Shellfish Aquaculture Bibliography

July 2023

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Virginia Institute of Marine Science

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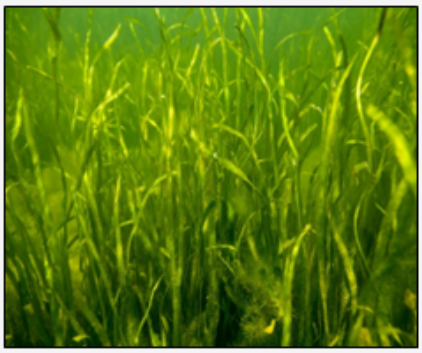
Aquaculture & Environment Interactions



Clam and oyster aquaculture involve direct interaction with the surrounding environment. Gear used in oyster aquaculture, specifically, provide structure that helps maintain important habitats, helps slow the rate of shoreline erosion, and provides substrate for many species to adhere to and seek refuge in, increasing biodiversity both within and surrounding an aquaculture operation. However, there is a growing need to better understand the ecological impacts of aquaculture to the surrounding ecosystem to help minimize or avoid potential negative effects as the industry expands.

Habitat

Overton, K., Dempster, T., Swearer, S. E., Morris, R. L., & Barrett, L. T. 2023. ***Achieving conservation and restoration outcomes through ecologically beneficial aquaculture***. In *Conservation Biology*. John Wiley and Sons Inc. https://doi.org/10.1111/cobi.14065

Melbourne researchers performed a metanalysis of the literature related to aquaculture activities and identified 12 potential ecological benefits of aquaculture: species recovery, habitat restoration, habitat rehabilitation, habitat protection, bioremediation, assisted evolution, climate change mitigation, wild harvest replacement, coastal defense, removal of overabundant species, biological control, and ex situ conservation.

Theuerkauf, S. J., Barrett, L. T., Alleway, H. K., Costa-Pierce, B. A., st. Gelais, A., & Jones, R. C. 2022. ***Habitat value of bivalve shellfish and seaweed aquaculture for fish and invertebrates: Pathways, synthesis and next steps.*** In *Reviews in Aquaculture* (Vol. 14, Issue 1, pp. 54–72). John Wiley and Sons Inc. https://doi.org/10.1111/raq.12584

- Bivalve aquaculture was associated with higher abundance and species richness of wild, mobile macrofauna.
- Suspended or elevated mussel and oyster culture yielded the largest increases in wild macrofaunal abundance and species richness.

- Bivalve and seaweed aquaculture may positively influence the structure and function of faunal communities by provision of structured habitat, provision of food resources and enhanced reproduction and recruitment.

Schatte Olivier, A., Jones, L., Vay, L. le, Christie, M., Wilson, J., & Malham, S. K. 2020. ***A global review of the ecosystem services provided by bivalve aquaculture.*** *Reviews in Aquaculture*, *12*(1), 3–25. https://doi.org/10.1111/raq.12301

This study collates the evidence available on the provisioning, regulating and cultural ecosystem services provided by the bivalve species commonly used in aquaculture.

- Goods from provisioning services include meat, worth an estimated $23.9 billion as well as, pearls, shell and poultry grit, with oyster shell being the most important, with a global potential worth of $5.2 billion.
- The most important regulating services are nutrient remediation.
- Cultivated bivalves remove 49,000 tonnes of nitrogen and 6,000 tonnes of phosphorus, worth a potential $1.20 billion.
- Our assessment indicates that the global, non-food bivalve aquaculture services are worth $6.47 billion ($2.95 billion–9.99 billion) per annum, representing 27% of the current value for bivalve meat.

Testa, J., Brady, D., Cornwell, J., Owens, M., Sanford, L., Newell, C., Suttles, S., & Newell, R. 2015. ***Modeling the impact of floating oyster (Crassostrea virginica) aquaculture on sediment-water nutrient and oxygen fluxes.*** *Aquaculture Environment Interactions*, *7*(3), 205–222. https://doi.org/10.3354/aei00151

- No additional nutrient input is required in the system because the oysters feed off suspended particles, plankton, and nutrients already found in the water body.
- Bio-deposits from oyster aquaculture tend to be concentrated on the farm and do not settle in the surrounding areas. The deposits, depending on the tidal and wave action in the area, can be dispersed without negative effects to the surrounding environment.

