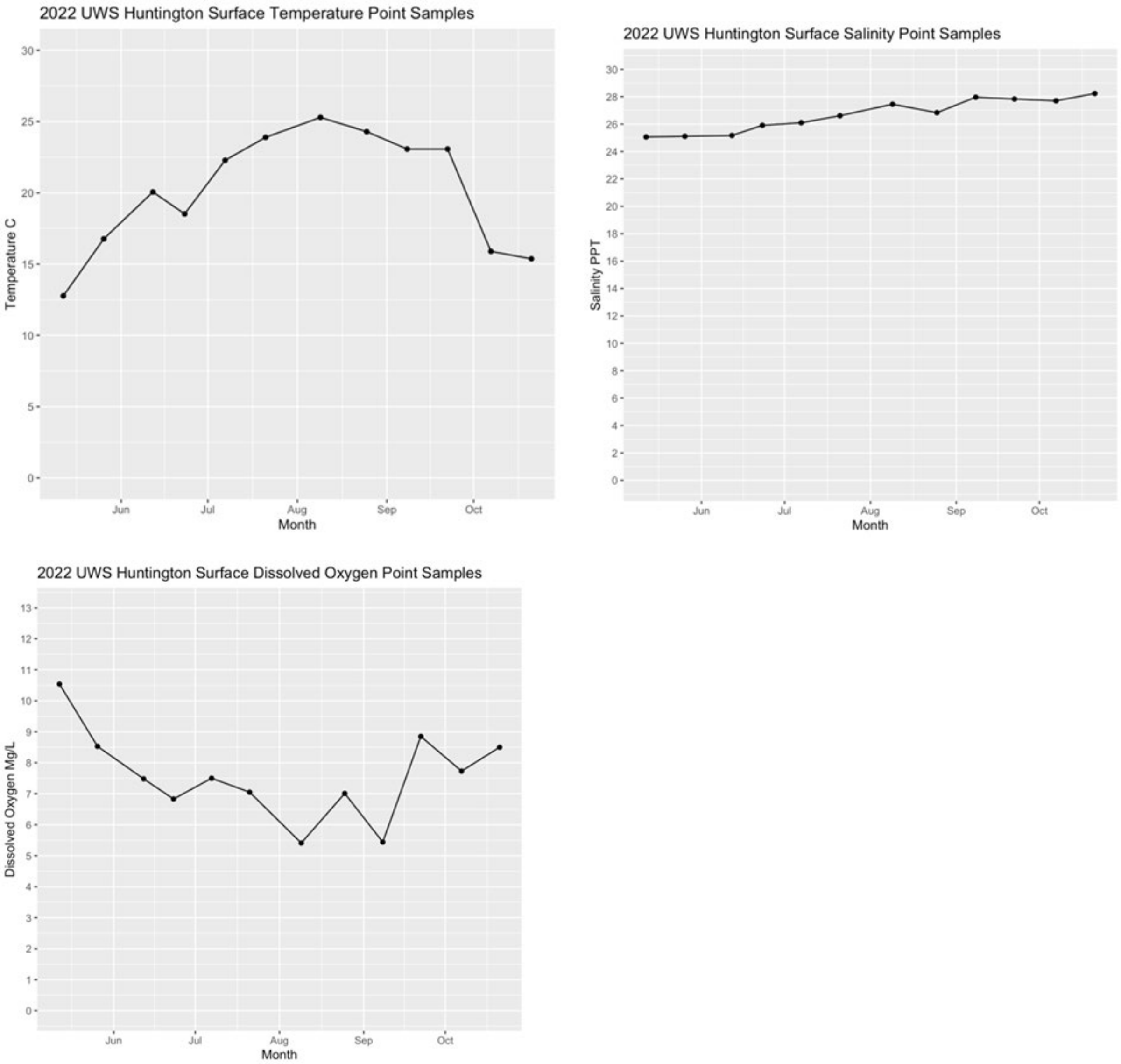

Figure 22. Plots for the 2022 surface temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Huntington Harbor station near the ribbed mussel grow-out dock (Gold Star facility). Data courtesy of the Unified Water Study monitoring program (Link to UWS).

