INSPIRED

Fall 2024

A Publication of the New Hampshire
Agricultural Experiment Station

AQUACULTURE RESEARCH REPORT

SCIENCE FOR THE PUBLIC GOOD

University of
New Hampshire
NH Agricultural
Experiment Station

MESSAGE FROM THE DIRECTOR

Dear members of the New Hampshire aquaculture community and beyond:

For over a century, the New Hampshire Agricultural Experiment Station has recognized the importance of diverse food production in the Granite State. For 70 years, the Station has supported research to better understand opportunities and challenges within the state's aquaculture industry and to enable farmers to sustainably raise seafood products—crestaceans, mollusks, salmon, kelp, among others—that are affordable and accessible within local and regional food systems. As New Hampshire undergoes a resurgence within the aquaculture industry, Station researchers continue to support and grow this growth through developing science-informed aquaculture management practices that help sustain resilient food and ecological systems.

The locally inspired research in this issue provides findings and perspectives about how the intersection of production tools and environmental factors can help guide aquaculture producers and surrounding communities. The briefs describe advances in understanding how synergies between fish species can enable chemical-free pest management, how oysters can aid in reducing nitrogen levels in estuaries while increasing farm viability, how monitoring invasive species and microplastics is key to ensuring safe and abundant production into the future, how the demography of the aquaculture sector can evolve to increase access, among many others.

Each research brief offers a perspective about the rigorous science and impactful takeaways that advance New Hampshire's resurgent, growing and increasingly diverse aquaculture sector, and the positive difference this sector can make on our state's food and ecological systems' resiliency.

Thank you for supporting our efforts to improve the lives of every Granite Stater through locally inspired, impactful scientific discoveries.

ANTON BEKKERMAN
Director, NH Agricultural
Experiment Station

INSPIRED CONTENT

SCIENCE FOR THE PUBLIC

LOCALLY INSPIRED. GLOBALLY IMPORTANT.

High-Stakes Issues
World-Class Science
Sustainable Advancement

The mission of your New Hampshire Agricultural Experiment Station (NHAES) is to ensure the resilience of the Granite State's diverse communities and local economies through high-stakes research, world-class science, and sustainable advancement. For over 130 years, we've served as the agricultural, food, natural resource and environmental research arm of the UNH land-grant mission. From the lab to the field, forest and sea, our researchers push scientific frontiers in pursuit of sustainable food production and natural resource management across New Hampshire and beyond.

Aquaculture is experiencing a revival in New Hampshire and across the northeast U.S., as environmental policies have improved long-term production conditions and consumers are seeking both more seafood and local products. The industry's annual economic contribution to the northeast region is at least $220 million, and over $5.5 million and more than 250 jobs to the Granite State.

From left to right, a researcher collects oysters in Great Bay Estuary; an oyster farmer holds out recently farmed oysters; and three scientists examine water samples for possible microplastic contamination. *Image credits: Left and center, Tim Briggs, New Hampshire Sea Grant; right, UNH Marketing*

GOOD

New Hampshire's oyster production—particularly suited to the environment in the state's Great Bay and Hampton-Seabrook estuaries—has led the industry's growth, with farms covering over 80 acres of water. As farmers look to diversify their production with other species of shellfish as well as finfish, there are many unknowns about optimal management for balancing productivity, environmental quality, access for new farmers, affordability and safety for consumers, and policy actions.

Scientific discovery that is based in modern methods and highly integrated with input and contributions from producers and surrounding communities will be key to continuing to build strong, data-informed capacity for a renewed aquaculture sector in the Granite State's food system. Station researchers are helping move forward these discoveries, which are, in turn, increasing the tools for developing sustainable management of pests and diseases, monitoring environmental quality and hazards to both aquatic species and food safety, adopting new technologies to collect and assess data, and setting industry standards and policies that ensure that all those who want to raise food to sustain New Hampshire's communities are able to do so.

CLIMATE CHANGE SHIFTS LUMPFISH DISTRIBUTION IN THE GULF OF MAINE

E. A. FAIRCHILD, E. R. WHITE, S. WULFING, S. BRADT, M. DOHERTY AND K. LEAVITT

Lumpfish (*Cyclopterus lumpus*) can provide biological controls of parasitic sea lice in salmon and trout farming operations. However, as the Gulf of Maine continues to rapidly warm, the changes are causing shifts in the distribution of marine species, including lumpfish. Understanding how the species' population dynamics in the Gulf of Maine change could be important to enabling biological pest controls in sustainable fisheries and aquaculture operations across the Northeast. Data from fisheries surveys can help to examine changes in the Gulf of Maine lumpfish distribution over time, understand the relationship between population shifts and environmental factors as well as establish a baseline for resource managers to support sustainable harvesting and aquaculture development.

KEY TAKEAWAYS

Lumpfish presence in the Gulf of Maine has increased since 1980.

The distribution of lumpfish has shifted northeast over time, likely as a result of climate induced warming.

Lumpfish can play a role in sustainable biocontrol of sea lice. Managing their wild populations in the face of climate change and fishing pressure requires continued sampling and monitoring.

Background and Key Concepts

As the farmed salmon and trout industry in the Gulf of Maine (GoM) continues to grow, producers increasingly face risks from sea lice—marine parasites that attach to salmon and trout and eat on their host's tissue, leading to production losses and mortality. Because lumpfish can naturally graze on sea lice, they are being increasingly considered as a sustainable biocontrol, reducing the more environmentally costly chemical treatments.

Despite their potential use in aquaculture operations, lumpfish are not currently regulated in U.S. waters, there is no management plan for the species, and in Canada, lumpfish are listed as threatened due to fishing-related population declines. A key factor to developing sustainable management is baseline data on lumpfish biomass, occurrence and distribution.

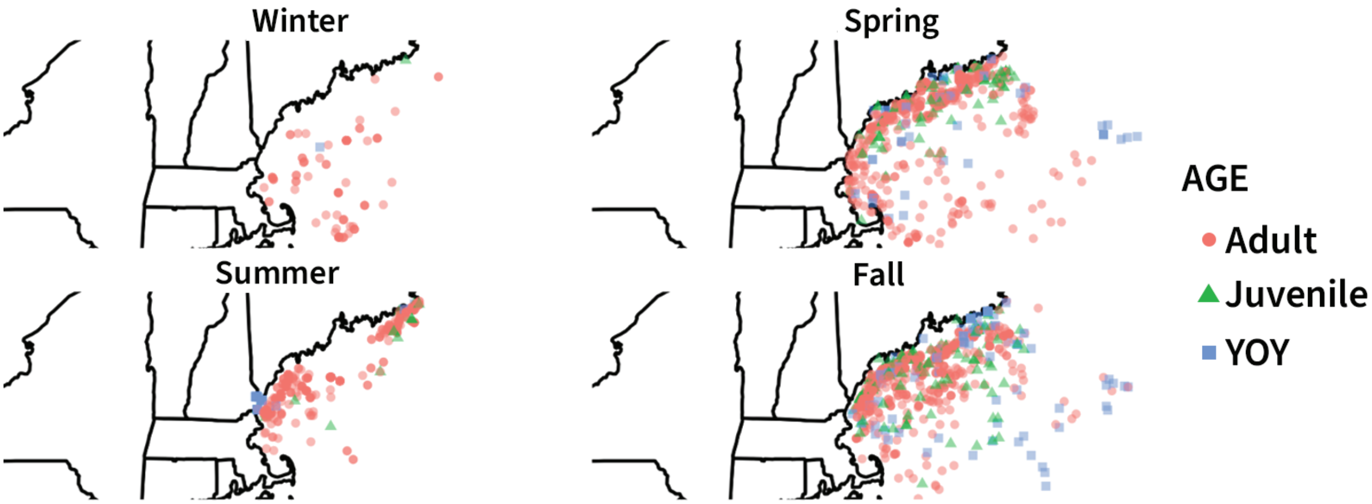
In the U.S., little is known about lumpfish populations. Lumpfish have been well studied in regions outside of the Gulf of Maine, but U.S. information is limited to studies in Great Bay Estuary, NH, and Schoodic Peninsula, ME.

Lumpfish inhabit temperate waters (3–10 °C) in both the eastern and western Atlantic, occupying both pelagic and demersal zones with seasonal and depth-based distribution preferences. Semi-pelagic adults spawn inshore from March to May in the southwestern

Table 1. Lumpfish catch data from fish surveys in the Gulf of Maine.

Location	*Agency*	*Survey Name*	*Gear Used*	*Date Range*	*Total Lumpfish*
ME/NH	Maine Dept. of Natural Resources	Maine-N. Hampshire Inshore Trawl Survey	Bottom trawl	2000–2021	1,357
NH	New Hampshire Fish & Game Depart	Survey of Juvenile Fish	Seine	1997–2021	104
MA	Massachusetts Divsion of Marine Fisheries	Bottom Trawl Survey	Bottom trawl	1978–2021	120
Federal waters	Northeast Fisheries Science Center (NEFSC)–National Oceanic and Atmospheric Administration (NOAA)	Bottom Trawl Survey	Bottom trawl	1963–2021	649
Federal waters	NEFSC–NOAA	Observer Data	Multiple	1989–2021	9,910

Figure 1. Distributions of young-of-year (YOY; meaning younger than one year of age), juvenile and adult lumpfish caught in the Gulf of Maine from 1963-2021 from all state and federal surveys. MA DMF data are not included as lumpfish life history stage could not be calculated.

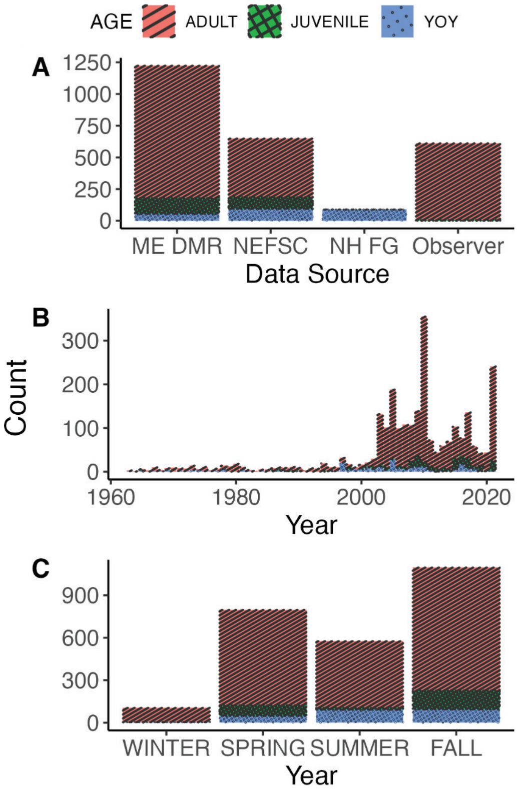


GoM, and May to June along northeast Maine. After spawning, females move offshore, while males guard the eggs. Juvenile lumpfish, associated with macroalgae, prey on small invertebrates before moving to deeper waters as they grow. Lumpfish can live up to 15 years, with males maturing in two to three years and females in three to four years.

Methodology

This study aggregated lumpfish catch data to characterize their distribution and assess the impact of water temperature on them over time. Catch data were sourced from Maine, New Hampshire, Massachusetts, and the Northeast Fisheries Science Center (NEFSC), from 1963 to 2021 (**Table 1**). The data included both fisheries-independent and fisheries-dependent surveys, detailing date, location, depth and environmental variables like bottom temperature. Various survey methods, such as trawl and seine, were employed. Data were combined to map lumpfish distribution across seasons and depths. Generalized linear models assessed correlations with environmental factors, accounting for spatial autocorrelation. This comprehensive approach provided insights into lumpfish distribution shifts and their drivers.

Figure 2. Number of lumpfish caught by life history category (adult, juvenile, younger than one year old [abbreviated as YOY]) in the Gulf of Maine from 1963-2021 from all state and federal surveys depicted by (A) data source, (B) year, and (C) season. Chart A data sources include: Maine Department of Marine Resources (ME DMR), Northeast Fisheries Sience Center (NFSC), New Hampshire Fish and Game (NH FG) and Observer data collected by commercial fishing vessels.



Discussion of Findings

The analysis revealed that lumpfish presence in the GoM has increased over time, with significant seasonal and depth-related variations. Lumpfish are more likely to be found in deeper waters during the fall, correlated with colder bottom temperatures (**Fig. 1**). Over time, lumpfish shifted their distribution northeast, likely as a response to rising water temperatures—consistent with other species' responses to climate change. For lumpfish, the GoM represents the southern end of their range and, as it continues to warm, will likely become increasingly less suitable. Additional work is needed to understand how changes in other oceanographic variables, such nitrate, salinity and productivity, may interact with temperature increases and changes to fishing pressures to affect GoM marine species.

Strategic Recommendations and Conclusion

To meet the growing demand for lumpfish in GoM's aquaculture sector, it is crucial to manage wild populations sustainably. This involves continuous monitoring of lumpfish distribution and abundance, along with developing regulations to prevent overfishing. The findings provide baseline data for resource managers to develop informed conservation and aquaculture practices, ensuring the long-term sustainability of lumpfish populations in the GoM.