Seagrass Interactions

Lazar, J., Vogel, R.L., Bruce, D.G., McGowan, A. 2022. ***Using satellite-derived total suspended matter data to evaluate the impacts of tributary-scale oyster restoration on water clarity.*** NOAA Technical Memorandum NMFS-OHC-10.

- Total suspended matter is linked to location and year.

- Results found a simultaneous increase in oyster biomass and SAV, indicating that one has an effect on the other.

Mann, R., Berman, M., Wesson, J., Southworth, M., Rudnicky, T. 2021. ***Assessment of aquaculture conflicts and SAV (submerged aquatic vegetation)***. *In patrial fulfillment of the project: expanding Virginia's oyster industry while minimizing user conflict.* https://cmap22.vims.edu/OysterProject/Reports/Card7_Assessment_of_Aquaculture_Conflicts_and_SAV_2Mar2021.pdf

- Cages were placed on a location with little to no SAV present. Over the season, density and coverage of SAV increased within and around cages.
- There did not appear to be impacts from intensive aquaculture activity on SAV presence as currently practiced in the Chesapeake Bay.
- "Results of the analysis support the assumption that SAV and intensive aquaculture can and in fact have been co-existing."

Munkacsy, M. 2022. ***Values in shallow water systems in Maryland's Chesapeake Bay.*** *Masters Thesis.* https://doi.org/10.13016/x03y-pqnp

"Being proactively restrictive on aquaculture for the sake of protecting SAV actually seemed to do little for SAVE and caused lots of damage for aquaculture operations."

Fales, R.J., Boardman, F.C., Ruesink, J.L. 2020. ***Reciprocal interactions between bivalve molluscs and seagrass: A review and meta-analysis***. Journal of Shellfish Research 39(3): 547-562.

A meta-analysis of field experiments testing bivalve response to seagrass (25 studies) and vice versa (11 studies), as well as surveys of bivalves in and out of seagrass (39 studies) showed:

- In experiments, seagrass improved bivalve survival and bivalves, at high cover, reduced seagrass density, but seven other response metrics showed no change.
- In surveys, bivalve densities were 1.6 times higher in seagrass than out of seagrass.
- Colocation of seagrass and bivalves reflect weak effects in some studies, but generalizations cannot be made due to inconsistencies.
- Coexistence is enabled by weak or positive interactions.

Ferriss, B.E., Conway-Cranos, C., Sanderson, B.L., Hoberecht, L. 2019. ***Bivalve aquaculture and eelgrass: A global meta-analysis.*** Aquaculture 498:254-262.

A literature review of 125 studies determined:

- On-bottom culture (laying directly on the sediment potentially including predator exclusion devices) corresponded to significant increases in eelgrass growth and reproduction, and a decrease in density and biomass.
- Off-bottom culture (e.g., longline and suspended bag) resulted in significant decreases in eelgrass density, percent cover, and reproduction.
- Results support a space-competition hypothesis for on-bottom culture and provide limited support for light limitation in off-bottom culture, although other mechanisms of interaction are potentially occurring as well.
- A US west coast case study revealed regional differences in eelgrass responses, including a more negative trend in eelgrass density from off- bottom culture, and a neutral effect on reproduction from on bottom culture (relative to neutral and positive trend, respectively, in the average of all other studies).
- Eelgrass densities recovered after all harvest methods, however mechanical harvest methods created greater initial impact and longer recovery times than manual harvest methods.
- These analyses suggest the response of eelgrass to bivalve aquaculture varies depending on eelgrass characteristics, grow-out approaches, and harvesting methods, with potential regionally specific relationships.

Bulmer, R., Kelly, S., Jeffs, A. 2012. ***Hanging basket oyster farming: Assessing effects on seagrass using aerial photography.*** Aquaculture Environment Interactions, 2(3): 285-292.

- Hanging basket oyster aquaculture has little to no impact on surrounding seagrass bed (minimal shading to the grasses directly below the beds).
    - Less of an impact than traditional on-bottom beds (68% less shading)
    - Hanging baskets can be implemented in deeper water than other traditional methods, this would allow growers to move away from the contested waterfront of homeowners BUT would potentially interfere with boating or other recreational activities.

