Selected Nutrient Bioextraction Peer-Reviewed Journal Articles

Bricker, Suzanne B., et al. "Role of Shellfish Aquaculture in the Reduction of Eutrophication in an Urban Estuary." ***Environmental Science and Technology*****, *vol.* 52, no. 1, 2018, pp. 173-183.**

Bricker et al. investigated the role of nutrient bioextraction and existing oyster aquaculture nutrient management in urban estuaries like Long Island Sound (LIS), Connecticut. The study aimed to evaluate 1) the total mass of nitrogen removed through oyster cultivation at current and expanded rates; 2) how significant oyster related nitrogen removal is in relation to the total nitrogen load; 3) the economic value of this ecosystem service; and 4) whether oyster nitrogen removal is significant enough to support a role for shellfish growers in a nutrient credit trading program.

Bioextraction through oysters occurs when phytoplankton, containing nutrients, are filtered from the water and are stored inside the tissue and shell. Thus, when oysters are harvested and removed from the water excess nitrogen and other nutrients are removed. Denitrification also occurs when the microbes that live on and amongst oysters convert harmful nitrate and nitrite compounds to harmless nitrogen gas. Bricker et al. found that together these processes could potentially remove as much as 16,800 tons of nitrogen year^{-1}, or about one-third of the total nitrogen input to LIS, given cultivation of 5% of bottom area. This cultivation could provide an ecosystem service value of $8.5 and $470 million at current and maximum expanded production. This could be used as a payment in a nutrient trading program as the average value per acre was $4,030. Additionally, the total nitrogen removed from the system could be greater if nitrogen removal by other bivalve mollusks such as clams was also included.

Bricker, Suzanne B. et al. "An Ecosystem Services Assessment using bioextraction technologies for removal of nitrogen and other substances in Long Island Sound and the Great Bay/Piscataqua Region Estuaries." ***NCCOS Coastal Ocean Program Decision Analysis Series,*** **No. 194. 2015, National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Silver Spring, MD and United States Environmental Protection Agency, Office of Research and Development, Atlantic Ecology Division, Narragansett, RI.**

Bricker et al. evaluated the potential of nutrient bioextraction using eastern oyster (*Crassostrea virginica*) and quahog clam (*Mercenaria mercenaria*). Using the Farm Aquaculture Resource Management (FARM) model and an economic analysis, this study evaluated ecosystem services by oysters at current and expanded scenarios.

A nutrient credit trading program is a 'market-based' approach to help reduce nutrient discharges. This is done by developing economic incentives for achieving water quality standards. Shellfish are a sink for nutrients thus generating 'credits' that could be sold to dischargers, such as wastewater treatment plants (WWTP) that face higher nitrogen removal costs. A discharger could then buy these nutrient credits from an aquaculture operation if they were to get close to their regulated discharge limit. This could help in creating a market price for nutrient reduction.

The local scale FARM model was used for both the Long Island Sound (LIS) and Great Bay/ Piscataqua, New Hampshire/Maine to determine N removal by local and upscaled aquaculture. The average removal rate in the LIS was found to be 318 ± 79 lb N acre^{-1} year^{-1}, while the average removal rate for the Great Bay Piscataqua was 0.35 ton nitrogen year^{-1}. This removal represents an ecosystem service value of $4,200 acre^{-1} year^{-1}, which can be additional income to the farmer if a nutrient trading program existed. An expansion of oyster aquaculture in the Long Island Sound and Great Bay Piscataquis would lead to removal of between 2- 3% of the total nitrogen load in both systems. Bricker et al. stated that oyster and quahog aquaculture combined could remove up to about 10% of total inputs at present levels and 14% in an expansion scenario. However, using quahogs as wild species does not include natural mortality and therefore, nitrogen removal may be overestimated. A cost avoided method of estimation represents the value of the amount of nitrogen removed through oyster cultivation and harvest. This method determined that in the Long Island Sound oyster cultivation was worth $8.5 to $230.3 million under the current practices. If LIS were to expand aquaculture production, the potential value could range between $17.4 and $469.3 million, depending on the methods used. The value of bioextraction estimated through the cost-avoided method for Great Bay Piscataqua is $1.1 and $1.3 million under the current acreage scenario.