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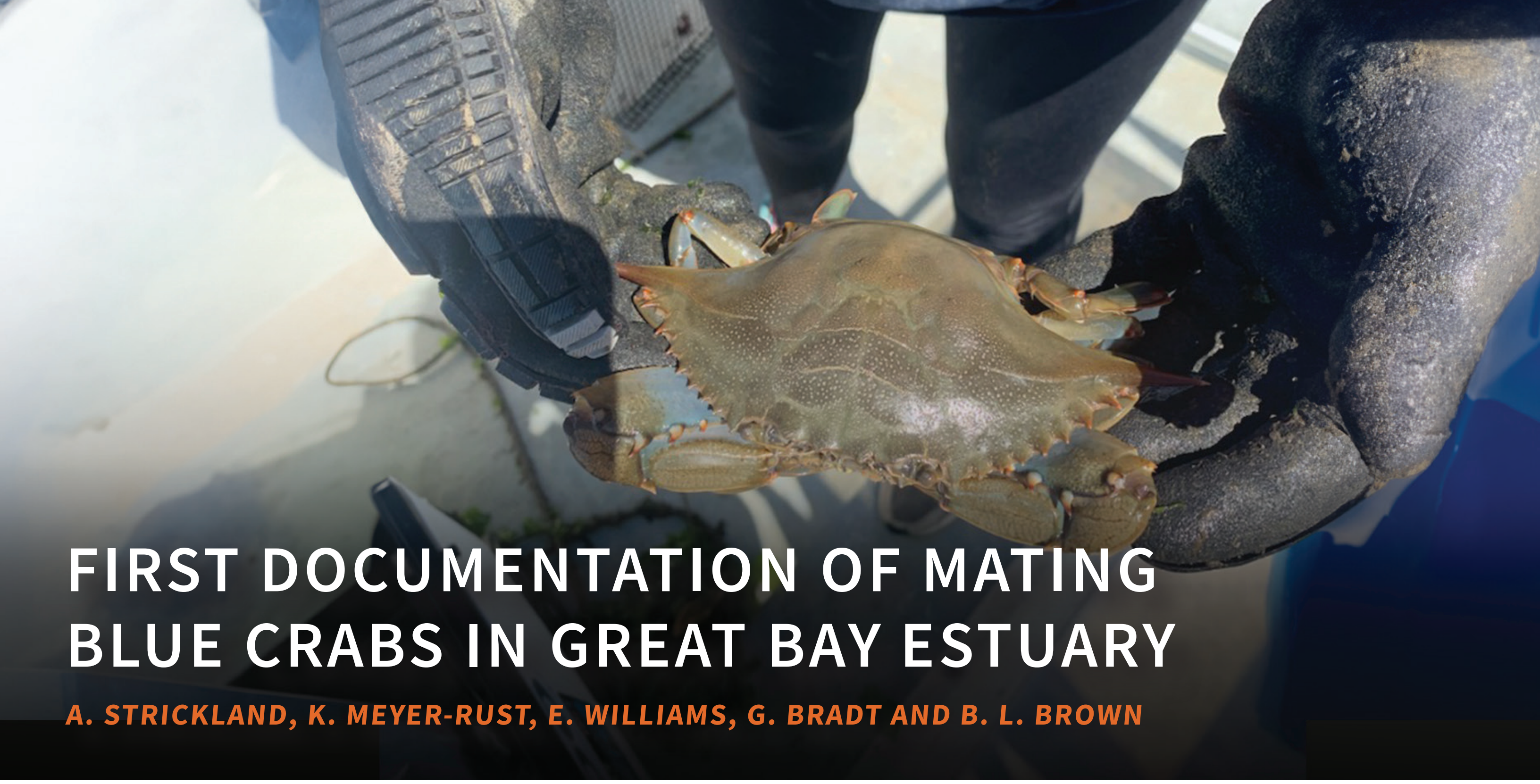
Meet the Lumpfish! Scan the QR code and view an interactive map on lumpfish in the Gulf of Maine.



FIRST DOCUMENTATION OF MATING BLUE CRABS IN GREAT BAY ESTUARY

A. STRICKLAND, K. MEYER-RUST, E. WILLIAMS, G. BRADT AND B. L. BROWN

The Gulf of Maine is projected to continue enduring numerous ecological changes due to climate change. Increasing water temperatures can shift marine species habitats and studies have shown that benthic organisms will expand northward as temperatures increase. Great Bay Estuary in New Hampshire, within the Gulf of Maine region, is experiencing notable ecological changes due to warming waters, including an invasion of non-native species that are successfully establishing sustained populations. An example of a marine organism shifting its range northward is the Atlantic blue crab (*Callinectes sapidus*). Not only can these crabs affect native species, but they also can affect flourishing oyster aquaculture industry Great Bay supports.

KEY TAKEAWAYS

Mated blue crabs were first documented in Great Bay Estuary, New Hampshire, in September and again in October 2022—evidence of a continued habitat range expansion.

The presence of blue crabs may threaten local species, such as eelgrass and oysters, risking declines that could contribute to further ecological imbalances.

Strategic and continued monitoring of blue crabs in Great Bay and proactive development of regional adaptive management plans are key to reducing adverse impacts of the blue crab range expansion.

Background

The New Hampshire oyster aquaculture industry has seen substantial growth in recent years, going from two businesses in 2010 to 32 in 2023. Oyster farms contribute significantly to the local economy and provide essential ecosystem services such as water filtration, excess nutrient mitigation, shoreline stabilization and habitat for other organisms. However, oysters and other bivalves can be preyed upon by blue crabs. While New Hampshire has not been a traditional ecosystem for blue crabs, climate change is expanding their habitat range. Monitoring the presence and movement of these predators can help mitigate impacts on both the native and farmed oysters and the associated industry.

Methodology

Researchers deployed traps (**Fig. 1**) at four sites in Great Bay Estuary (Nannie Island, Moody Point [outside the mouth of Lamprey River], Fox Point and Cedar Point) (**Fig. 2**) to collect crabs in April through November 2022.

Figure 1. Crab traps deployed in Great Bay Estuary, NH. Top shows trapezoid green crab traps from Brooks Trap Mill, Thomaston, ME. Bottom shows a Chesapeake cube style blue crab trap from Ketcham Supply, New Bedford, MA.

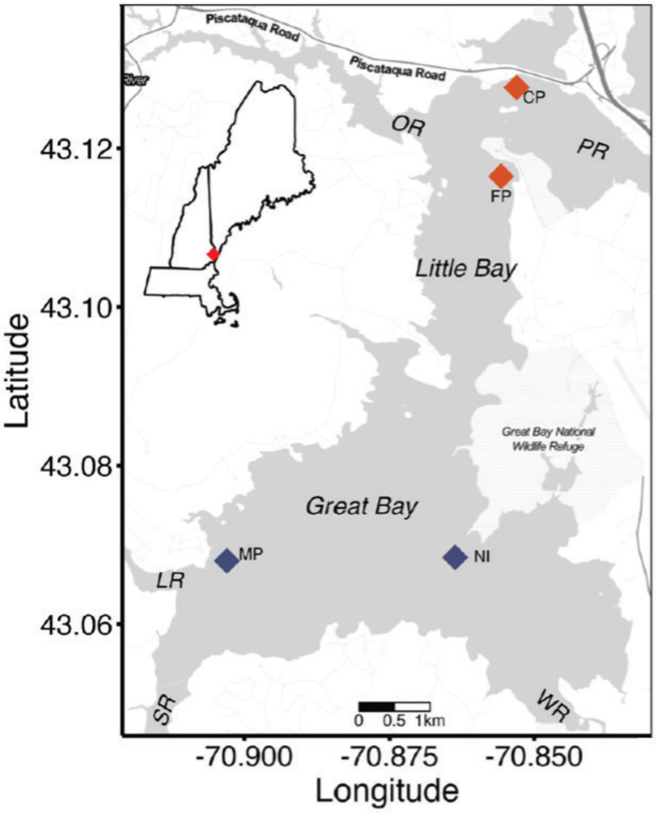
In July 2022, additional traps specifically designed for blue crabs were introduced. All traps were baited with preserved herring or frozen mackerel and were monitored weekly.

All captured blue crabs were bagged and frozen for later analysis of size, sex and diet. All crabs were wet weighed (in grams), measured (carapace width in millimeters) and molted females were dissected to determine presence of sperm plugs.

Discussion of Findings

On September 2, 2022, the first documented mated pair of blue crabs (*Callinectes sapidus*) in Great Bay Estuary (GBE) were captured at Nannie Island. A second pair was captured on October 7, 2022, at Fox Point. This confirmed the presence of an emerging blue crab population in GBE. The male caught in September weighed 159 g (wet) and its carapace width was 134 mm. The female, from the same sampling date, weighed 145 g (wet) with a carapace width of 155 mm. The male caught in October weighed 194 g (wet) with a carapace width of 141 mm, and the female, from the same sam-

Figure 2. Map of Great Bay Estuary, New Hampshire showing location of crab traps at oyster reefs (blue diamonds) and oyster farms (orange diamonds). Sites include Cedar Point (CP), Fox Point (FP), Moody Point (MP) and Nannie Island (NI).



pling date, weighed 146 g (wet) and with a carapace width of 147 mm.

The discovery of mated blue crabs in GBE marks the first scientific documentation of such an event. Blue crabs could have significant implications for the Estuary's ecosystem, particularly for the already vulnerable oyster populations, as captures happened at an oyster reef and at an oyster farm.

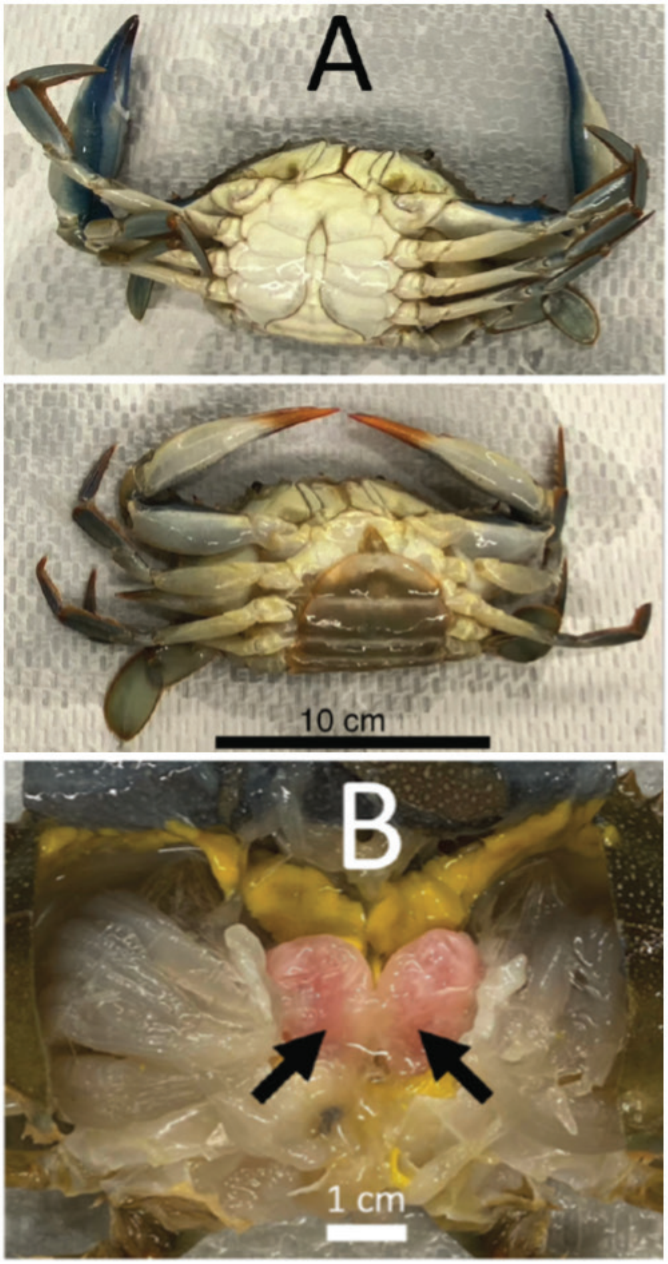
Both captured females showed clear signs of recent insemination, with turgid seminal receptacles and pink sperm plugs (**Fig. 3**). This finding extends previous observations of blue crabs in the Gulf of Maine, suggesting that the species is establishing a breeding population in GBE. A further study of the diet of these and additional blue crabs that were captured in 2023 is underway. If blue crabs are verified to be consuming oysters, they may be a factor affecting oyster populations due to predation. The result could lead to a trophic cascade, increasing primary production and disrupting the ecological balance of GBE.

Strategic Recommendations and Conclusion

To mitigate the potential impact of blue crabs in GBE, it is crucial to implement targeted monitoring and management strategies. Further observations are needed to confirm the establishment of a sustained blue crab population, including the detection of gravid females and early-stage larvae. Collaboration with local end users, enabling activities such as putting traps near oyster farms and restoration areas, can provide valuable data, enhance monitoring efforts and provide protection by trapping and removing crabs. Additionally, exploring methods to control the blue crab populations, such as selective trapping, can help protect native species. Policymakers should consider adaptive management plans that address the dynamic nature of invasive species and climate change.

The documentation of mating blue crabs in GBE and continued captures afterward highlights the increasing urgency to address the ecological implications of range-expanding marine species. This discovery underscores the importance of continued research and monitoring to understand and manage the impacts on local ecosystems. Community involvement and proactive management strategies are essential to mitigate the potential threats posed by blue crabs and to ensure the resilience of GBE's native species. Current monitoring of blue crabs by trapping throughout GBE is underway through collaboration of GBNERR, New Hampshire Sea Grant and Wells Research Reserve.

Figure 3. Blue crabs (*Callinectes sapidus*) caught in Great Bay Estuary, NH. (A) Male (top) and female (bottom). (B) Distended seminal receptables with sperm plugs (arrows).