Dumbauld, B., McCoy, L. 2015. ***Effect of oyster aquaculture on seagrass Zostera marina at the estuarine landscape in Willapa Bay, Washington (USA).*** Aquaculture Environment Interactions, 7(1): 29.47.

- Aquaculture gear such as oyster long-lines have little to no effect on the abundance of seagrass and floating bags only shade the grass directly below them. The negative effect is judged to be no more harmful than periodic, pre-existing natural disturbances such as storms, which seagrass are adapted to.
- Shellfish such as oysters can positively influence seagrass growth through output of essential nutrients and improving water quality by filtering plankton and particulate matter.

Sandoval-Gil, J.M., Camacho-Ibar, et al. 2015. ***Dissolved inorganic nitrogen uptake kinetics and δ15N of Zostera marina L. (eelgrass) in coastal lagoon with oyster aquaculture and upwelling influence.*** Journal of Experimental Marine Biology and Ecology, 472: 1-13.

- Eelgrass around oyster aquaculture sites exploit inorganic outputs from the waste of the oysters.
- Seagrass is very important for the health of estuarine systems and this relationship between oyster aquaculture and grasses could help not only with excess nutrient removal, but also in improving water quality.

Nutrient Removal

Cornwell, J., et al. 2016. ***Panel recommendations on the oyster BMP nutrient and suspended sediment reduction effectiveness determination decision framework and nitrogen and phosphorus assimilation in oyster tissue reduction effectiveness for oyster aquaculture practices.*** https://oysterrecovery.org/wp-content/uploads/2017/01/Oyster-BMP-1st-Report_Final_Approved_2016-12-19.pdf

- Oysters reduce the concentration of nitrogen, phosphorous, and floating particulate matter in the water column leading to heightened water quality. Oyster aquaculture based on these environmental benefits is considered a "Best Management Practice"
- Hatchery produced oysters can be bred to display traits including accelerated growth and disease resistance that isn't necessarily found in wild organisms.
- On-bottom oyster aquaculture tends to promote and abundant community with few negative consequences in terms of nutrient overloading.
- Oyster filtration leading to better water clarity has the potential to promote seagrass growth through increased light penetration and therefore help to restore populations of organisms dependent on the grasses.

Dumbauld, B. R., Ruesink, J. L., & Rumrill, S. S. 2009. **The ecological role of bivalve shellfish aquaculture in the estuarine environment: A review with application to oyster and clam culture in West Coast (USA) estuaries.** *Aquaculture*, *290*(3–4), 196–223. https://doi.org/10.1016/j.aquaculture.2009.02.033

- Shellfish aquaculture transfers nutrients from the water column to benthic (bottom) sediments in bio-deposits, rapidly recycles nutrients by releasing dissolved inorganic nutrients into the overlying water, and removes a portion of those excess nutrients when shellfish are harvested.
- Improvement in water clarity in areas struggling with eutrophication; submerged vegetation benefit from water clarity.
- Removal of nitrogen via denitrification; along with burial of nitrogen and phosphorus.
- Can act as a functionally similar habitat to that of seagrass beds for estuarine organisms. Can show higher abundance of these organisms than unstructured bottom environment like mudflats and sand.
- Shellfish aquaculture is more sustainable than other anthropogenic impacts on estuarine environments such as pollution, coastal development, and diversion of freshwater which can degrade water quality and remove area from the estuary.
- Disturbances caused by shellfish aquaculture are generally no more harmful than naturally occurring disturbance such as storms and therefore the surrounding ecosystem is well-equipped to recover.

Other

Williamson, T.R., Tilley, D.R., Campbell, E. 2015. ***Energy analysis to evaluate the sustainability of two oyster aquaculture systems in the Chesapeake Bay*.** Ecological Engineering, 85: 103:120.

- Less strain on the environment than other types of aquaculture (ex. fin fish) and approximately 28% higher local renewable energy (uses energy supplied by the environment).
- “Oyster aquaculture has a lower global environmental impact, higher sustainability rating, and a higher net benefit to society than other forms of aquaculture.”

- Oyster aquaculture removes some pressure on decimated stocks of wild oysters.
- A million oysters of market size have the potential to remove approximately 3823 kg of carbon per year, 132 kg of nitrogen, and 19 kg of phosphorus.