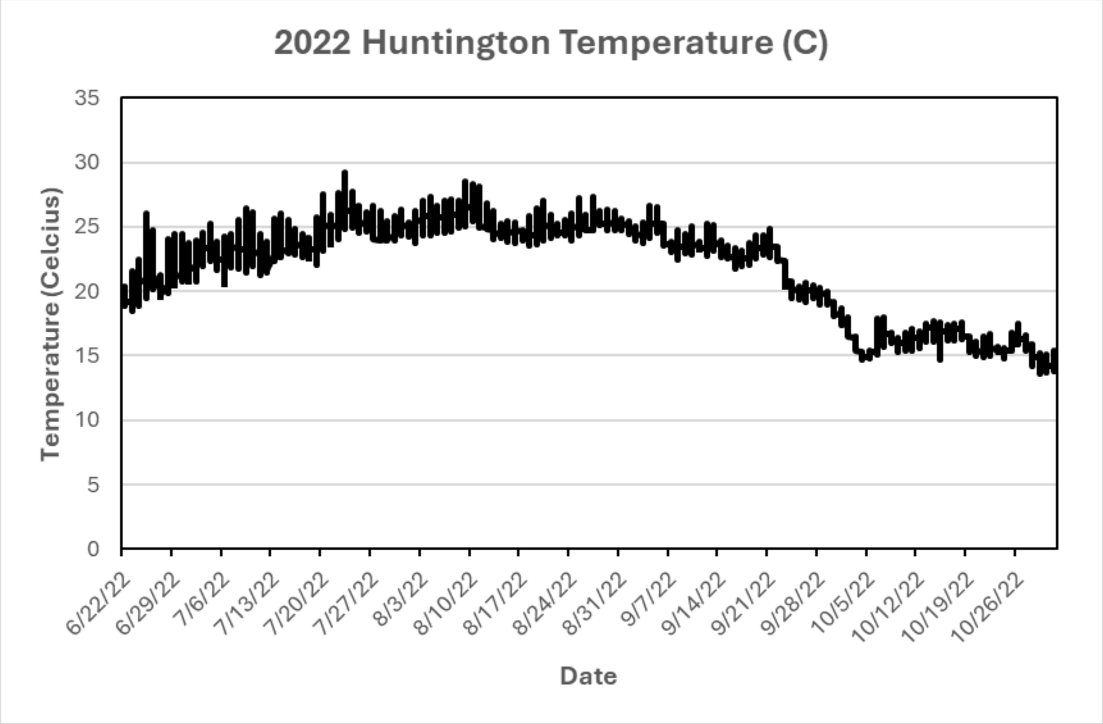

Figure 23. Plot of 2022 continuous surface temperature (Celsius) collected from an Onset Hobo data logger in the ribbed mussel grow-out dock at Huntington Harbor (Gold Star facility).