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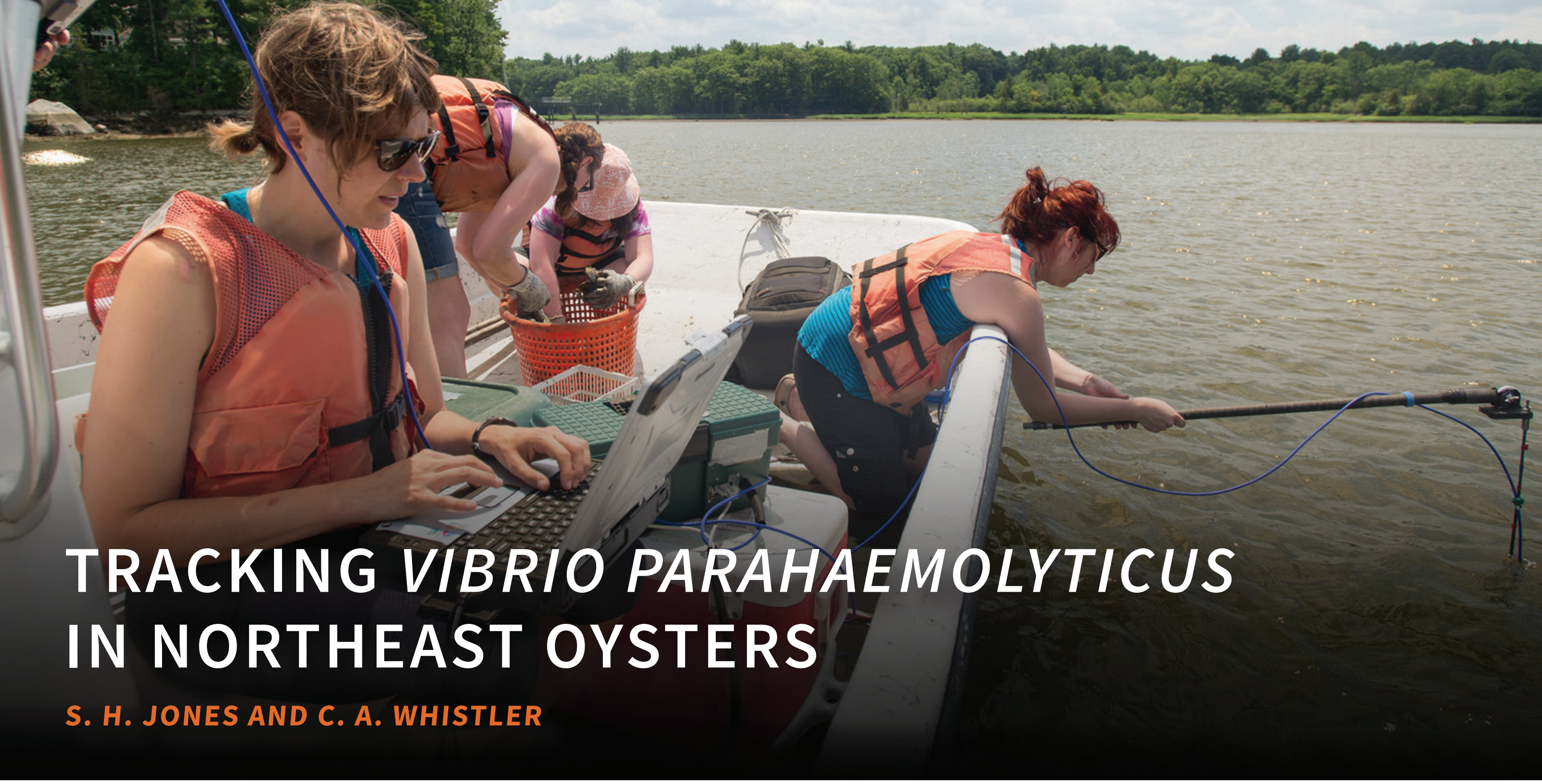


TRACKING *VIBRIO PARAHAEMOLYTICUS* IN NORTHEAST OYSTERS

S. H. JONES AND C. A. WHISTLER

In the past decade, pathogenic variants of *Vibrio parahaemolyticus* have increased Northeast aquaculture areas, bringing increased risks of human illnesses related to shellfish consumption. Though increasing ocean temperatures and the rapid expansion of regional oyster aquaculture have likely contributed to increases in disease from local sources, the introduction and establishment of a Pacific lineage of *Vibrio parahaemolyticus* sequence type (ST) 36 in the region is arguably the biggest driver of disease. Even as New Hampshire aquaculture has expanded in recent years, the invasive pathogens have not yet been linked to local products, nor have they been detected in growing production areas. Yet the northward expansion of pathogenic populations remains a serious concern and it is important to understanding factors that promote pathogen invasiveness and resilience.

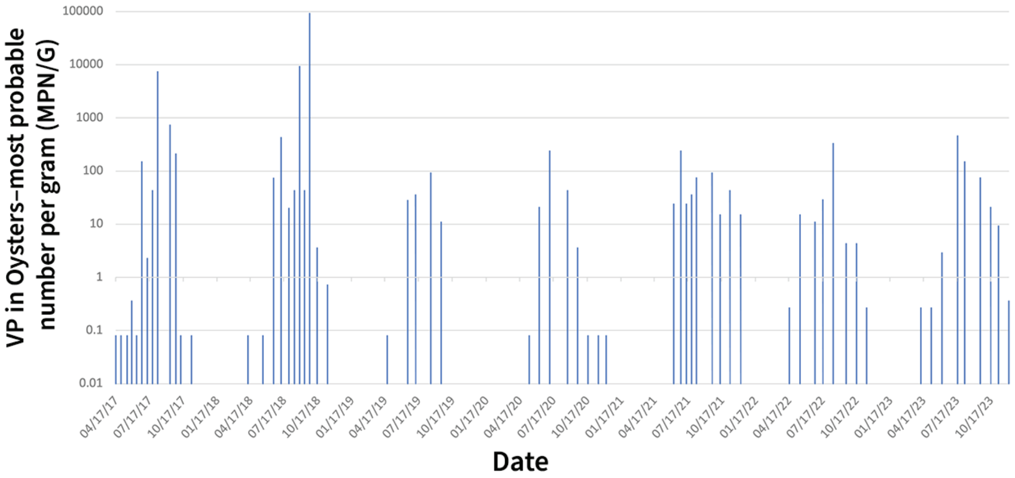
KEY TAKEAWAYS

The prevalence of *Vibrio parahaemolyticus* strains with human pathogenic potential in Great Bay Estuary oysters shifted from rare to common by 2020, and then declined.

An 18-year database analysis identified pH, temperature and plankton communities as key factors driving fluctuations in *Vibrio parahaemolyticus* concentrations, peaking in 2007–2016 and declining in 2018–2023.

The invasive *Vibrio parahaemolyticus* strain causing increased illness in New England has not been detected in New Hampshire aquaculture, emphasizing the need for locally based monitoring rather than reliance on regional data.

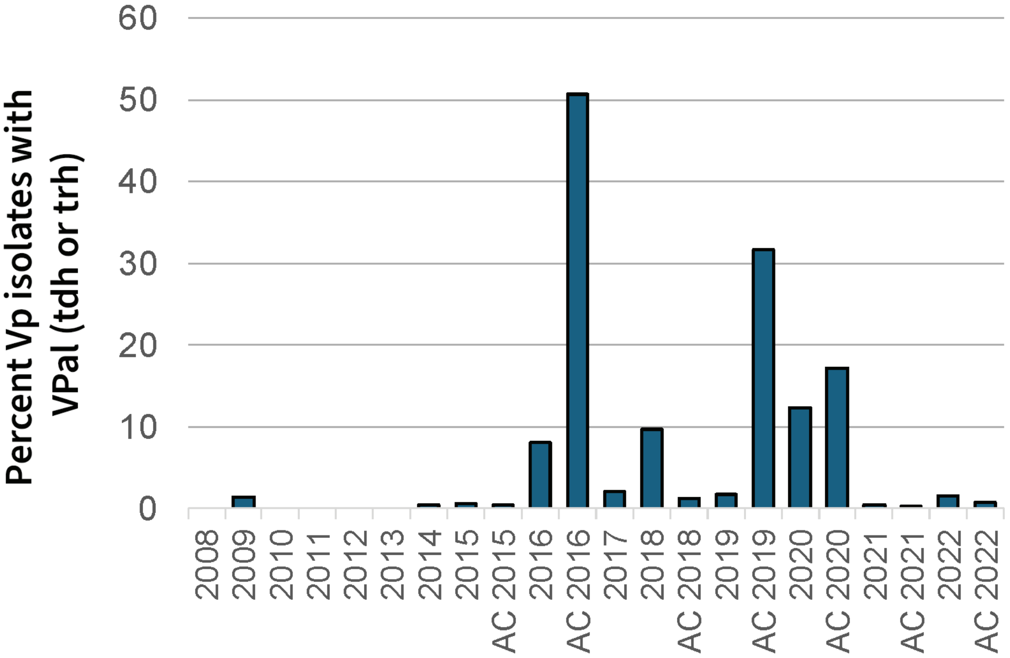
Figure 1. *Vibrio parahaemolyticus* concentration in NH oysters sampled from Nannie Island 2017–2023.



Background and Key Concepts

Environmental surveillance of oyster populations and analyses of changing epidemiology are core research approaches for examining the ecological drivers of disease population changes to aid in managing risk and increasing prevention. By identifying environmental conditions that precede or accompany increased pathogen abundance, the data can be used to develop models to forecast risk and help regional shellfish managers to create remediation strategies.

Figure 2. The percent of *Vibrio parahaemolyticus* isolates with pathogenic markers (*tdh*; *trh*) found in wild or aquacultured (AC) Great Bay Estuary, New Hampshire oyster sites in 2008–2022.



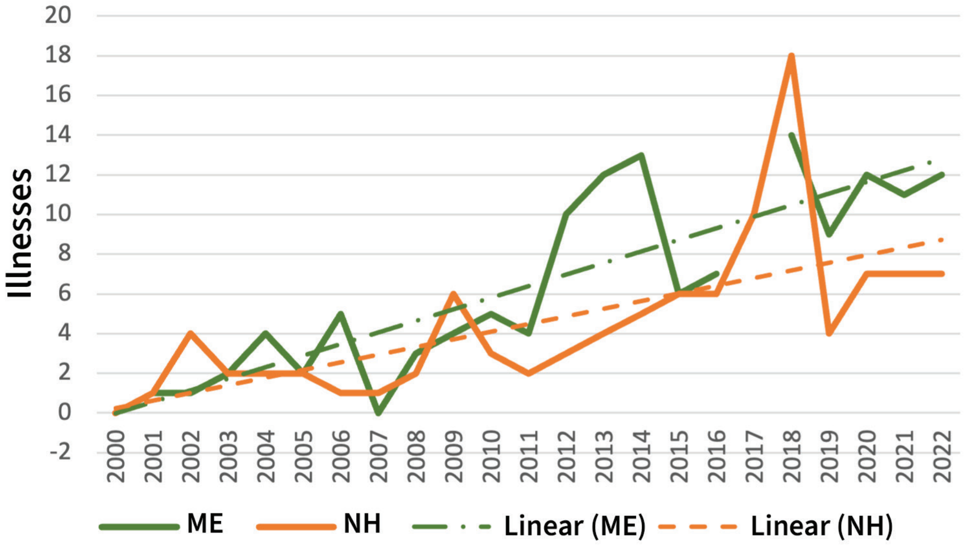
The ability to identify contributing factors and prevent disease is predicated on proactive and continuous environmental sampling preceding increased disease prevalence, as New Hampshire is on the northern range of regional changes that have led to increased disease burden and required costly management practices.

Through collaboration with seafood safety managers and public health entities, and partnerships with growers, the goal is continued integration of expertise to identify and address future issues of concern.

Methodology

Field Sampling and Lab Analyses: A collection of samples of oysters, sediment, water, phytoplankton and zooplankton allow temporal and spatial analyses of *Vibrio parahaemolyticus* concentrations and population traits, including the presence of gene content that confers human virulence (hemolysins *tdh* and *trh*) from the Great Bay Estuary using methods similar to what the U.S. Food and Drug Administration uses to track this potential pathogen in oysters. Existing methods were optimized and new analytical approaches were used to identify distinctive genetic markers in assays to track different strains of pathogenic *Vibrio parahaemolyticus* including regionally hypervirulent strains.

Figure 3. Number of reported *Vibrio parahaemolyticus* related illnesses from 2000–2022 in Maine (ME) and New Hampshire (NH) with linear trendlines.



Temporal Analysis and Predictive Modeling: A range of ecosystem conditions have been consistently tracked in water samples, including pH, dissolved oxygen, salinity, concentrations of *Vibrio parahaemolyticus*, nutrients, solids and plankton, and types of plankton over 18 years at two sites. A combination of descriptive and predictive modeling and multivariate community analysis representing sites and the harvest area were used to analyze *Vibrio parahaemolyticus* concentrations in oysters, resulting in identification of pH, temperature and plankton communities as drivers of *Vibrio parahaemolyticus* concentration variation.

Discussion of Findings

Temporal analyses and comparisons of archived environmental isolates with isolates from clinical sources helped to better understand how pathogenic lineages emerge from local reservoirs. Overall, *Vibrio parahaemolyticus* concentration in New Hampshire oysters has declined since 2017, but has remained relatively consistent at the lower level in 2019–2023, with concentrations peaking in the summer months (**Fig. 1**).

The endemic Northeast population of *Vibrio parahaemolyticus* is genetically distinctive, as are the prevalent virulence determinants compared to pandemic and Asian strains, which cause most infections world-wide. Since its peak in 2016, the presence of pathogenic markers in NH oysters that indicate genes that confer human virulence has decreased substantially (**Fig. 2**). This may help explain why there are a lower number of reported human illnesses due to *Vibrio parahaemolyticus* in New Hampshire than in Maine, and as yet no cases have been traced to commercial product from New Hampshire (**Fig. 3**).

Ancestral and geographic patterns and mapping virulence determinants upon lineages indicate that more recent emergent pathogens in the Northeast most often were either related to Pacific endemic lineages or acquired virulence gene content via genetic exchange with these invasive lineages. This helped develop tracking tools for genetic elements associated with virulence and enabled them to study the ecological interactions that may contribute to enhanced survival of pathogens, including resistance to phage and protist predation.

Strategic Recommendations and Conclusion

The prevalence of *Vibrio parahaemolyticus* in Great Bay has decreased since peaking in 2017, corresponding with a broader decline in regional vibriosis cases. Notably, the absence of the invasive Pacific-native strain in New Hampshire's aquaculture areas, despite its presence in Massachusetts, highlights a key distinction for local risk management. Specifically, that ongoing monitoring and mitigation strategies should be based in state-specific tracking and pathogen prediction tools, rather than relying on monitoring data from even nearby states and aquaculture sectors.

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PATHOGEN PRESENCE IN GREAT BAY ESTUARY: IMPLICATIONS FOR OYSTER RESTORATION

A. STRICKLAND, B. Y. LEE AND B. L. BROWN

Eastern oysters (*Crassostrea virginica*) are important to estuarine ecosystems in New England, providing habitat, buffering extreme weather and sequestering nutrients such as N, P and C. Oyster restoration supports local fisheries and aquaculture industries. However, in New Hampshire's Great Bay Estuary, oyster populations are at risk due to diseases like MSX and Dermo, caused by infectious agents *Haplosporidium nelsoni* and *Perkinsus marinus*, respectively. Improved assessment of the presence and distribution of these pathogens in GBE waters is key to strategic and effective oyster restoration efforts.