Hilborn, R., Banobi, J., Hall, S.J., Pucylowski, T., Walsworth, T.E. 2018. ***The environmental cost of animal source foods.*** **In** ***Frontiers in Ecology and the Environment*** (Vol. 16, Issue 6, pp. 329–335). Wiley Blackwell. https://doi.org/10.1002/fee.1822

- Mollusk aquaculture and small pelagic and whitefish fisheries have the lowest impact on the environment due to their production methods (i.e. animals are not fed, production (outside the hatchery) does not require energy for water circulation)

Genetic Improvement

The Virginia oyster aquaculture industry prefers genetically improved triploid seed because they are viewed as more viable from a commercial standpoint (i.e. disease-resistant, fast growth, can be harvested year-round). The clam industry in Virginia is reaching a saturation point as available habitat is constrained by suitable water and sediment conditions. Thus, there is a continued need to develop high performing shellfish stocks that thrive in regional environments to ensure continued success and sustain Virginia's position as an aquaculture leader.

Matt, Joseph L., Guévélou, Eric, Small, Jessica Moss, Allen, Standish K (2020) ***A field test investigating the influence of brood stock origin and ploidy on the susceptibility of Crassostrea virginica to "triploid mortality" in the Chesapeake Bay***. Aquaculture 526:735375
https://doi.org/10.1016/j.aquaculture.2020.735375

- In 2016, a mortality event occurred in late spring at only one testing site and only affected the triploid crosses. There was no evidence of substantial disease pressure from *Haplosporidium nelsoni* or *Perkinsus marinus,* or of stressful environmental conditions based on temperature, salinity, pH, and dissolved oxygen.
- At 18 months, shell height was similar in the diploids and triploids with the most similar genetic origin. Triploids maintained meat weight through the summer, while meat weight in diploids dropped sharply. Triploids may be especially susceptible to late spring mortality events in the Chesapeake Bay.

Guévélou, Eric; Carnegie, Ryan; Moss, JA; Hudson, Karen; Reece, Kimberly S.; Rybovich, Molly M.; and Allen, Standish K. Jr. (2019) ***Tracking triploid mortalities of eastern oysters Crassostrea virginica in the Virginia portion of the Chesapeake Bay***. VIMS Articles. 1333. https://scholarworks.wm.edu/vimsarticles/1333

Mortality peaked among triploid oysters at most experimental sites in the Chesapeake Bay during June, with no evidence of the major oyster pathogens

causing Dermo and MSX disease. Harmful algal blooms, abnormal salinities, and high temperatures were not associated with the mortalities. There was variability in mortality between oyster lines and between oyster lines at specific sites, with no clear relationship of genetic heritage and mortality. At some locations, triploid oysters seemed to be more susceptible to mortality than diploids and mortality in triploids coincidence with the timing of peak gametogenic development in diploids.

Ritter, Kate (2019) ***Fecundity of triploid eastern oyster (Crassostrea virginica) as a function of tetraploid lineage***. *Dissertations, Theses, and Masters Projects*. Paper 1582642221. http://dx.doi.org/10.21220/m2-9tyh-qe83

Several lines of tetraploids were crossed with diploid oysters to generate multiple triploid lines. Fecundity was estimated for triploid females after field exposure for 2 years. Results suggest that the site location had more to do with fecundity and mortality than the type of triploid produced, and the fecundity trait is not likely problematic because it occurred in significantly healthier oysters. Therefore, it does not seem likely that ABC inadvertently selected for fecundity in their tetraploid oysters.

Ropp, Ann Janette (2020) ***Population Structure Of The Hard Clam, Mercenaria Mercenaria, Along The East Coast Of North America***. *Dissertations, Theses, and Masters Projects*. William & Mary. Paper 1616444311. http://dx.doi.org/10.25773/v5-wa9q-8c19

This study used genotyping-by-sequencing to delineate the genetic stock structure of wild clams sampled from 15 locations along the East Coast of North America (Prince Edward Island, Canada, to South Carolina, USA). Data provided evidence of five genetic breaks separating six genetically distinct populations: Canada, Maine, Massachusetts, Mid-Atlantic, Chesapeake Bay and the Carolinas. Data were used to identify a subset of SNP markers capable of geographic discrimination and population assignment with 75–93% accuracy, which will be helpful for future testing and allow for this technology to be economically-feasible for the industry.