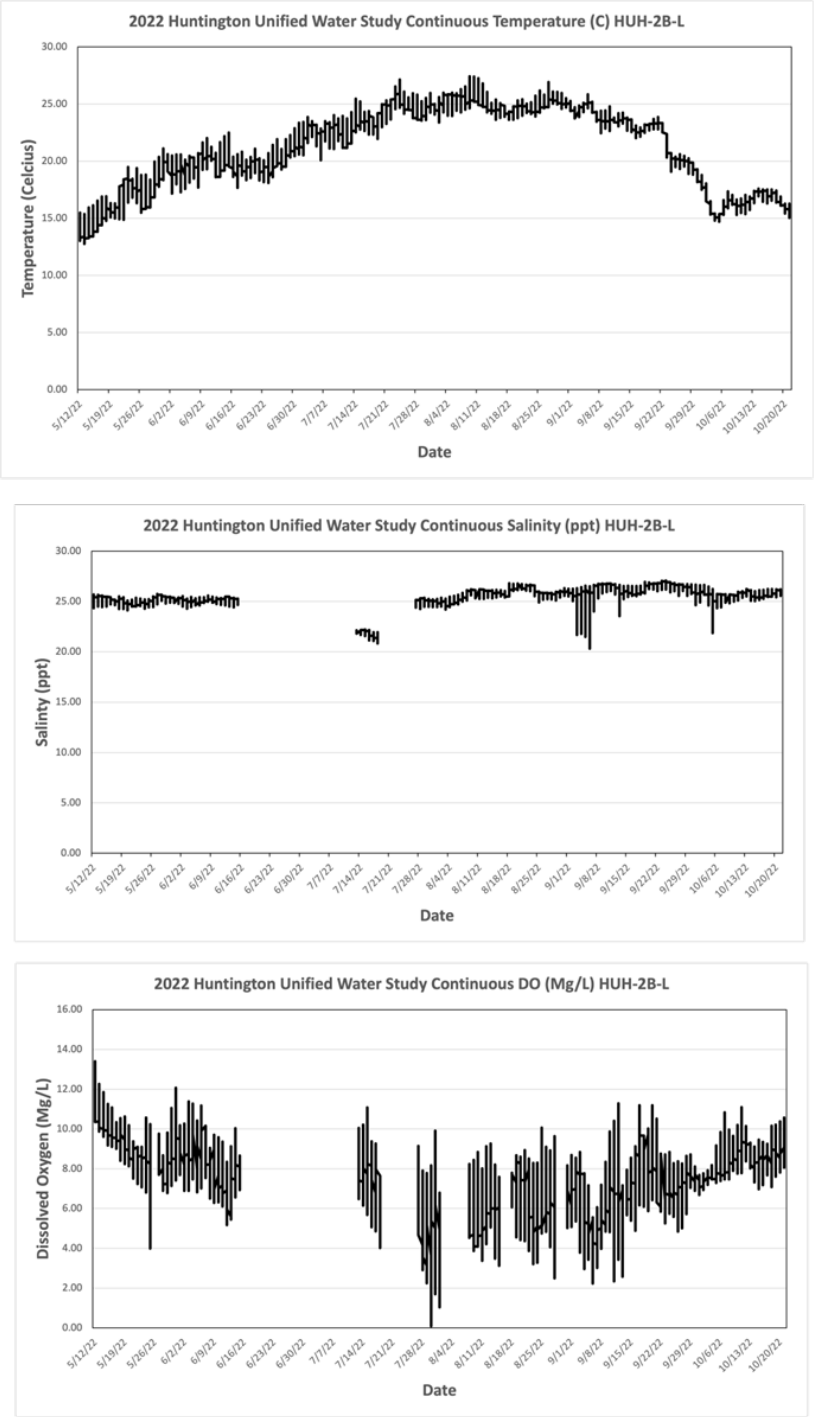

Figure 24. Plots of the 2022 Unified Water Study (UWS) continuous off-bottom data loggers for temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Huntington Harbor station (HUH-2B-L) near the ribbed mussel grow-out dock (Link to UWS).