Background and Key Concepts

One challenge to successful restoration of New Hampshire's declining wild oyster population is the presence of shellfish diseases. MSX and Dermo are protozoan pathogens affecting eastern oysters. MSX is caused by the pathogen *Haplosporidium nelsoni*, and Dermo is caused by the pathogen *Perkinsus marinus*.

KEY TAKEAWAYS

Waters near Eastern oyster habitat in New Hampshire's Great Bay estuary exhibited higher, more variable concentrations of DNA from the pathogens *Haplosporidium nelsoni* (which causes the disease MSX) and *Perkinsus marinus* (which causes the disease Dermo).

Significant peaks for *H. nelsoni* DNA were observed from late July through August, while higher levels of *P. marinus* DNA were detected in June and maintained throughout the summer in real-time.

Detection of *H. nelsoni* DNA in oyster larvae suggests potential pathways for disease transmission.

Both diseases have contributed to declines in oyster populations in various estuaries, including Great Bay Estuary (GBE). Understanding the prevalence and transmission mechanisms of these pathogens is crucial for effective management and restoration efforts. This study used molecular techniques to detect and quantify pathogen DNA in GBE water samples.

Methodology

The study was conducted at three sites (**Fig. 1**) in GBE: a native oyster reef at Nannie Island, an oyster farm in Little Bay and a reference site at Adams Point with no detectable oysters. Weekly water samples were collected from June to November 2020. DNA was extracted and disease intensity was quantified using a quantitative-competitive PCR assay developed at UNH that allows for the simultaneous detection of *Haplosporidium nelsoni* and *Perkinsus marinus* DNAs. The chosen sites represented different oyster population scenarios, providing a comprehensive overview of pathogen presence in various contexts within GBE.

Discussion of Findings

The study found significant levels of pathogen DNA at sites with oysters, with notable seasonal peaks (**Fig. 2**). High concentrations of *H. nelsoni* DNA were observed in late July through August, primarily at the native reef site, suggesting that wild oysters might be more susceptible to MSX. The farm site, which housed MSX-resistant oyster strains, showed relatively lower levels of *H. nelsoni* DNA. This indicates that breeding and deploying resistant strains can mitigate the impact of MSX.

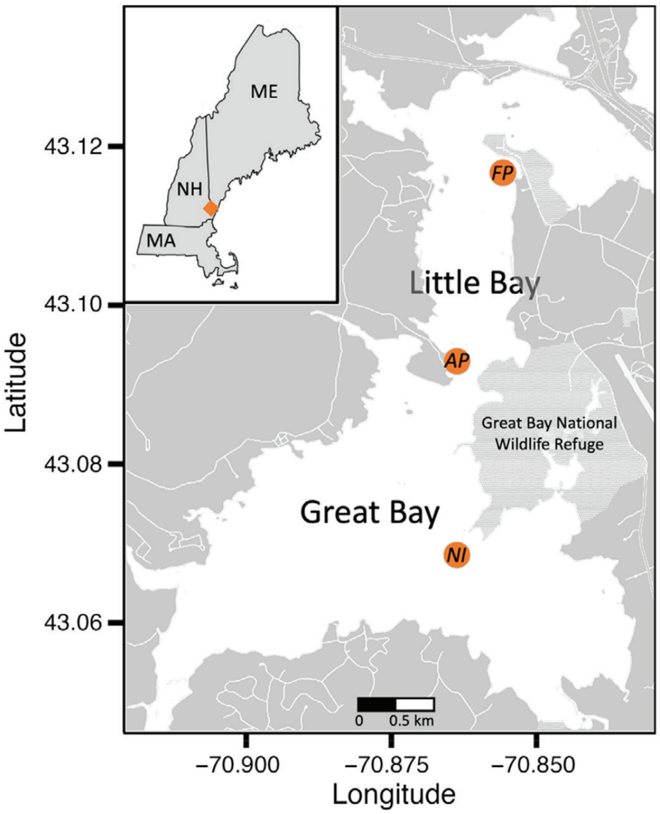
Perkinsus marinus DNA was consistently higher than MSX at sites with oysters compared to the reference site, with peak levels detected in June and maintained throughout the summer. The persistent high levels of *P. marinus* DNA highlight the need for ongoing monitoring and management of Dermo disease and for the development of a Dermo-tolerant strain.

The study also discovered *H. nelsoni* DNA in plantonic oyster larvae, suggesting that larvae could be potential vectors for disease transmission. This finding is significant as it underscores the importance of monitoring not only adult oysters but also larval stages to understand the full scope of pathogen dynamics.

Strategic Recommendations and Conclusion

Continuous monitoring of pathogen levels in estuarine waters is crucial for effective disease management. Restoration projects should consider incorporating pathogen-resistant oyster strains to mitigate disease impacts. Further research into the transmission mechanisms of MSX and Dermo, particularly the role of oyster larvae and other potential intermediate hosts, is essential for developing comprehensive restoration strategies.

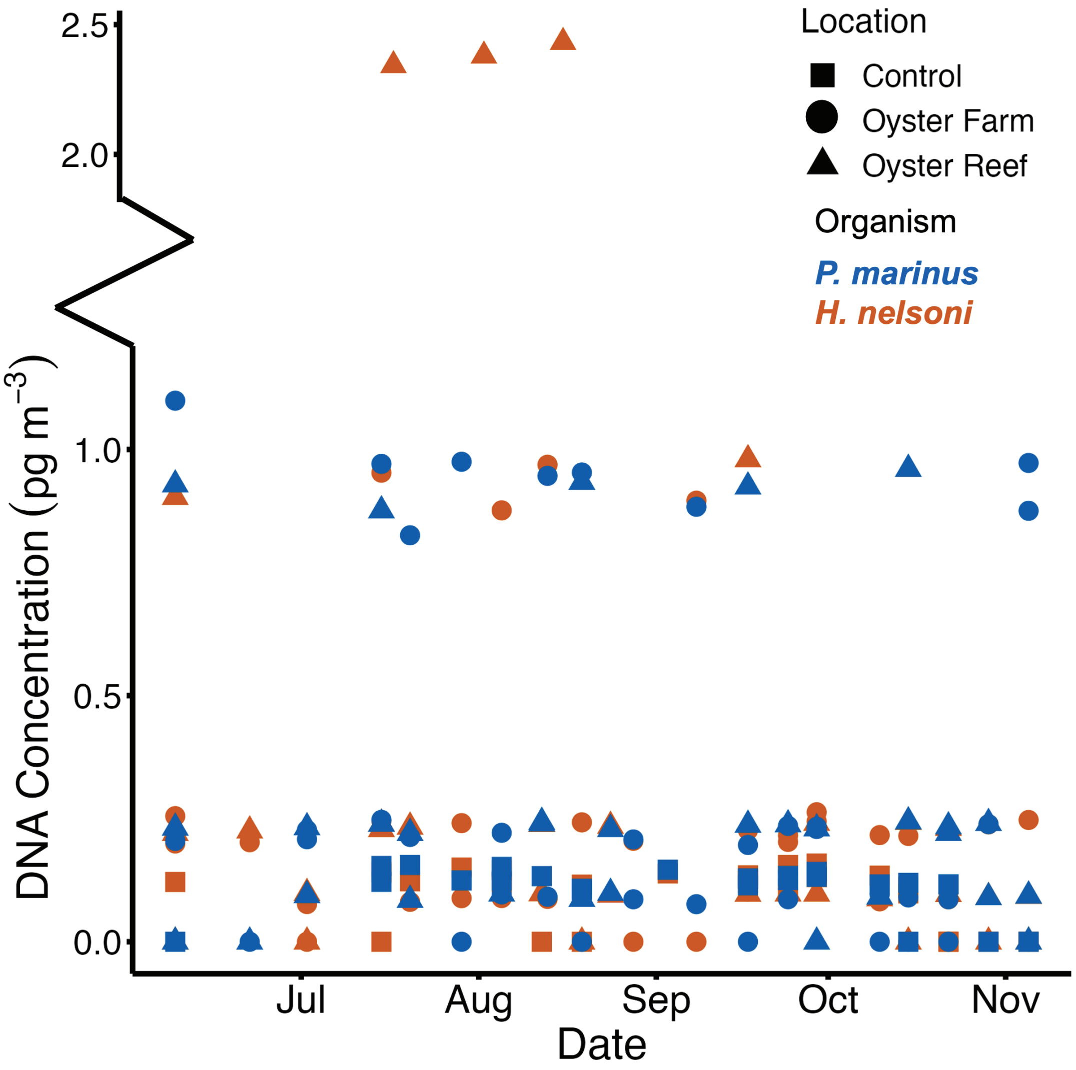
Figure 1. Great Bay Estuary (orange diamond in regional inset of US New England states bordered in black). Sampling sites (orange points) included an oyster reef at Nannie Island (NI), an oyster farm near Fox Point (FP), and a site lacking a substantial oyster population between the other two sites near Adams Point (AP).



Tonging for oyster samples at experimental reefs.

The findings of this study underscore the importance of understanding pathogen dynamics in GBE for successful oyster restoration. High levels of MSX and Dermo pathogens in waters associated with oyster habitats highlight the need for integrated disease management approaches, including continuous monitoring, strategic use of resistant strains and further research into transmission pathways. These integrative strategies are vital to support the recovery and sustainability of oyster populations in GBE. Ongoing research and adaptive management practices are likely to increase the likelihood of long-term health and viability of New Hampshire's estuarine ecosystems.

Figure 2. Trends in water concentration of *H. nelsoni* and *P. marinus* DNA in Great Bay Estuary, New Hampshire



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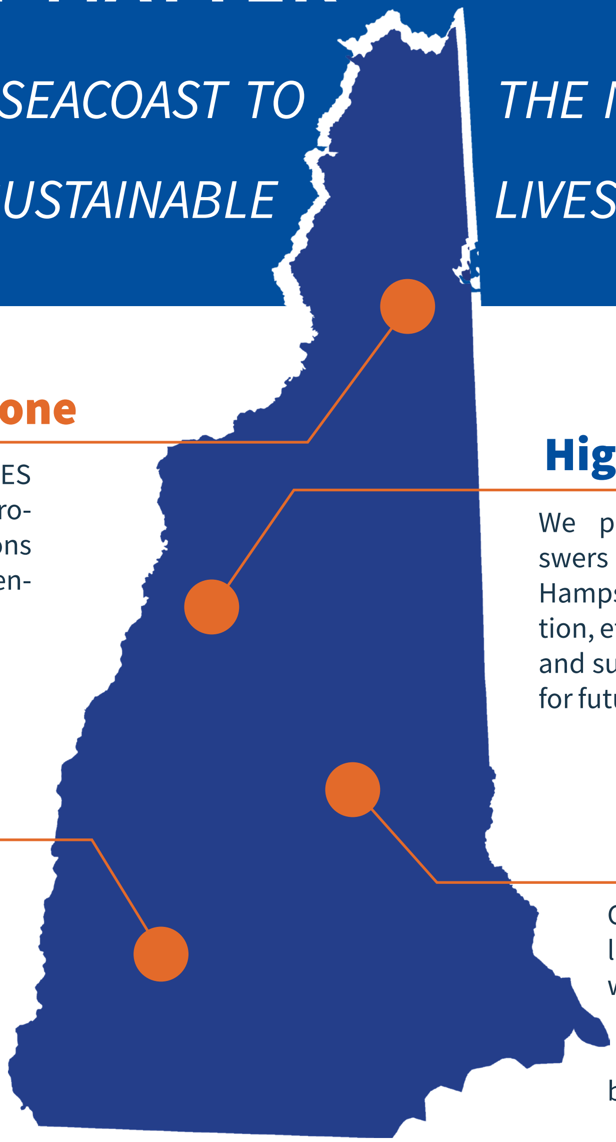
IMPACTS THAT **MATTER**

FROM THE SEACOAST TO THE NORTH WOODS,
SCIENCE FOR SUSTAINABLE LIVES & LIVELIHOODS



Research Cornerstone

For more than 130 years, the NHAES has served the Granite State to provide research for critical questions that increase food security and environmental health.

High-stakes Issues

We provide science-based answers to critical issues in New Hampshire: Resilient food production, effective forest management and sustainable natural resources for future generations.

World-class Science

Our research pushes scientific frontiers and develops data-informed solutions to help the economic, environmental and societal well-being of New Hampshire's many diverse communities.

Economic Driver

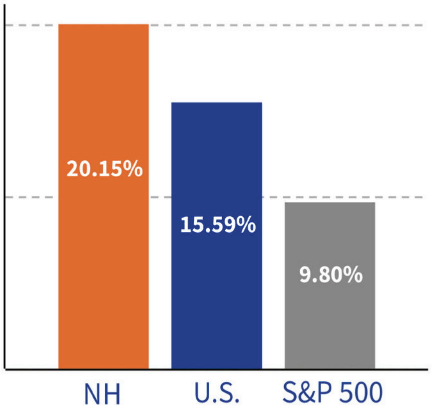
Growing innovative private-public partnerships, training the workforce of tomorrow and providing new technologies and knowledge that grow small business success.

BY THE NUMBERS

The Experiment Station Supports:

52	Scientists
38	Graduate students, postdoctoral fellows
810	Research farm and forest acres
304	Research dairy cows
1,395,231	Stakeholders across New Hampshire

Annual Rate of Return on Agricultural R&D Investment



Source: Data from Plastina (2012), "Rates of return to public agricultural research in 48 states."

$23.8 million

in competitive federal, state, and industry grants awarded to Station scientists to further support locally important research.

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LUMPFISH AS A BIOCONTROL FOR SEA LICE PARASITES IN STEELHEAD TROUT FARMS

E. A. FAIRCHILD, M. DOHERTY AND M. CHAMBERS

Infestations by sea lice—marine parasites that attach and injure salmon and trout—are a major challenge for seafood farmers due to the high management costs and lower productivity. Traditional control methods, such as chemotherapeutics and thermal treatments, are costly and often require specialized equipment, consistent regulatory approval and can have detrimental environmental impacts, making them less practical for widespread use. One sustainable solution could be to use cleaner fish. In Europe and Canada, lumpfish (*Cyclopterus lumpus*) have been effectively used as a biological control for sea lice (*Caligus elongatus* and *Lepeophtheirus salmonis*). However, their use within U.S. steelhead trout farms is not as widespread, in part because there are limited data and associated best management practices for using lumpfish on steelhead trout farms.