Environmental Challenges

The Chesapeake Bay has been identified as a vulnerable region due to the emergence of multiple environmental stressors. In Virginia, the occurrence and frequency of HABs have increased over the past several years. The shellfish aquaculture industry is most concerned about the effect of HABs on larvae and small seed, but an emerging concern is the potential for human illness when toxins from HABs are concentrated in shellfish that are consumed. Ocean acidification poses another threat to shellfish aquaculture, as a more acidic ocean may impact the ability of shellfish to properly form and maintain their shells, grow, and ultimately survive. Heavy precipitation events are predicted with global climate change scenarios, which can result in eutrophication, dead zones, and decreased salinity levels in coastal areas. Success of the Virginia shellfish aquaculture industry relies, in part, to understanding how these cultured species react to these emerging environmental challenges.

Harmful effects of *Alexandrium monilatum* and a toxin it produces goniodomin A (GDA) on aquatic organisms were demonstrated by laboratory and field studies.

- GDA was detected in oysters that were deployed during *A. monilatum* blooms with the highest concentrations in those just after the bloom peak.
- Laboratory exposure studies also demonstrated the uptake and depuration of GDA in oysters even at exposure to very low concentrations of *A. monilatum* cells.
- Bioassays with *A. monilatum*, *Margalefidinium polykrikoides* and *Karlodinium veneficum* (VA and MD isolates) indicated that mortality was higher and more rapid with exposure to *A. monilatum* assays than to the other two HAB species.
- Histopathological analyses demonstrate that exposure causes tissue pathology, most notably gill erosion.
- Oyster field studies done in collaboration with aquaculturists in the York River region indicated that oyster mortality was generally slightly higher at the bloom impacted sites.
- Models indicated that growth rate was lower when there were bloom concentrations of *M. polykrikoides* or *A. monilatum*.

Most relevant publications from this work include:

Fortin, SG, Song, B, Anderson, IC, Reece, KS (2022). ***Blooms of the harmful algae Margalefidinium polykrikoides and Alexandrium monilatum alter the York River Estuary microbiome.*** *Harmful Algae 114(102216)* doi:10.1016/j.hal.2022.102216

Blooms of two HAB species, *Margalefidinium* (formerly *Cocholodinium*) *polykrikoides* (Marge) and *Alexandrium monilatum* (Alex), impacted the estuarine microbiome in different ways, likely leading to shifts in estuarine carbon and nutrient cycling.

Wolney, J.L., Tomlinson, M.C., Uz, S.S., Egerton, T.A., McKay, J.R., Meredith, A., Reece, K.S., Scott, G.P. and R.P. Stumpf. (2020) ***Current and Future Remote Sensing of Harmful Algal Blooms in the Chesapeake Bay to Support the Shellfish Industry.*** 7: article 337 https://doi.org/10.3389/fmars.2020.00337

A summary of common marine and estuarine HAB species found in the Chesapeake Bay, *Alexandrium monilatum*, *Karlodinium veneficum*, *Margalefidinium polykrikoides*, and *Prorocentrum minimum*, that have been detected from space using multispectral data products from the Ocean and Land Colour Imager (OLCI) sensor on the Sentinel-3 satellites and identified based on *in situ* phytoplankton data and ecological associations.

Onofrio, Michelle D.; Egerton, Todd A.; Reece, Kimberly S.; Pease, Sarah K.D.; Sanderson, Marta P.; Jones, William III; Yeargan, Evan; Roach, Amanda; DeMent, Caroline; Reay, William G.; Place, Allen R.; and Smith, Juliette L. (2021). **Spatiotemporal distribution of phycotoxins and their co-occurrence within nearshore waters.** *Harmful Algae* 103:101993 doi:10.1016/j.hal.2021.101993

This study characterized and mapped the spatial and temporal distribution of eight algal toxins across the Chesapeake Bay and identified which of these biotoxins are a current threat to shellfish health and seafood safety in the Lower Chesapeake Bay.