2022 - Northport Harbor

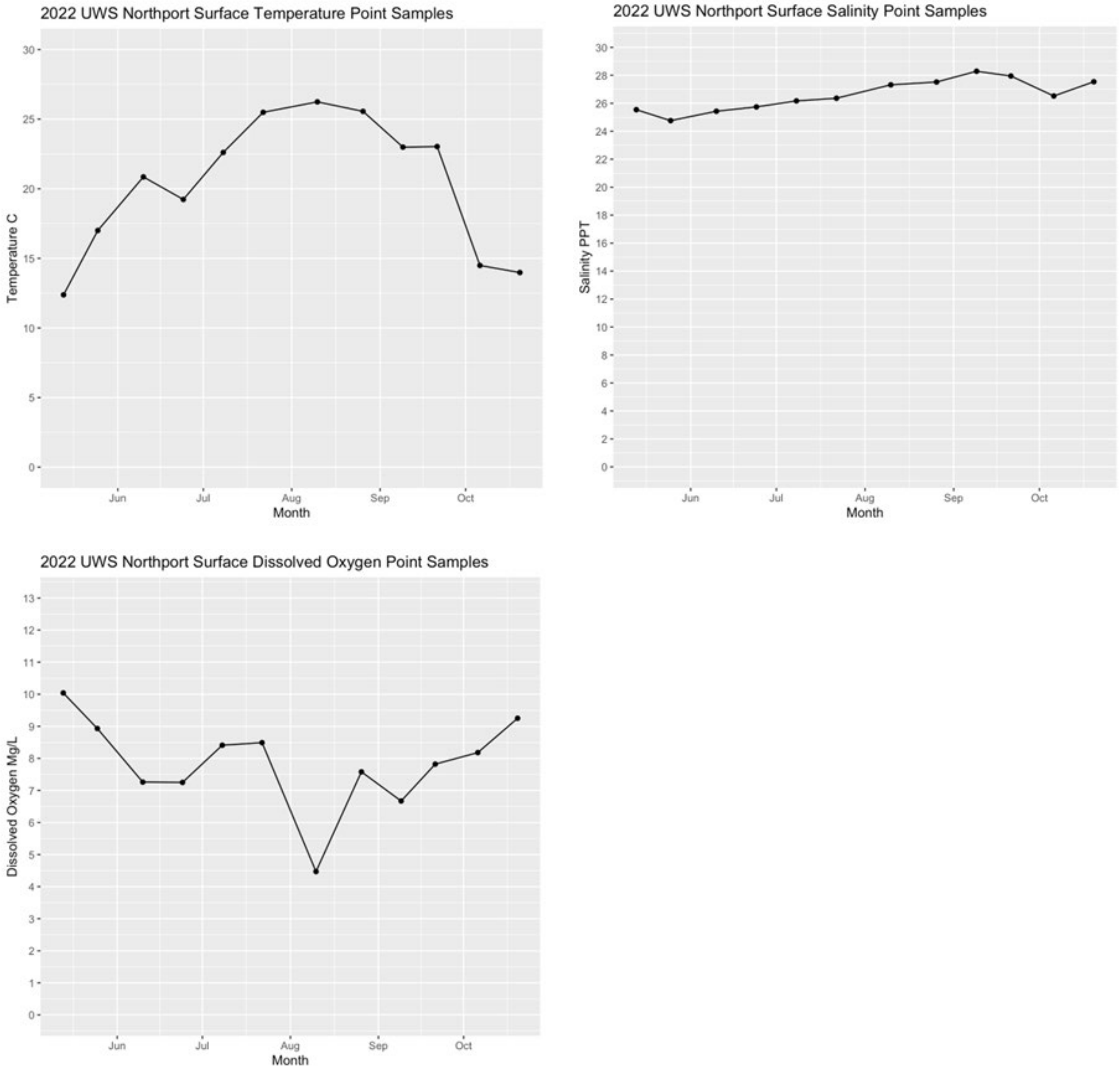

Figure 25. Plots for the 2022 surface temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Northport Harbor station near the ribbed mussel grow-out dock (Gold Star facility). Data courtesy of the Unified Water Study monitoring program (Link to UWS).

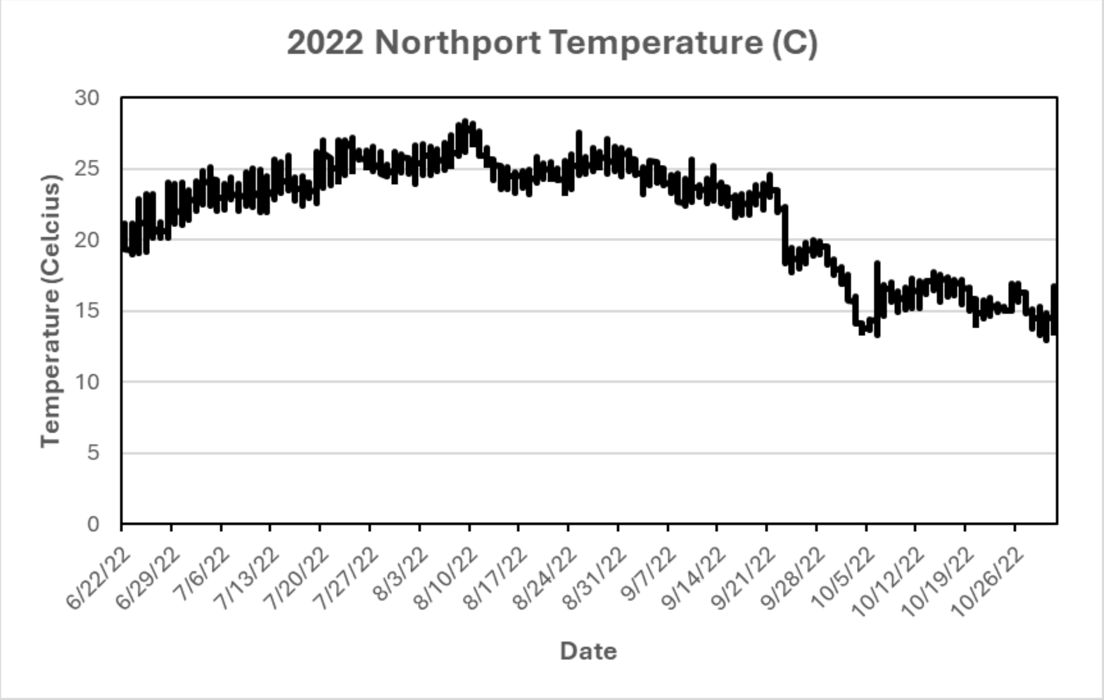

Figure 26. Plot of 2022 continuous surface temperature (Celsius) collected from an Onset Hobo data logger in the ribbed mussel grow-out dock at Northport Harbor.