KEY TAKEAWAYS

Steelhead trout farms in New Hampshire experience sea lice issues, with peaks observed during the winter months.

Lumpfish reduced sea lice infestations by 37% in steelhead trout farms.

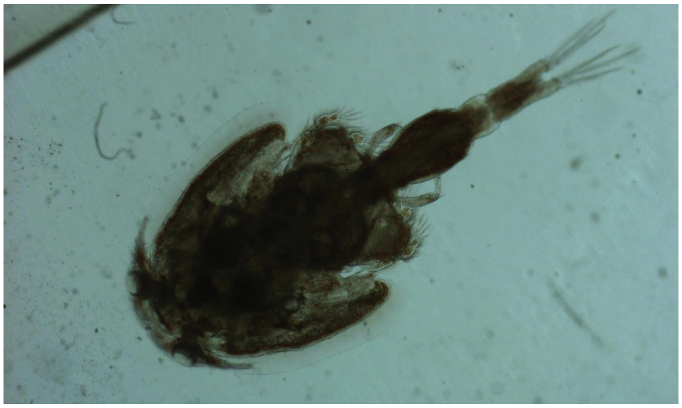
Sea containers that use kelp hides rather than PVC can further reduce sea lice loads and improve overall management effectiveness.

Background and Key Concepts

The steelhead trout farming industry in the northeastern United States is growing rapidly, driven by increasing consumer demand for local and sustainably sourced seafood. According to market reports, the U.S. trout market is expected to exhibit a compound annual growth rate of 6% from 2024 to 2032, with the Northeast region playing a significant role in this expansion. Steelhead trout are being increasingly cultured as a partial alternative to wild-caught species, providing economic benefits to local communities and supporting the infrastructure used by commercial fishermen.

Sea lice (**Fig. 1**) are ectoparasites that attach to fish, causing stress, reduced growth rates and increased susceptibility to diseases. *Caligus elongatus* is the dominant species in New Hampshire waters, and they are an important economic and management barrier to seafood farmers who are considering or have already included steelhead trout production.

Figure 1. A sea louse under a microscope.



Methodology

Two trials were conducted at the University of New Hampshire's Judd Gregg Marine Research Complex Pier, each lasting five weeks. Steelhead trout were sourced from New Hampshire's Sumner Brook Fish Farm and acclimated before being placed in six cylindrical experimental cages, each stocked with 15 steelhead trout (**Fig. 2**). Four of these cages included lumpfish at a density of 20%. The cages were equipped with different hide designs—kelp and PVC panels—to optimize lumpfish welfare and cleaning efficiency (**Fig. 3**).

Throughout the trials, data on sea lice loads, water temperature, fish survival and lumpfish stomach contents were collected to assess the effectiveness of lumpfish in controlling sea lice infestations. Sea lice loads on steelhead trout were monitored weekly, while water temperature was recorded every two hours. At the end of each trial, all fish were euthanized following approved procedures by the UNH Institutional Animal Care and Use Committee, weighed and dissected to examine their stomach contents and assess their overall health. Statistical analyses were conducted to determine the significance of differences in sea lice loads between treatments.

Figure 2. Experimental design of the *in situ* steelhead trout study. C1-C6 represent the individual trout Containers. General tidal current directions are represented by arrows.

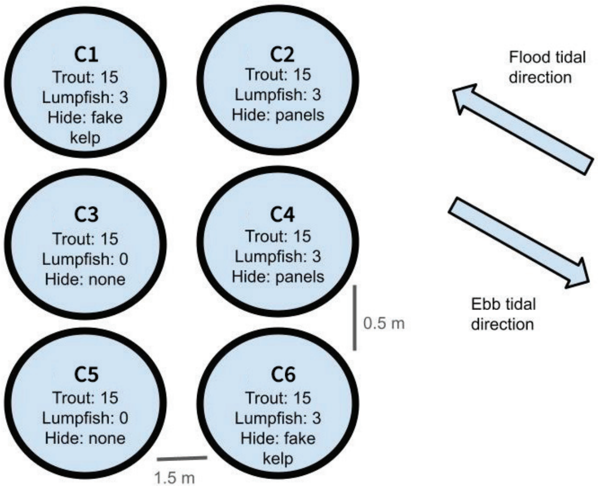


Figure 3. Treatments for this study include fake kelp (left image) and PVC hides (right image).

Discussion of Findings

Sea lice loads on steelhead trout peaked in January, with an average of 3.6 lice per fish. The study confirmed the predominance of *Caligus elongatus* in New Hampshire waters. The presence of lumpfish significantly reduced sea lice loads, particularly in cages with kelp hides. Kelp hides were more effective than PVC panels in supporting lumpfish cleaning activities and reducing sea lice infestations, indicating the importance of providing suitable habitats for cleanerfish within aquaculture systems.

In both trials, steelhead survival ranged from 94% to 99%, while lumpfish survival ranged from 75% to 100% (**Table 1**). Lice loads were 40% lower in kelp hide containers than in PVC hide containers, and 46% lower than in control containers without lumpfish or hides. The presence of lumpfish reduced lice loads by 37%. Lumpfish also carried lice, with weekly counts ranging from 0 to 9 per fish. Additionally, the absence of sea lice in lumpfish stomachs suggests indirect cleaning behavior, possibly through deterrence or non-ingestive removal mechanisms.

Strategic Recommendations and Conclusion

Scaling up the use of lumpfish at commercial operation sites by optimizing stocking densities and hide designs can improve sea lice management in steelhead trout farms. Sustainable aquaculture practices, including the use of biological controls like lumpfish rather than reliance on chemical treatments, could help minimize detrimental environmental impacts and support industry growth through cost-effective integrated pest management. The use of lumpfish as biological controls for sea lice in steelhead trout aquaculture shows promising results. Continued research and optimization are essential to fully integrate cleanerfish into commercial steelhead trout farming operations in New Hampshire.

Specific recommendations include:

Optimal Conditions: Utilize smaller lumpfish (20–140g) during colder months or in colder regions, as they are more effective in reducing sea lice loads.

Hide Designs: Incorporate kelp hide designs in sea containers to enhance the delousing efficacy of lumpfish.

Further Research: Larger-scale trials are needed to validate findings and explore the interaction of lumpfish and steelhead trout on commercial farms.

Table 1. Final mean metrics ± one standard deviation of steelhead trout in Trials 1 and 2 by hide design, cleanerfish treatments and all containers combined. Mean weekly lice load is the overall mean number of lice per fish per week. Unique letters signify statistical differences between the variables within a given treatment based on results of GLM F-tests ($p<0.05$).

			Trial 2			*Trial 1*		
Treatment	***Variables***	***Replicates***	***Mean Weekly Lice Load***	***Mean Weight (g)***	***Survival (%)***	***Mean Weekly Lice Load***	***Mean Weight (g)***	***Survival (%)***
Hide	Kelp	2	0.27 ± 0.63a	312.0 ± 1.89	100	0.01 ± 0.12a	307.90 ± 8.15	97
	PVC	2	0.45 ± 0.74b	359.33 ± 63.64	90	0.03 ± 0.18a	291.00 ± 12.73	100
	No Hide	2	0.50 ± 0.78b	278.25 ± 45.46	93	0.09 ± 0.27b	285.83 ± 23.81	100
Cleanerfish	Present	4	0.36 ± 0.69a	335.17 ± 45.46	95	0.02 ± 0.15	299.50 ± 13.09	98
	Absent	2	0.50 ± 0.78b	278.25 ± 45.46	93	0.09 ± 0.27	285.83 ± 23.81	100
All Containers	All	6	0.41 ± 0.72	316.20 ± 46.39	94	0.04 ± 0.20	294.90 ± 16.3	99

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OYSTER BIOSENSORS AS A TOOL FOR REAL-TIME BEHAVIOR TRACKING

M. EDWARDS, A. VILLENEUVE, B. JELLISON AND E. R. WHITE

Shellfish, both farmed and wild, are increasingly experiencing physiological stress due to the impacts of climate change, nutrient pollution and invasive species on coastal marine systems. Traditional assays of stressor impacts using physiological experiments can identify the consequences of simple interactions on shellfish and expected trends from increasing environmental disturbance. However, the results from these approaches fail to accurately identify stressful conditions in coastal environments. Coastal managers and shellfish farmers require real-time information about how shellfish are responding to current conditions to make decisions that protect human, environmental and economic health.

Background and Key Concepts

The Gulf of Maine is changing rapidly, marked by rising surface temperatures and heightened occurrences of coastal acidification events driven by freshwater inflow. Within the Gulf of Maine, Great Bay is a semi-enclosed

KEY TAKEAWAYS

Eastern oysters are affected by multiple stressors, including warmer waters and invasive species like European green crabs.

Biosensors attached to oysters is shown to measure oysters’ gaping behavior in real time, enabling more accurate understanding of their responses to stressors.

Oysters have the greatest response to predator cues in nighttime and exhibit higher stress in high temperatures, low dissolved oxygen and extreme water acidity levels.

and tidally influenced estuary in New Hampshire that is the epicenter of oyster aquaculture efforts in the state. Overall, oyster aquaculture contributed $4.6 million in economic benefits to the State of New Hampshire in 2020 and has expanded 774% since 2013.

However, wild oyster populations have continued to decline despite restoration efforts. Invasive species like European green crabs have also become more prevalent in the region, adding new stressors to already vulnerable oyster populations by affecting their behavior and survival. These changes are challenges for both wild and farmed oyster populations, and the long-term sustainability of this aquaculture industry.

Methodology

In 2023 and 2024, researchers developed a series of oyster biosensor prototypes (**Fig. 1**) to monitor oyster health in both lab and field settings. In the lab, the system was tested by exposing oysters to invasive European green crabs (**Fig. 2**) to observe gaping behavior—the degree to which oysters open—after a week-long habituation period. The research assessed the impacts of environmental stressors such as high temperatures, low dissolved oxygen and extreme pH levels on oyster behavior, growth and survival. This provided an opportunity to understand oysters' complex responsiveness to multiple stressors in real time.

For field deployments, biosensors were placed at oyster farms in Little Bay, New Hampshire. The sensors measured oyster health continuously, linking behavioral responses—like changes in gaping behavior—to environmental variables such as temperature fluctuations and water quality.

Discussion of Findings

The research findings highlight the complex interactions between oyster behaviors and both environmental stressors and invasive predators. In lab-based research, oysters exposed to predator cues from European green crabs showed increased gaping behavior, particularly during nighttime (**Fig. 3**). This change in behavior may initially seem beneficial, allowing for more feeding and respiration, but it also leaves oysters vulnerable to poor water quality or additional stressors. Additionally, oysters subjected to high temperatures, low dissolved oxygen and extreme pH levels in the lab demonstrated changes in gaping behavior linked to their overall health.

In field deployments, oysters stopped filtering and feeding after stressful events, such as heavy rain, suggesting that both predator presence and environmental conditions play a role in oyster behavior and, ultimately, their health.

Figure 1. Oyster biosensor prototypes being tested.