Improving Aquaculture Production

Virginia leads the nation in hard clam production and leads the east coast in eastern oyster production, and the eastern oyster is the most rapidly developing sector of Virginia's shellfish aquaculture industry. For the industry to continue expanding, it is important to identify methods that increase fertilization success and survival in the hatchery, to optimize methods of larval rearing, setting, and field grow-out, and to better understand the effect of domestication and genotype-by-environment interactions. Additionally, there is an opportunity to improve efficiency and profitability through innovative techniques and new technology, positioning the industry to thrive and be a national leader. Co-culture of multiple species, multi-trophic aquaculture, and the culture of new species will further expand the Virginia aquaculture industry.

Pease, Sarah K.D., Reece, Kimberly S., O'Brien, Jeffery, Hobbs, Patrice L.M., Smith, Juliette L (2021). ***Oyster hatchery breakthrough of two HABs and potential effects on larval eastern oysters (Crassostrea virginica).*** *Harmful Algae* 101(101965) doi:10.1016/j.hal.2020.101965

Dinoflagellate species *Karlodinium veneficum* and *Prorocentrum cordatum* (prev. *P. minimum*) were detected in water samples from a local Virginia oyster hatchery collected during the oyster spawning season, meaning the species were not degraded or removed by the hatchery's water treatment process. Results from laboratory experiments suggest that low concentrations of both *K. veneficym* and *P.cordatum* are harmful to larval oysters and *K. veneficym* seems to be more harmful than *P. cordatum*. This research shows that certain water filtration techniques are not successful at removing harmful algal species from ambient water, which could cause reductions in oyster productivity during the spawning season.

Sanderson, Marta Pilar, Hudson, Karen L., Gregg, Lauren S., Chelser-Poole, Amanda B., Small, Jessica M., Reece, Kimberly S., Carnegie, Ryan B., Smith, Juliette L. (2022). ***Breakthrough of toxins and HAB cells into shellfish hatcheries and efforts towards removal.*** *Aquaculture* 562:738714 doi:10.1016/j.aquaculture.2022.738714

Several types of toxins were detected is post-treatment water from six different hatcheries in the Chesapeake Bay, but the HAB species themselves were not identifiable. An investigation into the water treatment process found two steps, 24-hour circulation through sand filters and activated charcoal filtration, that were successful in removing a substantial portion of toxins from incoming water.

Shellfish Health and Biosecurity

Historically, disease has had devastating effects on shellfish stocks and aquaculture farms along the east coast of the United States. Growth and expansion of the shellfish aquaculture industry has largely relied on transfer of hatchery seed between states, and historic disease spread was often associated with the transfer of shellfish. It is important to regulate and streamline the transfer of seed between locations to control for disease. Today, reduced and/or failed clam and oyster hatchery production has been reported in our region. Hatchery production is critical to the shellfish aquaculture industry in Virginia and effective management of shellfish pathogens, both endemic and emerging, remains key to sustainable aquaculture development.

Bienlien, LM, Audemard, C, Reece, KS, Carnegie, RB. (2022) ***Impact of parasitism on levels of human-pathogenic Vibrio species in eastern oysters.*** *Journal of Applied Microbiology* 132(2): 760-771. DOI: 10.1111/jam.15287

Histology revealed that oysters infected with *Perkinsus marinus,* the parasite that causes Dermo disease in oysters, displayed increased levels of *Vibrio vulnificus* (*Vv*), but there was no correlation between *P. marinus* infection and *Vibrio* spp. levels. These results suggest that factors other than *P. marinus* presence influence *Vibrio* spp. levels in oysters.

Audemard, C., Reece, K. S., Latour, R. J., Bienlien, L. M., Carnegie, R. (2023) ***Influence of oyster genetic background on human-pathogenic Vibrio spp.*** *Aquaculture* 562 https://doi.org/10.1016/j.aquaculture.2022.738763

Human-pathogenic *Vibrio* bacteria are common inhabitants of oyster tissues, but our understanding of factors driving the wide range of concentrations found in individual oysters is extremely limited. We examined the influence of oyster sex and parasitism in light of their profound effects on oyster tissues against a backdrop of eastern oysters, *Crassostrea virginica*, from two diploid and two triploid aquacultured lines. A key outcome of these analyses was the consistent inclusion of oyster line as a predictor variable across *Vibrio* targets. A potential effect of *Perkinsus marinus* infections and/or oyster sex was also suggested, although the combination of

variables varied with *Vibrio* target. This study suggests that the dynamics of human-pathogenic *Vibrio* spp. in oysters is likely driven by multiple, interacting factors.