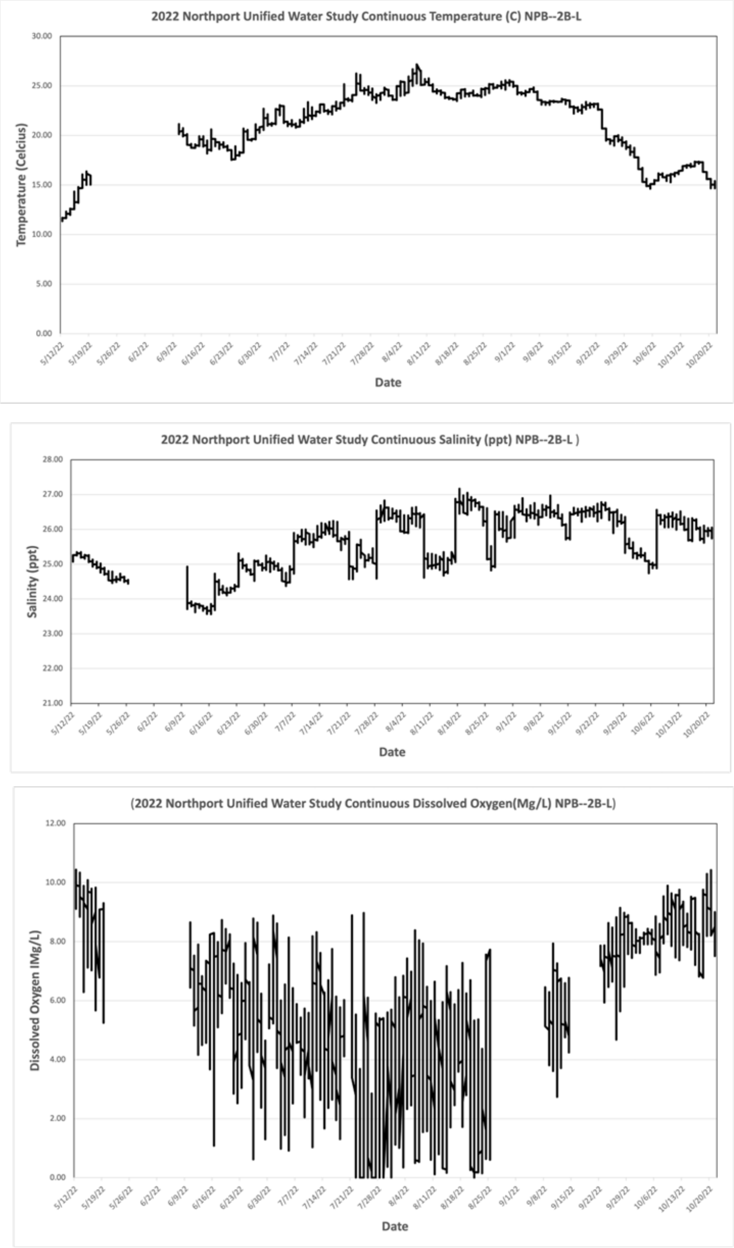

Figure 27. Plots of the 2022 Unified Water Study (UWS) continuous-off-bottom data loggers for temperature (Celsius), salinty (ppt) and dissolved oxygen (mg/L) collected at the Northport Harbor station (NPB-2B-L) near the ribbed mussel grow-out dock (Link to UWS).