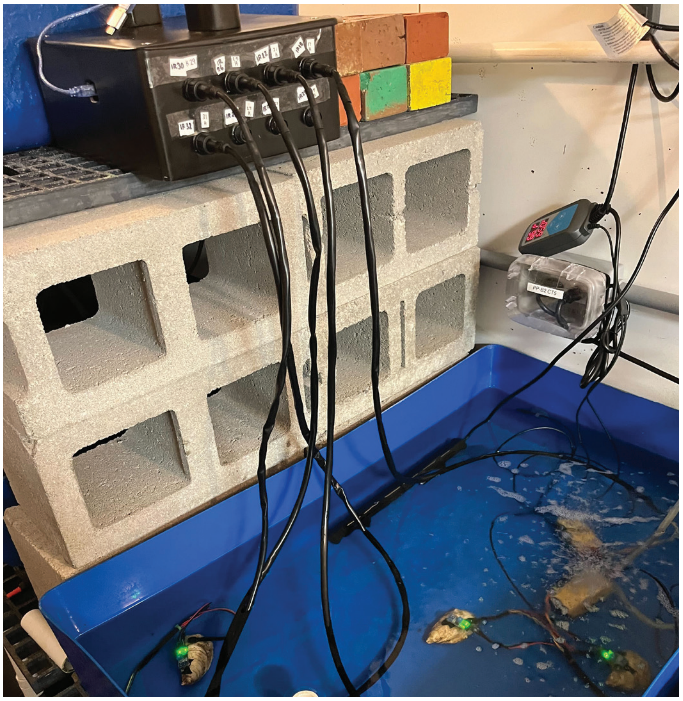


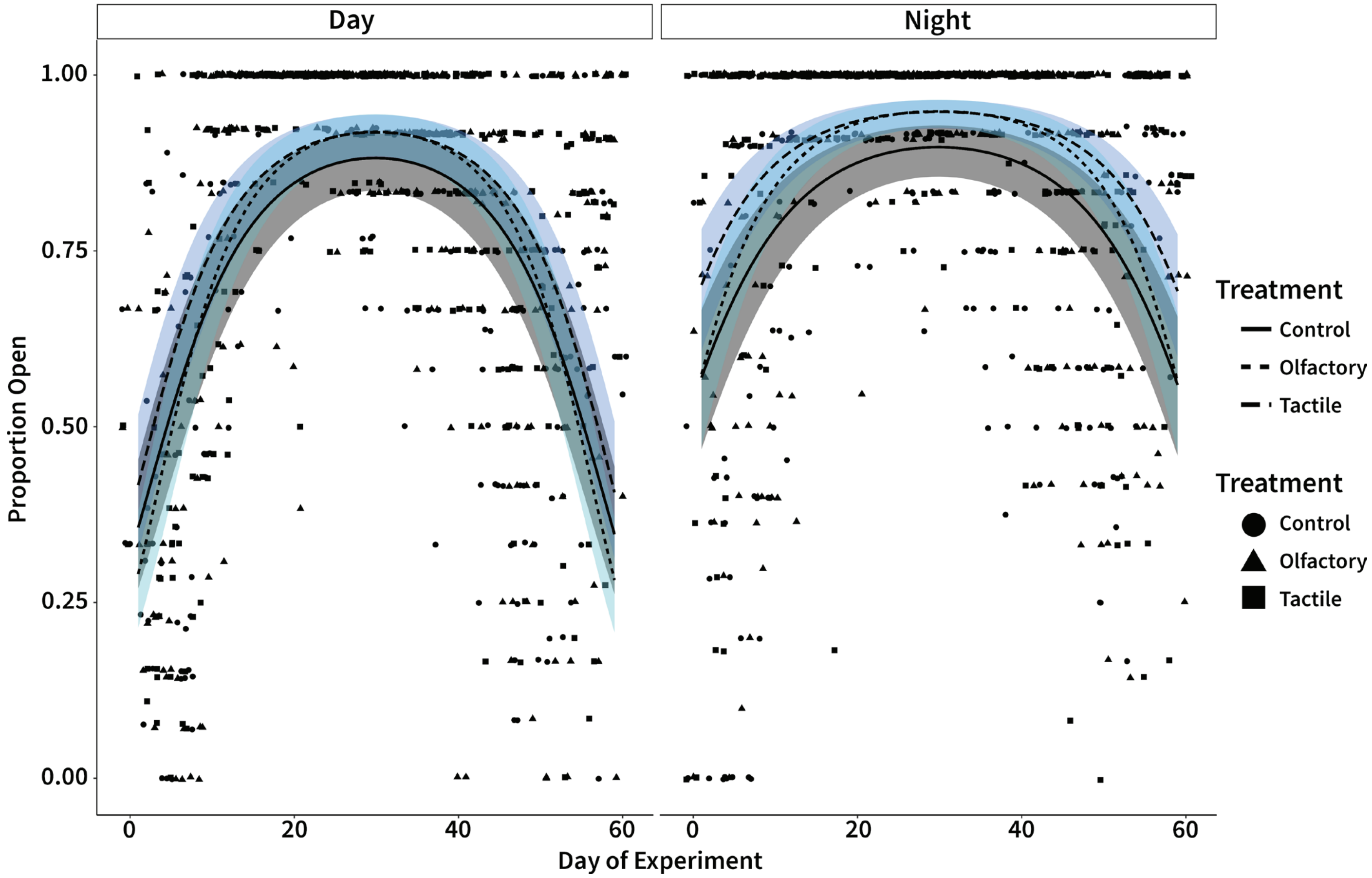
Figure 2. Oyster gaping tested by exposing oyster to invasive European green crab.

Strategic Recommendations and Conclusion

The findings indicate that oyster behavior can be impacted by a combination of environmental stressors and predatory cues poses significant challenges to oyster survival, particularly in the Gulf of Maine, where green crab populations are increasing. The research shows that oyster responses are dynamic and influenced by a combination of real-time environmental variables, highlighting the need for continuous monitoring to understand the long-term impacts on both wild and farmed oysters. Oyster farmers and coastal managers should consider the additive effects of predator cues and environmental stressors when developing strategies to protect oyster populations, both wild and farmed, in New Hampshire and beyond.

The deployment of biosensors in Little Bay is a crucial step toward achieving real-time insights into oyster behavior and environmental conditions. Over the next two years, more biosensors will be deployed to further study these dynamics and their implications for both oyster health and water quality management. Additional data will enable researchers and producers to be better equipped to predict oyster responses to extreme events, such as heatwaves or predator influxes, and implement proactive measures to safeguard the ecological and economic value of oysters. Expanding monitorings system across more oyster farms could help better prepare and mitigate the risks posed by environmental and predatory stressors, ensuring the resilience of oyster populations in the face of ongoing environmental change.

Figure 3. Percentage of time spent gaping for all three treatments for daytime and nighttime. For treatment types, olfactory refers to a crab and oyster in same container but physically separated, whereas tactile refers to a crab and oyster in the same container with crab being able to physically interact with an oyster but not consume it.



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ASSESSING MICROPLASTIC POLLUTION IN NEW ENGLAND'S ESTUARIES

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Microplastics, tiny plastic particles less than 5mm in size, are pervasive pollutants that pose significant risks to aquatic ecosystems and human health. However, there is no quantified baseline of microplastics presence in three key New England estuaries: Great Bay Estuary, Hampton-Seabrook Estuary and Great Marsh Estuary. Developing a quantified benchmark is an important first step to any future monitoring efforts to inform emerging policies to manage microplastics levels in New England waterways. This benchmark is critical to determining whether mitigation strategies can be effective.

Background and Key Concepts

Microplastics are plastic fragments smaller than 5mm that persist in the environment, affecting both freshwater and saltwater habitats. These tiny particles originate from the degradation of larger plastic items and can come from various sources, including industrial processes, wastewater and urban runoff.

KEY TAKEAWAYS

Microplastics (MP) are present in over 98% of samples from New England estuaries: Great Bay, Hampton-Seabrook and Great Marsh.

Hampton-Seabrook Estuary exhibited significantly higher MP concentrations in surface waters and marsh sediment.

Seasonal variations show MP levels peaking in summer. Various types were identified, along with rubber and other biogenic materials like chitin, cellulose, aragonite and calcite.

Estuaries, which are transitional areas between rivers and oceans, play a crucial role in filtering pollutants and providing habitat for a diverse array of species. They support vital economic activities, such as fishing and aquaculture, making the study of microplastic pollution in these areas essential for environmental and public health.

Previous studies have shown that microplastics can accumulate in marine sediments and salt marsh peat, where they pose risks to aquatic organisms and potentially humans through the food chain. These particles can block digestive tracts, alter feeding and reproductive behaviors, and transport harmful chemicals and microorganisms. However, there are limited data on the presence and impact of microplastics in New England's estuarine systems. This study aimed to fill that gap by providing a comprehensive baseline assessment of microplastic levels in three estuaries: Great Bay Estuary (GBE), Hampton-Seabrook Estuary (HSE), and Great Marsh Estuary (GME). Understanding the distribution and types of microplastics in these regions is crucial for developing effective mitigation strategies and protecting both ecosystems and human health.

Methodology

Water samples were collected at each site (**Fig. 1**) using a combination of plankton nets, manta trawls and discrete grab samples (**Table 1**). In GBE, samples from the water column were obtained through horizontal tows using a 64 µm mesh net, while in HSE and GME surface water samples were collected with a 330 µm mesh manta trawl. Additional bulk water samples were taken in HSE using 1L glass jars. Sediment cores from high and low marsh areas in HSE were collected using a piston coring device, which provided samples representing approximately 35–40 years of sediment accretion.

Samples were analyzed for microplastic content using both confocal microscopy and laser direct infrared spectrometry (LDIR) (**Fig. 2**). For water samples, the preserved material was filtered, digested to remove organic matter and stained with Nile Red for fluorescence analysis. Representative samples were then subjected to LDIR to identify and quantify the types of microplastics present.

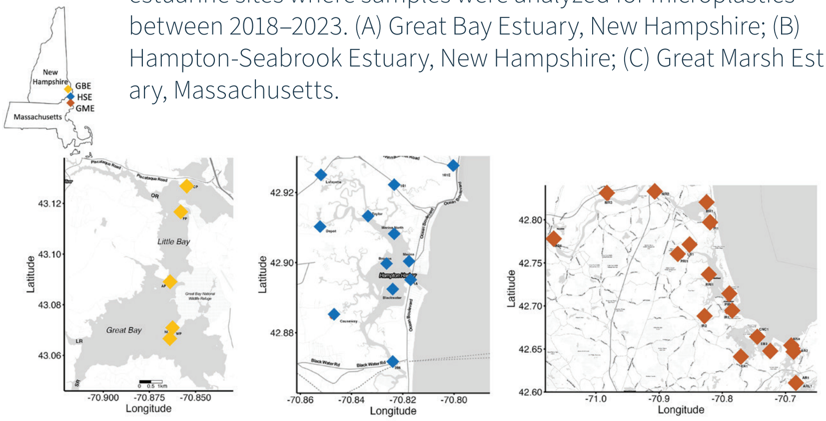


Figure 1. Map of New England (top left) and individual maps of estuarine sites where samples were analyzed for microplastics between 2018–2023. (A) Great Bay Estuary, New Hampshire; (B) Hampton-Seabrook Estuary, New Hampshire; (C) Great Marsh Estuary, Massachusetts.

Sediment samples underwent a similar process, including sieving, density separation and visual assessment under a microscope. Field blanks and replicates were integrated into the sampling plan to ensure accuracy and to minimize contamination. Statistical analyses, including the Shapiro-Wilk normality test and Kruskal-Wallis test, were performed to assess the variability

Table 1. Details of samples from three New England estuaries that were investigated for microplastic content.

Sampling Location	*Sampling Sites*	*Number of Samples*	*Sampling Period*	*Collection Method*	*Flow rate (m-s-1)*	*Filter Size cutoff*
GBE water (Column)	7	179	Feb–Nov 2018–2022	Subsurface trawl	0.5–1.0	5 µm–5 mm
HSE water (Surface)	12	72	Jul–Sep 2021	Bulk	N/A	5 µm–5 mm
HSE water (Surface)	12	72	Jul–Sep 2021	Manta trawl	0.2 ± 0.01 (0.003-0.6)	5 µm–5 mm
HSE intertidal sediment	9	18	Jul 2021	4 cm x 10 cm cores	N/A	1 µm–5 mm
GME water (Surface)	17	18	May–Nov 2021–2023	Manta trawl	0.5 ± -0.04 (0.2-1.3)	5 µm–5 mm

and significance of microplastic concentrations across different sites and years.

Discussion of Findings

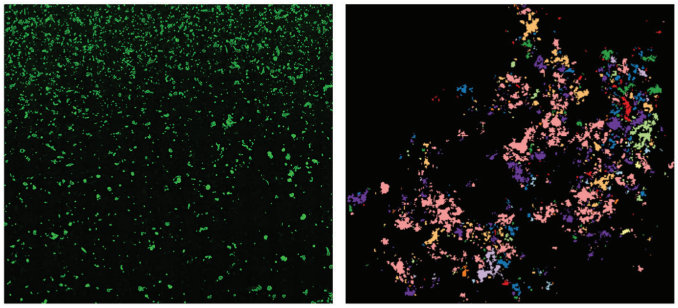
Microplastics were found in over 98% of the samples collected from the three estuaries, with concentrations varying significantly by region, site and season. The HSE exhibited the highest levels of microplastic pollution (**Fig. 3**), likely due to its rapid water flushing compared to the other estuaries. Seasonal trends were noted, with microplastic concentrations peaking during the summer months. There was also a wide range of microplastics, including various polymers and biogenic materials such as chitin, rubber and coal. This diversity highlights the complex nature of microplastic pollution and its potential sources.

Estuarine marshes play a critical role in collecting microplastics. These marshes act as natural filters, trapping microplastics within their dense vegetation and sediment layers. This trapping mechanism helps reduce the movement of microplastics further into the aquatic system. In the HSE, higher microplastic concentrations were found in marsh sediments compared to water samples, emphasizing the marshes' role in capturing these particles. Understanding how estuarine marshes interact with microplastics can inform the development of conservation strategies aimed at enhancing their natural filtering capacities.

Strategic Recommendations and Conclusion

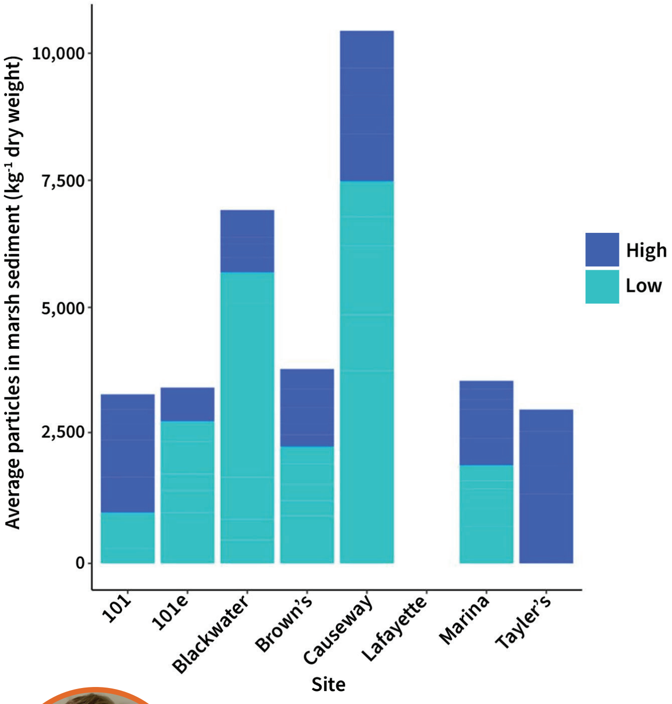
To address microplastic pollution effectively, targeted cleanup and prevention strategies should focus on high-risk areas, such as the HSE, which exhibited the highest concentration of microplastics. Using the baseline data from this study, policymakers and industry leaders in waste management, water treatment, aquaculture and fishing can implement practices to minimize contamination. Additionally, enhancing the natural filtering capacities of estuarine marshes by protecting and restoring these habitats could significantly reduce the movement of microplastics further into the aquatic system.

Figure 2. Confocal (left) and Laser Direct Infrared (LDIR) comparison images showing microplastics.



Future research should prioritize understanding the long-term impacts of microplastics on estuarine ecosystems and human health. Developing improved hydrodynamic models to predict microplastic distribution and identifying sources will be crucial. Engaging in continuous monitoring and integrating findings into policy frameworks will help mitigate the risks posed by these pollutants. Protecting estuarine environments through informed strategies ensures the sustainability and health of these critical ecosystems and the industries they support.

Figure 3. Microplastics found at eight locations in coastal marsh sediments of Hampton-Seabrook Estuary, each subsampled at high and low marsh elevations.



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OYSTERS AS ENVIRONMENTAL STEWARDS: NUTRIENT MITIGATION IN COASTAL WATERS

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Eutrophication—excess nutrients like nitrogen (N) and carbon (C)—in coastal waters remains a critical global issue, which can lead to harmful algal blooms and degraded water quality. Traditional nutrient management has focused on reducing land-based sources, such as agricultural runoff and wastewater discharge, but recent research highlights the potential for farmed bivalve shellfish such as oysters to help mitigation efforts. New Hampshire's Great Bay provides a useful ecosystem in which this potential can be tested and assessed because of the location's resurging aquaculture industry, the continued efforts and issues associated with nutrient-rich runoff from rivers and the diverse ecosystem that the estuary provides to the region.