***Gorman, Leah. et al*. "The Effects of Temperature on the Growth Rate and Nitrogen Content of Invasive Gracilaria Vermiculophylla and native Gracilaria Tikvahiae from Long Island Sound, USA". *Algae, vol. 32, no. (1),* 2017, pp. 57-66.**

This study investigated a strain of invasive seaweed to Europe and the Americas and narrowed its focus on Long Island Sound (LIS). *Gracilaria vermiculophylla* is native to Korea and has been seen growing along with a native seaweed, *Gracilaria tikvahiae*. The goal of this study was to determine whether the two strains of *Gracilaria vermiculophylla* from different regions of the world (Korea and Long Island Sound) have evolved genetic differences (i.e., ecotypic differentiation) or if the physiological performance of the strains simply reflects phenotypic plasticity.

The native Korean strain of *Gracilaria vermiculophylla*, the invasive Long Island Sound strain of *Gracilaria vermiculophylla*, and the native Long Island Sound strain of *Gracilaria tikvahiae* were grown at the same time on a temperature gradient table at the University of Connecticut. They were grown at 20, 24, 29 and 34 degrees Celsius and were weighed weekly over four weeks. At the end of the four-week growth period, the Korean strain of *Gracilaria vermiculophylla* consistently had the fastest growth rate and the Long Island Sound strain of *Gracilaria vermiculophylla* and *Gracilaria tikvahiae* had similar growth rates. The Long Island Sound strain of *Gracilaria vermiculophylla* had a higher concentration of nitrogen averaging between 4-5%, while the Korean strain of *Gracilaria vermiculophylla* and *Gracilaria tikvahiae* were around 2-3%. These results suggest that the Long Island Sound strain of *Gracilaria vermiculophylla* either has different physiological characteristics or has evolved differences from the strain obtained from its native range. Several factors indicate that the invasive species to Long Island Sound will outcompete the native *Gracilaria tikvahiae* despite them having similar growth rates. This is because *Gracilaria vermiculophylla* is better adapted to handle a wider range of temperatures (up to 34 degrees Celsius). As ocean temperatures continue to rise, species that are better adapted to handle warmer temperatures are more likely to thrive.

Grizzle, Raymond E. et al. "Growth, Morphometrics and Nutrient Content of Farmed Eastern Oysters, Crassostrea Virginica (Gmelin), in New Hampshire, USA." ***Aquaculture Research,*** **vol. 48, 2017, pp. 1525-1537.**

Grizzle et al. investigated the growth and productivity success of aquaculture reared eastern oysters near their northern geographical range in Great Bay, NH. Annual growth rates of the eastern oyster typically vary but are fastest in warmer regions due to an extended growing season. Growth variations also exist between farmed and wild oysters across an estuary, likely due to environmental variations.

In this study, six sites were chosen to represent a range of ambient nutrient concentrations and environmental conditions. Oysters were divided into two size classes: (1) small: 19–42 mm initial shell height (0.3 year old); and (2) large: 28–79 mm initial shell height (1.3 year old). At each of the six sites, approximately 1000 small size class oysters were deployed in a 9 mm mesh and approximately 200 large size class oysters in a 24 mm mesh flat ('envelope' style) polyethylene bag. The two bags were suspended side-by-side 10 cm off the bottom attached to plastic coated wire cages.

The results of the study showed that, on average, a cocktail size oyster (63 mm) would be reached in the third growing season and regular size (76 mm) would require a full 3 years. This is slower than oysters grown in more southern regions like the Chesapeake Bay where market individuals can be reached in 2 years. The data strongly suggested that there is a substantial decrease in soft tissue nitrogen content as an oyster gets older. The FARM model was used to estimate the bioextraction potential of oyster aquaculture in Great Bay, New Hampshire. The FARM model predicted an average total nitrogen removal of 142 kg ha^{-1} $year^{-1}$ (=0.35 metric ton ac^{-1} $year^{-1}$) from the ecosystem via oyster harvest. Grizzle et al. predicted bioextraction potential using a more direct approach, using a mean of 0.14 g total nitrogen per regular size oyster and assuming a harvest of 1,000,000 oysters ha^{-1} $year^{-1}$. Results were comparable to the FARM model, with a total nitrogen removal from the Great Bay system of 140 kg nitrogen/ha.

Hudson, Robbie. et al. "Ribbed Mussel Nutrient Bioextraction Pilot Project." 2016, Kingston, RI.

The authors of this study investigated the potential of ribbed mussel (*Geukensia demissa*) for nutrient bioextraction in polluted ecosystems, such as upper Narragansett Bay, Rhode Island. Mussels were grown in three different environmental settings: (1) a fringing salt marsh; (2) continuously submerged in shallow water hanging from a floating raft; and (3) in a shellfish aquaculture upweller. Hudson et al. measured mass and dimensions to estimate tissue mass growth, which was used as a proxy for net seasonal bioextraction efficiency.