2023 – Huntington Harbor

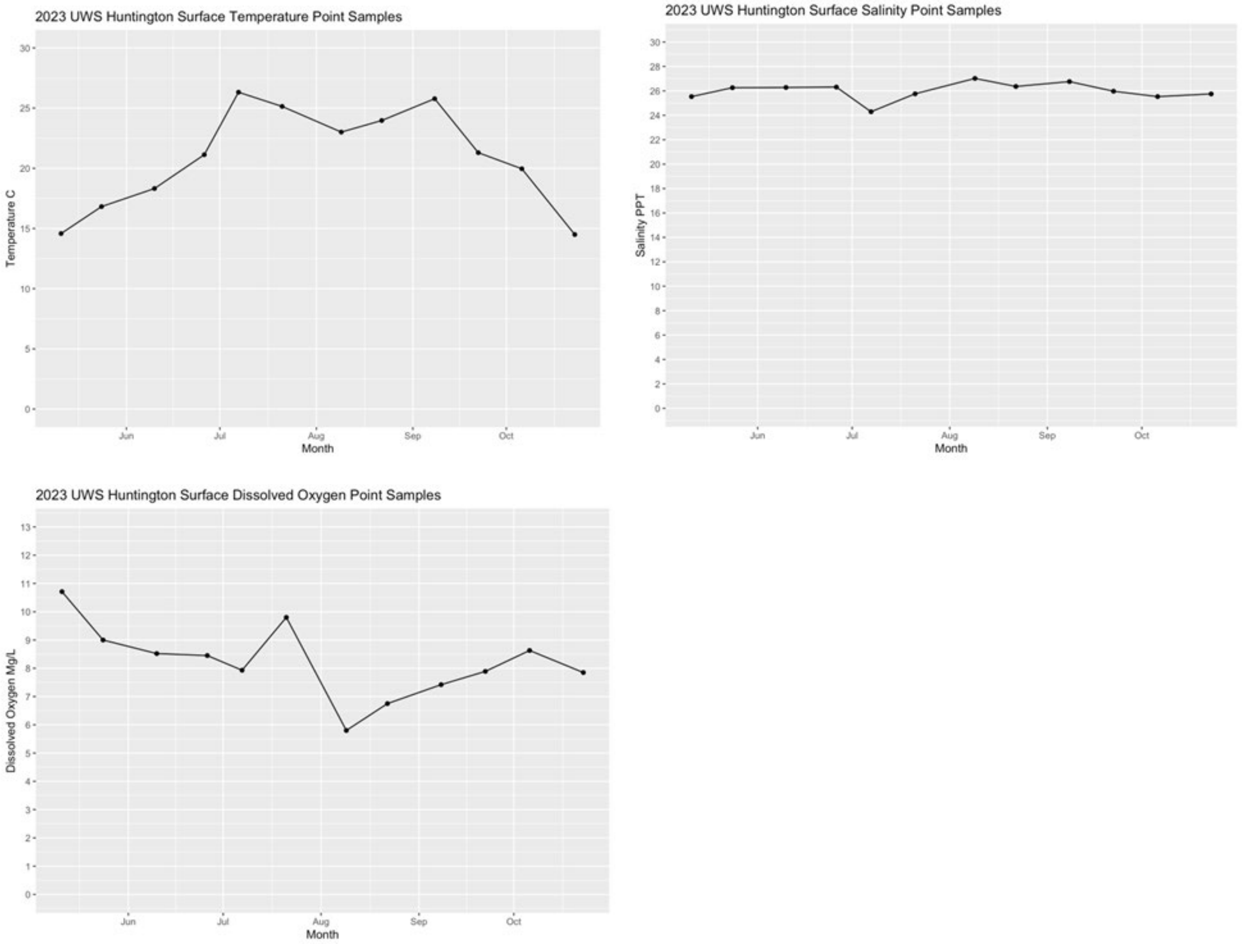

Figure 28. Plots for the 2023 surface temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Huntington Harbor station near the ribbed mussel grow-out dock (Gold Star facility). Data courtesy of the Unified Water Study monitoring program (Link to UWS).