KEY TAKEAWAYS

Farmed oysters could play an important role in removing nitrogen (N) and carbon (C) from aquatic environments, contributing to water quality improvement and local food markets.

Local environmental conditions including chlorophyll-a concentrations and strong tidal currents support faster oyster growth.

Ambient nutrient levels, oyster size and seasonal changes, significantly impact the N and C content in oyster tissues and shells.

Background and Key Concepts

Eutrophication is the process by which water bodies become enriched with excess nutrients, leading to excessive algal growth and degraded water quality. This overgrowth of algae results in harmful algal blooms, which can produce toxins detrimental to aquatic life and human health. Additionally, it leads to oxygen depletion as decomposing algae consume oxygen, creating “dead zones” where most marine life cannot survive. The loss of biodiversity follows, disrupting the balance of aquatic and surrounding ecosystems.

Nutrient bioextraction is the process of biological removal of excess nutrients from the ecosystem. Nutrient assimilation is the process by which organisms incorporate these nutrients into their biomass, effectively sequestering them.

Bivalve shellfish aquaculture could play a crucial role in estuarine nutrient management. Studies have shown that suspension-feeding bivalves, like Eastern oysters (*Crassostrea virginica*), can effectively filter out and assimilate nutrients from the water, thus helping mitigate eutrophication. As such, oyster farming could provide dual benefits: increase regional food production and help reduce nutrient levels, improving water quality and enhance estuarine ecosystem help.

This study assessed how the growing oyster farming industry in the New Hampshire’s Great Bay could aid nutrient management in this key estuary.

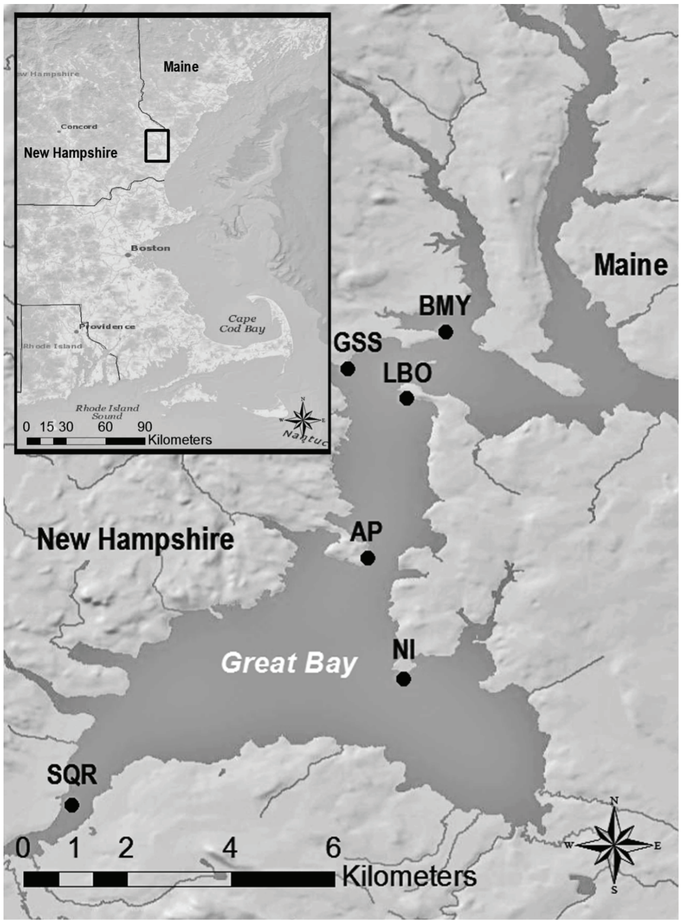
Methodology

The six sites (**Fig. 1**) chosen for this study included two oyster farms and four locations near river mouths with varying environmental conditions. Hatchery-reared oysters were deployed in polyethylene bags and monitored over a 2-year period. Measurements were taken multiple times, and measured variables included shell height, wet weight, dry weight and nutrient content (N and C) in both the soft tissue and shells.

Elemental analysis was performed using standardized laboratory procedures to determine nutrient concentrations. Data analysis involved comparing growth rates and nutrient content across sites and seasons to assess environmental impacts on oyster performance. Statistical analyses, including ANOVAs and regression models, were used to interpret the data.

Discussion of Findings

Figure 1. Six sites where oysters were deployed, 2010–2012. Sites include Bellamy River mouth (BMY); Granite State Shellfish (GSS); Little Bay Oyster Company (LBO); Adams Point (AP); Nannie Island (NI); and Squamscott Rivers (SQR).



The study revealed significant variability in the growth rates and nutrient content of eastern oysters across the six sites. Oysters at sites with higher ambient nitrogen levels, such as those near river mouths with elevated dissolved inorganic nitrogen, exhibited increased nitrogen content in both their soft tissue and shells (**Fig. 2**). This suggests that oysters in nutrient-rich environments can more effectively assimilate and sequester nitrogen and carbon.

Growth rates differed notably among sites, indicating that environmental conditions play a crucial role. Locations with higher chlorophyll-a concentrations and stronger tidal currents supported faster oyster growth. For example, oysters at Nannie Island showed the highest growth rates, while those at Granite State Shellfish had the slowest.

Seasonal variations also impacted nutrient content, with oysters generally exhibiting higher nitrogen levels in the fall compared to the spring. This seasonal fluctuation aligns with changes in the oysters’ physiological states and environmental nutrient availability, highlighting the complex interplay between biological and environmental factors in nutrient assimilation.

Strategic Recommendations and Conclusion

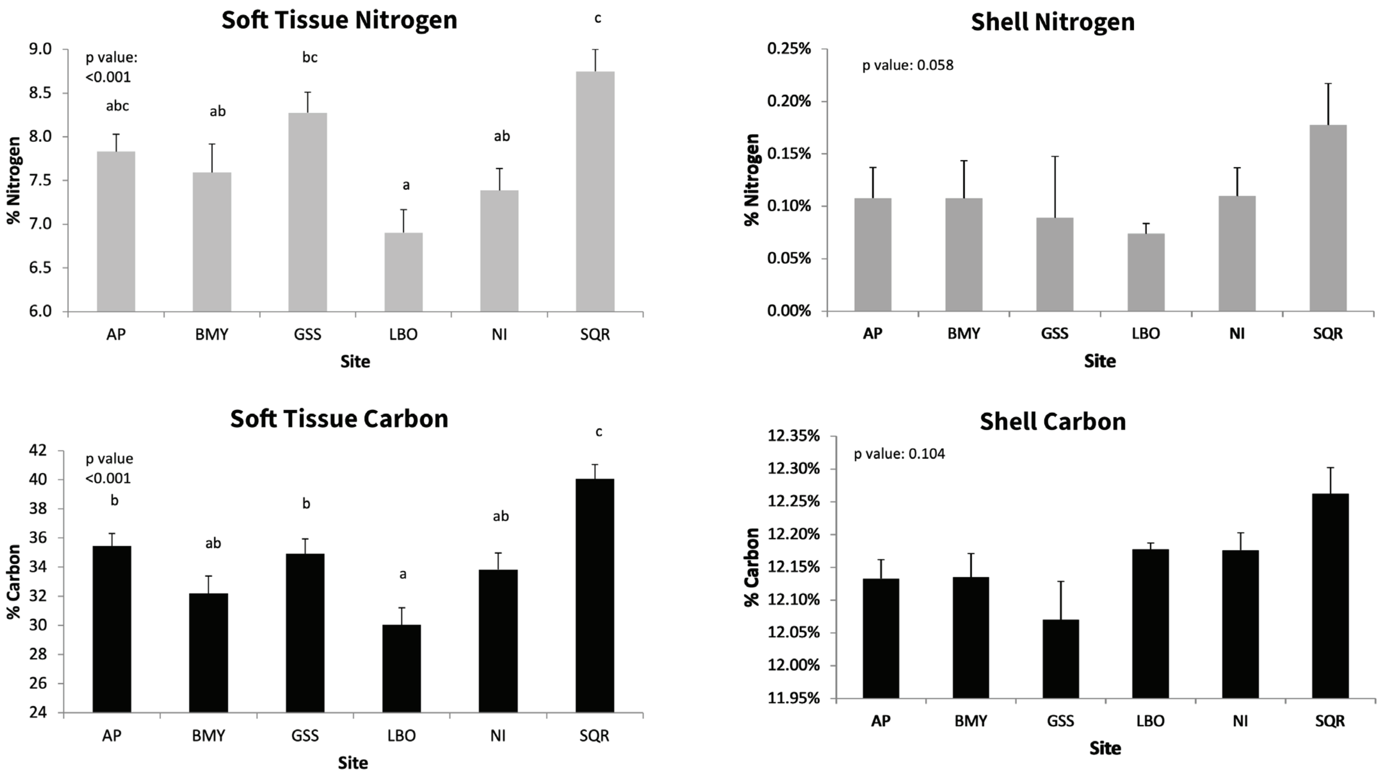
Oyster farming presents a valuable strategy for nutrient management in estuarine ecosystems, particularly in mitigating coastal eutrophication. To maximize the bioextraction benefits, however, it is crucial to consider site-specific environmental conditions, such as ambient nutrient levels, tidal currents and chlorophyll-a concentrations. Strategic placement of oyster farms in nutrient-rich areas can enhance nitrogen and carbon removal efficiency.

Additionally, adjusting farming practices to account for seasonal variations can optimize nutrient assimilation.

Regional planning efforts that integrate these findins can simultaneously enhance ecological and economic sustainability of oyster farming and the environment.

Policies that recognize shellfish farming’s contribution to environmental sustainability are likely to more accurately account for the benefits in the trade-off calculation of enabling greater access to shellfish farming sites. Future research should explore the impact of diverse farming methods and further investigate the dynamics of nutrient content across various environmental contexts to fully harness the ecological potential of oyster farming.

Figure 2. Soft tissue (left) and shell (right) %N and %C by site using combined data from all years and seasons. *P*-values shown are for an ANOVA testing the effect of site. Letters indicate significans among means. Sites include Adams Point (AP); Bellamy River mouth (BMY); Granite State Shellfish (GSS); Little Bay Oyster Company (LBO); Nannie Island (NI); and Squamscott Rivers (SQR).



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THE HUMAN DIMENSIONS OF AQUACULTURE

N. LORD AND E. R. WHITE

The diversity of industries and sectors within the seafood economy presents a challenge for understanding the demographics of those that work in the sector. Current approaches to characterizing the sector's demographics use coarse estimates of the number of workers and average wages. Even in New Hampshire's fastest growing seafood sector—oyster aquaculture—there are no demographic estimates across its supply chain. As the aquaculture industry in New Hampshire continues to expand, understanding the demographics of those involved is key to developing policies and best practices that ensure an equitable and just seafood system as well as for understanding industry barriers and opportunities to enable the industry to maximize its economic and ecosystem benefits for the state and region.

KEY TAKEAWAYS

Demographic data are key for ensuring social and economic sustainability in New England's aquaculture sector.

The existence of gender inequity in the aquculture sector is perceived differently by current aquaculture producers, with nearly 50% of women and nonbinary respondents reporting gender discrimination.

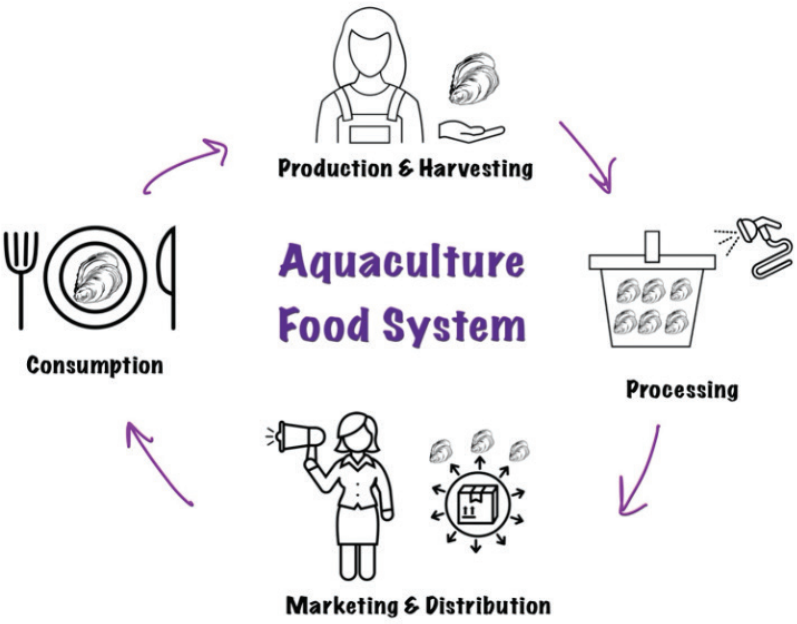
Women oyster farmers participate in the full production and marketing cycle as a means to avoid or minimize gendered outcomes.

Background and Key Concepts

Opportunity exists for new policies and industry best practices to ensure social equity within the seafood sector. New Hampshire's and the Northeast's seafood industry are growing and reaching a pivotal point for development, yet minimal research and decision-making has incorporated all dimensions of sustainability (ecological, social and economic), instead focusing primarily on ecological factors to enhance production and increase market value.

Investigating aquaculture development through a social lens provides an opportunity to understand how wild capture fisheries and aquaculture can sustainably co-exist in the Gulf of Maine, as there is a need for both to address growing seafood demand. There is a growing body of social science research on the domestic seafood sector covering topics such as perceptions of aquaculture, livelihood diversification and gender equity. However, research has lacked an intersectional approach due to deficiencies in demographic variables such as gender, race/ethnicity and income as a baseline of information.

Figure 1. Researchers found that participants in this study engaged in all sectors of the food system as oyster farm owners.



Methodology

New England supports the largest network of women aquaculturists in the country. As such, data collection focused on identifying the role of gender for the oyster aquaculture workforce in Maine and New Hampshire could help fill the demographic information gap and highlight unique challenges of women and nonbinary farmers. These data could help identify barriers to entry for underrepresented groups aspiring to enter the aquaculture workforce.