Ben-Horin, T., Audemard, C., Calvo, L., Reece, K.S., Bushek, D. (2022) ***Pathogenic Vibrio parahaemolyticus increase in intertidal-farmed oysters in the mid-Atlantic region, but only at low tide.*** *North American Journal of Aquaculture* 84(1):95-104. DOI: 10.1002/naaq.10218

Another concern to the shellfish industry is *Vibrio* concentrations in intertidal cultured oysters, as *Vibrio* spp. proliferate rapidly in shellfish tissues exposed to warm ambient conditions. Results reveal slight evidence for increased *Vp* concentrations in oysters grown with exposure to ambient air at low tide (intertidal) compared to subtidal oysters, but these differences disappeared with the incoming tide. These results do not suggest restricting intertidal harvest, which is important as many oysters are grown intertidally, but support the current time-to-cooling protocols put in place by many state *Vibrio* control plans detailing the amount of time harvested shellfish can be held before they are cooled or refrigerated.

Audemard, C., Ben-Horin, T., Kator, H. I., Reece, K.S. (2022) **Vibrio vulnificus and Vibrio parahaemolyticus in oysters under low tidal range conditions: Is seawater analysis useful for risk assessment?** *Foods* 11(24) https://doi.org/10.3390/foods11244065

We investigated whether concentrations of total and human pathogenic *Vibrio vulnificus* (*vvhA* and *pilF* genes) and *Vibrio parahaemolyticus* (*tlh*, *tdh* and *trh* genes) measured in seawater reflect concentrations of these bacteria in oysters (*Crassostrea virginica*) cultured within the US lower Chesapeake Bay region. We found seawater concentrations of these bacteria to predictably respond to temperature and salinity over chlorophyll *a*, pheophytin or turbidity. We also inferred that *Vibrio* concentrations in seawater strongly predict their respective concentrations in oysters. We hypothesize that such seawater-oyster coupling can be observed in regions of low tidal range.

Arfken, A, Song, Bongkeun, Allen, SK, Carnegie, RB. (2021) ***Comparing larval microbiomes of the eastern oyster (Crassostrea virginica) raised in different hatcheries.*** Aquaculture 531:735955 doi:10.1016/j.aquaculture.2020.735955

Differences were detected in the microbiome of oyster larvae collected from separate spawning events and from four different hatcheries in the Chesapeake Bay, and the

larval microbiome composition differed compared to the microbiome of the hatchery water they were grown in. In addition, the species richness of the larval microbiome decreased as the larvae grew, suggesting a shift towards a more selective microbiome as the larvae developed. These results highlight potential differences in larvae microbiome composition that may be related to oyster health and disease resistance.

Ben-Horin, T., Burge, C., Bushek, D., Groner, M., Proestou, D., Huey, L., Bidegain, G., & Carnegie, R. 2018. ***Intensive oyster aquaculture can reduce disease impacts on sympatric wild oysters.*** *Aquaculture Environment Interactions*, *10*, 557–567. https://doi.org/10.3354/aei00290

- The density of oysters in aquaculture, which is commonly thought to lead to the spread of disease through farms and out to nearby populations in the wild, has only indirect effects on *Perkinsus marinus* transmission through its interaction with the rate of aquaculture harvests.
- Sufficient aquaculture harvest, which varies with the susceptibility of farmed oysters to *P. marinus* infection and their lifespan once infected, reduces disease by diluting parasites in the environment.

Socioeconomics

It is important to understand how society perceives and interacts with the shellfish aquaculture industry for the industry to grow and expand. Societal changes and/or changes in the economic climate may make it difficult for the industry to succeed and action may be necessary to help overcome these obstacles. Furthermore, with increasing production, there may be a need to expand markets and increase consumer demand. Understanding marketing opportunities, consumer attitudes and distribution channels may increase in importance.