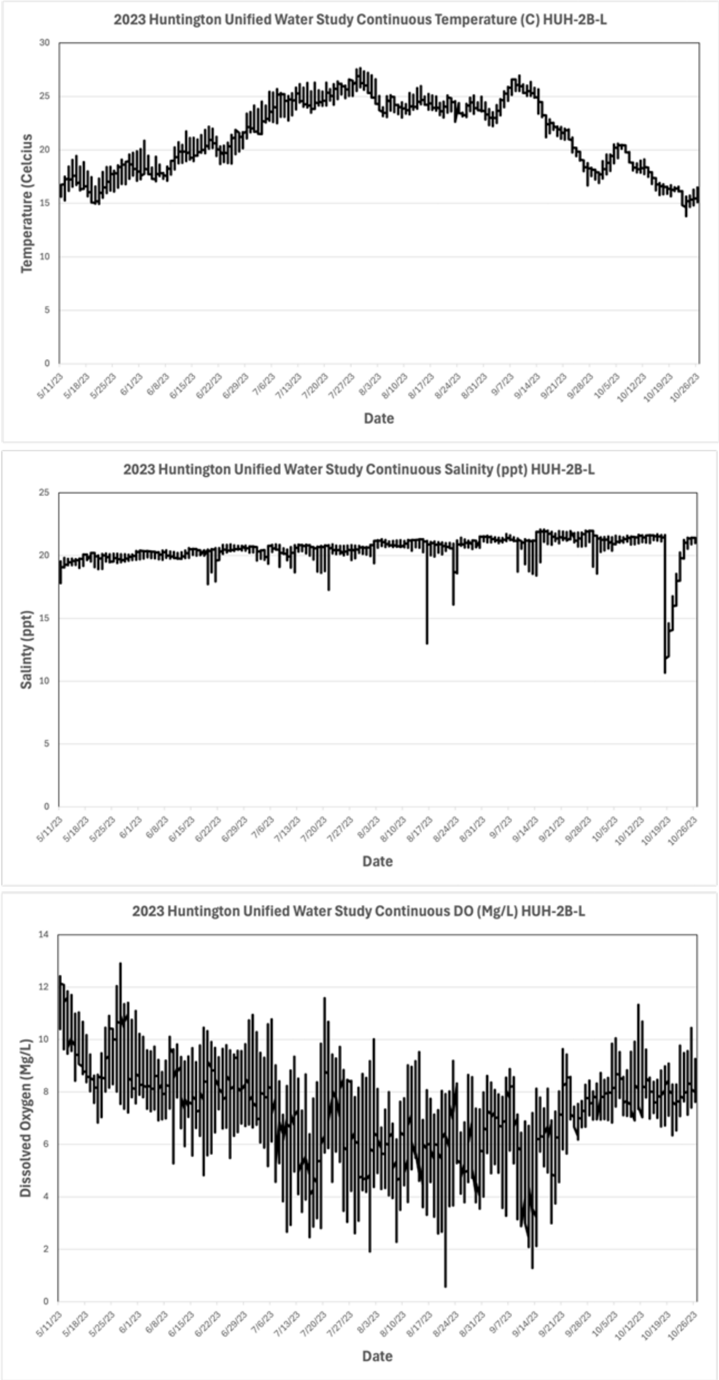

Figure 29. Plots of 2023 Unified Water Study (UWS) continuous off-bottom data loggers for temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Huntington Harbor station (HUH-2B-L) near the ribbed mussel grow-out docks. Note: this data has not yet been QA/QC'd by the UWS (Link to UWS).

2023 – Northport Harbor

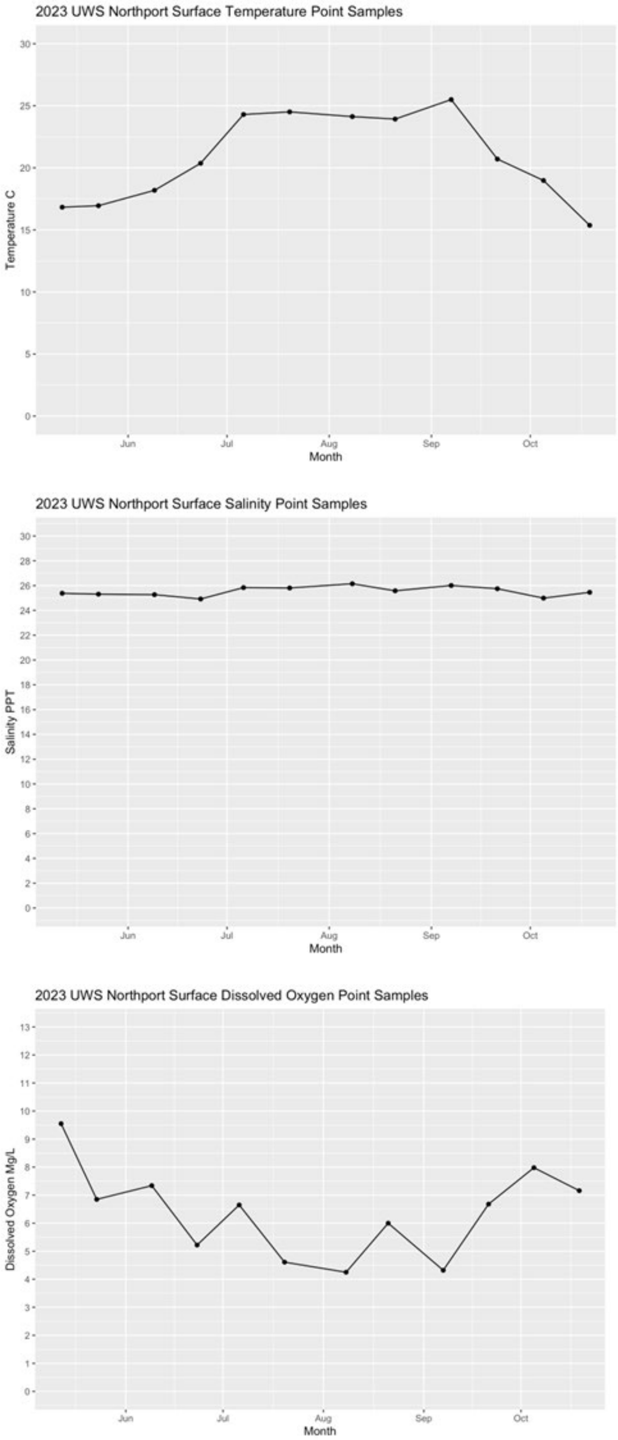

Figure 30. Plots for the 2023 surface temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Northport Harbor station near the ribbed mussel grow-out dock. Data courtesy of the Unified Water Study monitoring program (Link to UWS).