The results of the study showed that the average net nitrogen removal capacity for ribbed mussels was between 7 and 13 mg per animal over the sampling period (May-October 2015). Additionally, the data showed that continually submerged and intertidally submerged mussels grew at a similar rate, while ones grew in an aquaculture-style upweller grew at the slowest rate.

Johnson, Ronald. et al.* "Nitrogen allocation of Gracilaria tikvahiae grown in urbanized estuaries of Long Island Sound and New York City, USA: a preliminary evaluation of ocean farmed Gracilaria for alternative fish feeds*". Algae, vol. 29, no. (3), 2014, pp. 227-235.

Johnson et al. investigated the potential for a warm temperate red algal species, *Gracilaria tikvahiae*, to be used as a fish feed in aquaculture systems. *Gracilaria tikvahiae* has historically been a commercial source of food grade and biotechnological grade agar; however, beyond its traditional uses, *Gracilaria* may be suitable for biofuel production, an ingredient for fish feeds, and employed for nutrient bioextraction systems. The objective of this study was to determine the protein and amino acid composition of *Gracilaria tikvahiae* harvested from these nutrient bioextraction systems over a four-month harvest period and evaluate the potential of this algal protein as an ingredient for fish and shrimp feeds.

Gracilaria tikvahiae was suspended 0.5m below the surface on two 50m long lines. These lines were placed in Long Island Sound, CT and Bronx River Estuary, New York. Seaweed was harvested on August 16, September 15, and November 4, 2011. Samples were then evaluated in a lab for total nitrogen, protein and amino acid content.

The results showed that non-protein nitrogen levels were similar to what is found in hay. The two main amino acids that were present were aspartic and glutamic acid which accounted for over 20% of the protein. Lysine was detected between 5.8 and 11 gkg^{-1} which is unlikely to be a limiting factor. Histidine and methionine were detected at lower levels at 1.2-3.7 gkg^{-1} , which suggested that they may be limiting in feed. Tryptophan was also found to be lower in plants harvested in August at 0.7 gkg^{-1}, which also presents a potential limiting factor. Ideally all of the amino acids would be in balance for the animal. However, it has been shown that nutritional additions to the feed, such as blood meal, can counteract the lower amino acid levels.

The results of this preliminary study suggest that cultivated *Gracilaria* may be a suitable protein ingredient for aquaculture feeds, especially when harvested late in the season. With its moderate levels of amino acids, including lysine, methionine and taurine, *Gracilaria tikvahiae* has the potential of overcoming many nutrient deficiencies associated with terrestrial plant proteins currently used in alternative fish feeds.

Kellogg, Lisa M. et al. "An Updated Model for Estimating the TMDL Related Benefits of Oyster Reef Restoration"*. 2018.*

In 2017, the United States Environmental Protection Agency (EPA) provided a formal opinion to the Chesapeake Bay Program Partnership's Oyster Best Management Practice Expert Panel stating that restored oyster reefs could be considered a best management practice for removing nitrogen, phosphorus and sediments from the Chesapeake Bay waters. Currently the EPA uses a total maximum daily load (TMDL) approach for setting nutrient reduction targets. This study aims to create a quantitative tool that shows the effects of the TMDL and the ecosystem benefits of oyster restoration.

In 2014, a web-based model was developed to estimate the TMDL-related benefits of oyster reef restoration per unit area. The purpose of this report is to discuss the updates and rationale made to the model in 2018. The goals for the model were to determine: 1) the amount of nitrogen removed via denitrification; 2) the volume of water filtered; 3) the amount of chlorophyll-A and suspended solids removed from the water column; 4) the amount of nitrogen and phosphorus buried in the sediments; and 5) the amount of nitrogen and phosphorus sequestered in animal tissue and shell. The model also included nutrient trading credits, as this estimates the economic value of each restoration option.

Harris Creek, Maryland was selected as the study site due to a large restoration effort in 2015, which resulted in two billion oysters spread out over approximately 350 acres. The study site was broken up in into five sections each marking different geomorphic constrictions within the estuary. The model then used the data from the monitoring stations to measure water quality and the productivity of the oysters to show TMDL-related benefits of oyster reefs restoration per unit area.