Economics

Hudson, K. 2019. ***Virginia Shellfish Aquaculture Situation and Outlook Report*** (Results of 2018 Virginia Shellfish Aquaculture Crop Reporting Survey), VIMS Marine Resource Report No. 2019-8

- Virginia is 1st in the U.S. for hard clam production and 1st on the East Coast of the U.S. for eastern oyster production
    - 2018 farmgate value for VA shellfish aquaculture was $53.3 million
        - $38.8 million hard clams and $14.5 million oysters
- Oysters are the most rapidly developing sector of Virginia's shellfish aquaculture
- Clams are the biggest contributor to VA's shellfish aquaculture economic value
- Oyster and clam farms employed more than 300 full- and part-time employees

Gonçalves, F. H., van Senten, J., Schwarz, M. H., & Hegde, S. 2022. ***Economic contributions of the Virginia Seafood Industry*.** www.arec.vaes.vt.edu/arec/virginia-seafood

- Most of the seafood production is concentration on the Eastern Shore of VA
- In 2019, the total economic output effect of the VA seafood industry was estimated at $1.1 billion and supported 7,187 jobs.

Consumer Preferences

Kecinski, M., Messer, K.D., Knapp, L., & Shirazi, Y. 2017. ***Consumer preferences for oyster attributes: field experiments on brand, locality, and growing method.*** Agricultural and Resource Economics Review, 46(02): 315-337.

- Regular consumers of oysters prefer those raised in an aquaculture setting than wild-caught. Additionally, these people were willing to pay a premium for the farm-raised oysters.
- In 2014, the US oyster industry produced $5.5 billion and 9.5 billion pounds of oysters
    - Income for oyster growers in Virginia alone was approximately $15.4 million

Manalo, A.B., Gempesaw, C.M. II. 1997. ***Preferences for oyster attributes by consumers in the U.S. northeast***. Journal of Food Distribution Research, 55-63.

- Consumers prefer farm-raised oysters (main information consumers look for pre-purchase is source, inspection, and price).
- Some consumers associate farm-raised oysters as being the safer choice and were willing to pay a higher price to have information on the source (wild vs farmed).

Barriers to Aquaculture Expansion

Beckensteiner, J., Kaplan, D.M., Scheld, A.M. 2020. ***Barriers to Eastern Oyster Aquaculture Expansion in Virginia.*** *Frontiers in Marine Science* 7:53. doi: 10.3389/fmars.2020.00053

Non-productive use of shellfish leases has been a long-standing concern in Virginia's aquaculture industry. From 2006 to 2016, only a third of commercial leases reported production, and that over 60% of leaseholders had no history of commercial harvests. Non-used leases tended to be smaller and located in densely populated areas.

Beckensteiner, J., Scheld, A.M., St-Laurent, P., Friedrichs, M.A.M., Kaplan, D.M. 2021. **Environmentally-determined production frontiers and lease utilization in Virginia's eastern oyster aquaculture industry.** *Aquaculture* 542. doi: 10.1016/j.aquaculture.2021.736883

Econometric production frontier models were used to evaluate production efficiency for leases growing oysters using intensive culture methods. Findings indicated that given the available area and environmental conditions, production could double or triple in many leases. Additionally, leaseholders holding multiple leases were seen to be more efficient, possibly benefiting from economies of scale, while leases in densely populated areas tended to be less efficiently used.

Sudhakaran, P.O., Puggioni, G., Uchida, H, Opaluch, J. 2021. ***Do oyster farms actually reduce the property values?*** Empirical evidence from Rhode Island, Aquaculture Economics & Management, 25:2, 202-222, DOI: 10.1080/13657305.2020.1869857

In this paper, house sales data from Rhode Island between 2000 and 2013 is analyzed to evaluate the effect of oyster farm construction on property values using a difference-in-difference (DiD) approach within a hedonic price model (HPM). Given the use of sales data, this study focuses on the perceptions of people in the housing market. We found that the impacts are more nuanced and complex: overall on average the construction of oyster farms increased the value of the houses located closer to the farm. When the houses are grouped by their value category, however, our results show that the value of luxury houses decreased significantly.

Stump, K. 2019. ***Impact of oyster aquaculture in Virginia on Waterfront Property Values.*** Masters Thesis. Virginia Polytechnic Institute and State University.

Results suggest that oyster aquaculture has a positive effect on waterfront property values, but a negative effect when using cage equipment.