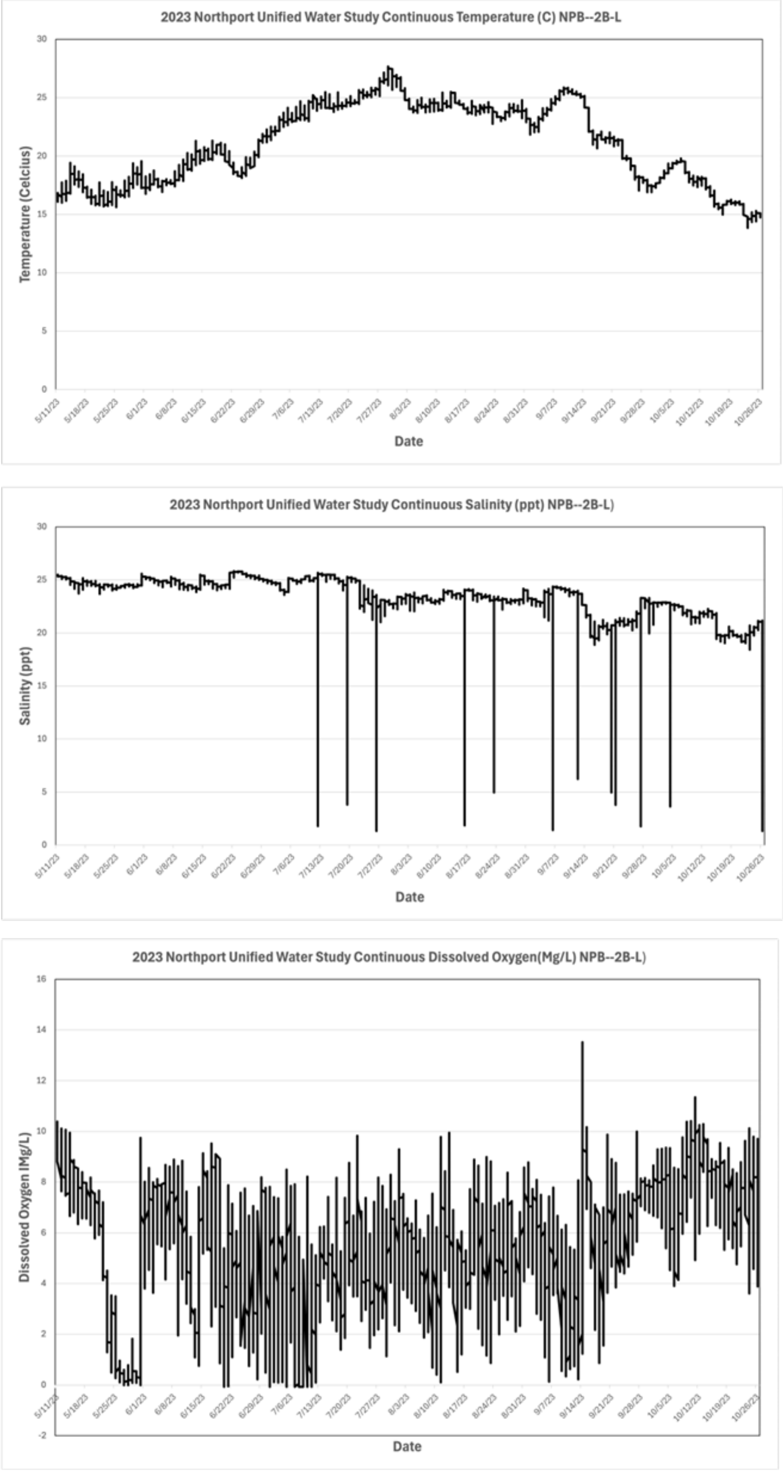

Figure 31. Plots of 2023 Unified Water Study (UWS) continuous-off-bottom data loggers for temperature (Celsius), salinity (ppt) and dissolved oxygen (mg/L) collected at the Northport Harbor station (NPB-2B-L) near the ribbed mussel grow-out docks. Note: this data has not yet been QA/QC'd by the UWS (Link to UWS).