The research used a participatory methodology called photovoice, which incorporates visual storytelling with interviews, a focus group and a community photo exhibit. The case studies provided deeper insight into the potential sources of gender discrimination amongst participants.

Discussion of Findings

The research findings helped establish baseline demographic data and determine how gender influences participation in aquaculture. In contrast to other seafood systems, women oyster farmers engage in all parts of that product's food system as a means to avoid gendered outcomes (**Fig. 1**).

Approximately half (46%) of the women and nonbinary survey respondents have experienced differential treatment while working on an oyster farm (**Fig. 2**). These results indicate that women and nonbinary participants likely have additional barriers for launching and operating oyster aquaculture farms than their male counterparts. Barriers include access to funding, relevant training programs, appropriate farm gear and equipment and overcoming gender norms of the maritime industry.

Strategic Recommendations and Conclusion

These findings help inform efforts to overcome gender-based barriers. For example, women-led social networks may be needed to overcome gender-based barriers that exist in aquaculture systems, which may historically lack support due to gender-blind policies and programming. Such efforts have been previously successful—in summer 2024, a women and non-binary-targeted aquaculture training program was developed by Maine Sea Grant and an industry-led women and gender nonconforming networking group of the Maine Aquaculture Innovation Center.

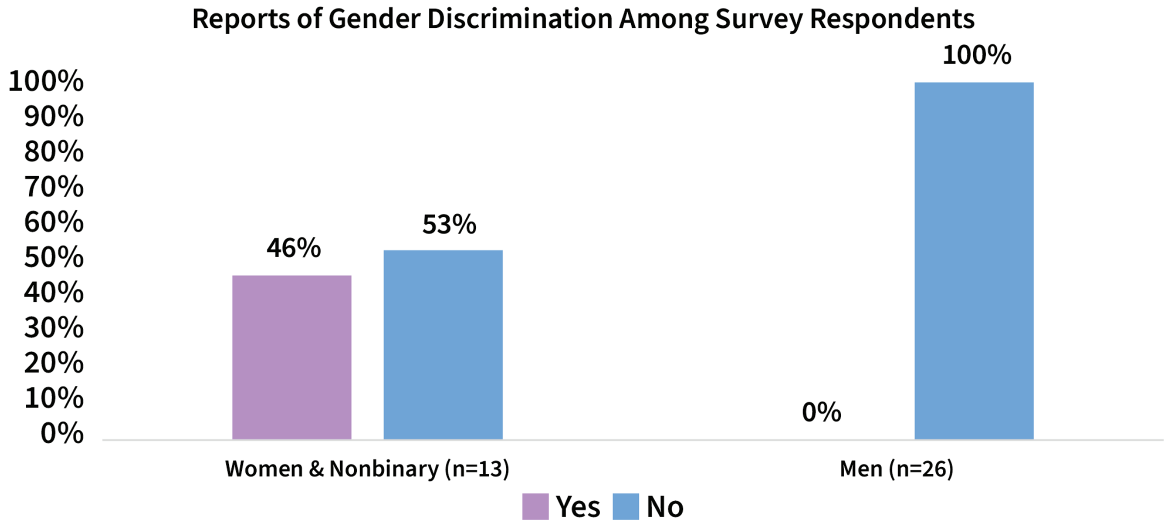
The gap in baseline demographic data identified by this research in New England's seafood sector also provides information that can be leveraged by federal and state agencies, many of which are putting an emphasis on programs, policies and rulesetting that increases equity and environmental justice. To further strengthen the evidence-based needs assessments, collection of demographic information alongside commercial fisheries and aquaculture permits is an achievable first step.

Beyond new training and network opportunities, other recommendations include alternative funding mechanisms such as microloans for aquaculture entrepreneurship and reduced licensing fees for socially disadvantaged and underserved groups to remove barriers to entry into the aquaculture workforce.

Future research could help expand demographic characterization of the aquaculture workforce in New England to include commercial fisheries and the recreational fishing sector, helping identify barriers to participation and reflect the diversity of the broader seafood workforce in the region. Insights from these data could help information workforce development programs that lower barriers to entry for those seeking employment in the seafood sector.

When combined with knowledge from research that assesses challenges across different New England communities to access and consume local seafood products, the findings could help steer businesses and policies to promote sustainable working conditions, compensation and access to resources that might be different for diverse demographic groups, as well as strengthening the resiliency of regional food systems.

Figure 2. Survey respondents reporting differential treatment at work in the oyster aquaculture industry in ME and NH by gender. Women and non-binary identifying (n=13), men identifying (n=26). Relationship between gender and differential treatment is statistically significant (p<0.001).



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OYSTER FARM GEAR CAN ENHANCE SEAWEED BIODIVERSITY IN GREAT BAY ESTUARY

M. GLENN, A. MATHIESON, R. E. GRIZZLE AND D. BURDICK

Oyster farming has rapidly grown in New Hampshire's Great Bay Estuary. In addition to strengthening the regional food system, shellfish aquaculture can provide other ecological benefits by increasing seaweed biodiversity and habitat services to the broader ecosystem. However, there's been uncertainty about the extent to which gear for farmed oyster operations may aid to or detract from seaweed biodiversity, especially in comparing them to three natural subtidal habitats—an oyster reef, eelgrass bed and mudflat.

KEY TAKEAWAYS

In New Hampshire's Great Bay, oyster farm gear and eelgrass beds supported the greatest number of seaweed species.

Seaweed biomass was also greater on oyster farm gear than in natural habitats, particularly mudflats, demonstrating the gear's capacity to support dense seaweed growth.

Non-native seaweeds dominate the biomass on oyster farm gear and mudflats, comprising over 80% of the total biomass.

Background and Key Concepts

Oyster aquaculture has seen rapid growth in the Great Bay Estuary (GBE), with production increasing significantly over the past decade. In 2013, New Hampshire oyster farmers harvested 81,274 oysters, which grew to 821,157 oysters by 2022, reflecting a more than 1,000% increase in the industry's since 2013. This expansion necessitates a deeper understanding of the ecological impacts of oyster farming, particularly the role of farm gear in altering marine habitats. Previous studies have shown that oyster farm gear increases habitat complexity, supporting diverse marine communities and promoting biodiversity, which is essential for the sustainable development of the industry.

Seaweed biodiversity is crucial for the health of estuarine ecosystems. Seaweeds provide food and habitat for numerous marine organisms, contribute to nutrient cycling and help stabilize sediments. Diverse seaweed communities support higher productivity and resilience, offering ecosystem services such as water purification, coastal protection and enhanced habitat for fish and invertebrates. Understanding the interactions between seaweed and oyster farm gear can inform better management practices and enhance the ecological benefits of aquaculture.

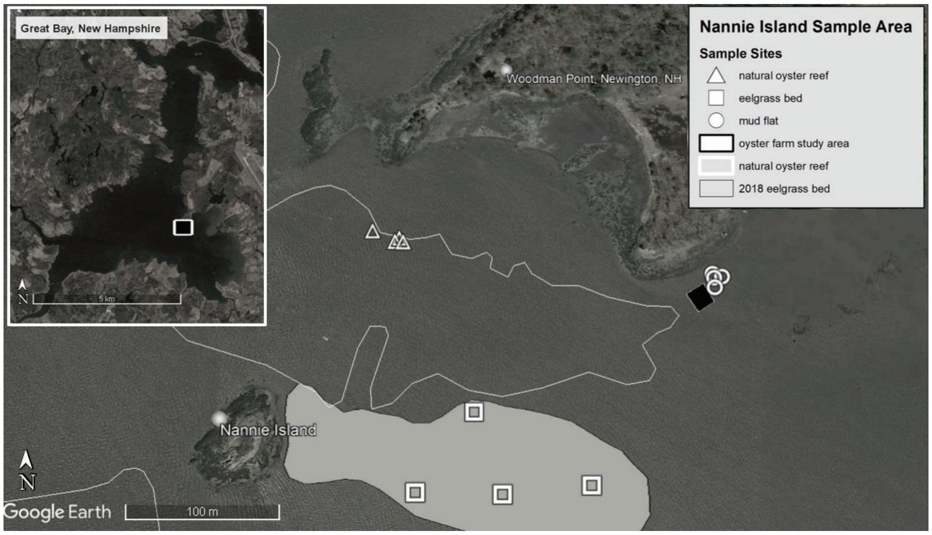
Methodology

The study was conducted in Great Bay Estuary, a mesohaline, macrotidal system in New Hampshire with a tidal range of approximately 2.7 meters. Four subtidal habitats (**Fig. 1**) were examined: oyster farm gear, an oyster reef, an eelgrass bed and a mudflat. To simulate the farm gear habitat, 12 replicate cubical oyster racks (**Fig. 2**) were deployed on a mudflat, each holding three bags containing approximately 190 oysters. The natural habitats were sampled using a custom-made device capturing a standard area of 0.25 m^2.

Sampling occurred in August and October 2014, and in August 2015. Four replicates were taken per habitat on each sampling occasion, totaling 12 replicates per habitat. Collected seaweeds were sorted, identified and weighed in the laboratory. Statistical analyses, including ANOVAs and multivariate analyses using PRIMER software, were conducted to compare species richness, biomass and community composition among the habitats. Data transformations were applied as necessary, with Tukey's HSD test used for post-hoc comparisons.

Figure 2. Oyster rack ("farm gear") used to hold oyster bags. Racks in this photo are empty, bags would be located on each of the three levels. Sampling device used to extract samples from all four study habitats.

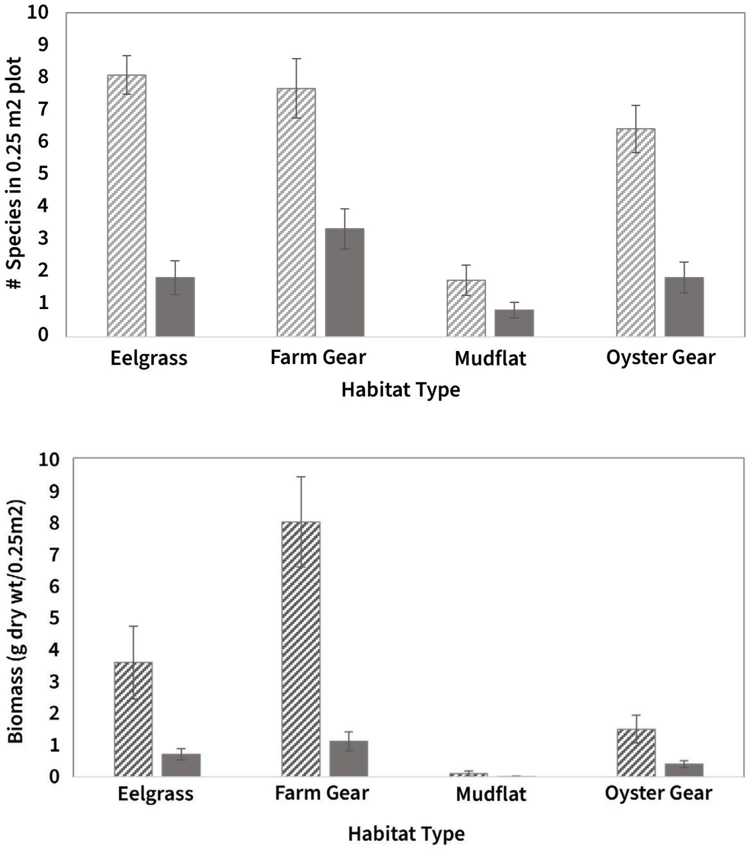
Figure 1. Study area in Great Bay, New Hampshire and locations of sample sites on natural oyster reef and in eelgrass bed.



Discussion of Findings

The study revealed significant differences in seaweed species richness and biomass across the four habitats. Eelgrass beds supported the highest species richness, with an average of 35 species, followed by oyster reefs with 28 species and oyster farm gear with 25 species. Mudflats exhibited the lowest species richness, averaging only 12 species (**Fig. 3**). This indicates that the structural complexity of oyster

Figure 3. Habitat means +/− SE of algae for species richness (top) and biomass (bottom) with all sampling dates averaged (N = 12). Red algae (hashed bars) and green algae (solid bars) are shown separately for each habitat but were analyzed together and both analyses showed significant differences among habitats.



farm gear provides a favorable environment for diverse seaweed communities.

Biomass comparisons showed a similar trend. Oyster farm gear had the highest biomass, significantly greater than that of eelgrass beds, oyster reefs and mudflats. This suggests that the vertical structure and hard surfaces of farm gear enhance seaweed growth, supporting dense algal communities. Mudflats had the lowest biomass, reflecting their less complex habitat structure.

The comparison of native and non-native species distribution revealed that non-native seaweeds dominated the biomass on oyster farm gear and mudflats, comprising over 80% of the total biomass in these habitats. Conversely, native species were more prevalent in eelgrass beds and oyster reefs. Notably, the non-native species *Agarophyton vermiculophyllum*, *Gracilaria tikvahiae*, and *Ulva lactuca* contributed to the high biomass on farm gear and mudflats.

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Strategic Recommendations and Conclusion

The study underscores the ecological benefits of oyster farm gear in supporting diverse seaweed communities, indicating its potential for enhancing biodiversity in the GBE. Regulatory policies and market structures that create benefits and incentives to incorporate habitat enhancement through informed oyster farming practices could promote biodiversity and ecosystem services that benefit the public good while supporting the industry's growth.

Recommendations for Enhancing Biodiversity through Aquaculture Practices:

Farm Gear Design: Use gear that maximizes habitat complexity to support diverse seaweed communities, including vertical structures and hard surfaces.

Monitoring Non-Native Species: Regularly monitor seaweed communities to manage non-native species effectively and mitigate potential negative impacts.

Integration with Restoration Projects: Integrate oyster farming with eelgrass and oyster reef restoration efforts to enhance overall ecosystem health.

Policy Considerations for Sustainable Oyster Farming:

Comprehensive Management Plans: Develop plans recognizing oyster farms' dual role in aquaculture and biodiversity enhancement.

Stakeholder Collaboration: Foster collaboration between farmers, researchers and regulatory agencies to implement best practices and address challenges.

FOR FURTHER READING & ACKNOWLEDGEMENTS

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