While collecting information for the online tool there was valuable scientific information collected. It was found that the restored oyster reefs filtered on average 7.3% of the volume of the creek. Oysters were predicted to filter the greatest amount of water followed by mussels and tunicates. There were large inputs of outside nutrients coming from the Choptank River. Therefore, only a smaller fraction of inputs was removed compared to if it were just the inputs from Harris Creek. It was calculated that 22% of total suspended solids were removed and just under 10% of N, P and OC inputs were removed.

Users can access the model online and enter their own parameters to simulate ecosystem benefits and economic values of nutrient removals. The model can be accessed at: http://www.vims.edu/research/departments/bio/programs/semp/models/index.php.

Kim, Jang K. et al. "Seaweed Aquaculture: Cultivation Technologies, Challenges and its Ecosystem Services." ***Algae*****. vol. 32, no.(1), 2017, pp. 1-13.**

Researchers Jang et al. discuss the major species of macroalgae used for commercial aquaculture, the ecosystem services seaweed aquaculture provides, and the challenges to seaweed cultivation.

Global seaweed aquaculture production accounts for approximately 20% of the total world marine aquaculture production by weight. It has an annual value of $6.7 billion, as of 2013. However, most of the seaweed aquaculture occurs in Asia. Seaweed production is dominated by relatively few species: the brown kelps (*Saccharina japonica* and *Undaria pinnatifida)* and the red seaweeds (*Pyropia*/*Porphyra* spp., *Kappaphycus alvarezii* and *Eucheuma striatum* and *Gracilaria* / *Gracilariopsis* spp). Markets for seaweed aquaculture include: human food, animal feed, chemicals, paper, fertilizer, biofuel, derivative products, and to test biological toxicity for human and environmental health.

Seaweeds take up nitrogen, phosphorus and carbon dioxide, which the plants use for growth and production. The total nitrogen and carbon removal by these five major seaweed groups is approximately 65,000 tons of nitrogen per year and 760,000 tons of carbon per year (to 2.8 million tons of CO_2), respectively.

Brown kelp is mostly produced in Asia with 8.0 million tons cultivated and harvested in 2014 (~$1.4 billion annually). However, sugar kelp and winged kelp represent some of the fastest growing industries for western countries.

Red seaweed is one of the most successful aquaculture industries in Asia. It has a high commercial value ($523 per wet metric ton) in comparison to other algae species. Currently there are no commercial red seaweed operations in the US due to lack of success.

Red algae represent some of the world's most cultivated seaweeds, with >3.8 million tons of annual production (~$1 billion). It is the main source of food grade agar and as an animal feed.

Kim, Jang K. et al. **"Evaluation of the metal content of farm grown Gracilaria tikvahiae and Saccharina latissima from Long Island Sound and New York Estuaries."** ***Algal Research.*** **vol. 40, 2019.**

Kim et al. investigated the ability of cultured seaweed to accumulate contaminants such as heavy metals when grown in urbanized estuaries. Most cultivated seaweed in the United States is harvested for direct human consumption, including *Saccharina latissima*. Due to the locations of where seaweed is cultivated, tissue composition is a concern.

Gracilaria tikvahiae was cultivated on two 50m long-lines at two near-shore sites: (1) Western Long Island Sound (LIS), New York; and (2) Bronx River Estuary (BRE), New York. *Saccharina latissima* was cultivated on three 50 m long-lines at three near-shore sites: (1) Western Long Island Sound, New York; (2) Bronx River Estuary, New York; and Central Long Island Sound (CLIS), New York. Both *Gracilaria tikvahiae* and *Saccharina latissima* where grown, collected and analyzed for arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb).

As a result, the samples grown in the Western Long Island Sound, Central Long Island Sound and Bronx River Estuary sites had significantly higher metal concentrations compared to similar samples grown in a lab. For *Gracilaria tikvahiae* metal concentrations of As (11 ppm), Cd (<0.3 ppm) and Hg (<0.06 ppm) were significantly greater at Western Long Island Sound than Bronx River Estuary. Meanwhile Cr (>3 ppm) and Pb (>4 ppm) were higher at the Bronx River Estuary sites. Central Long Island Sound was also included in this study where *Saccharina Latissima* was grown. The results showed that As and Cr concentrations did not differ much among the three sites. Cd (<0.4 ppm) and Pb (<2 ppm) were higher at the Bronx River Estuary and Hg ranged across all sites with Central Long Island Sound having the highest concentration. With the exception of Pb, all the metal concentrations recorded fell below the limits set by the US and international agencies. The higher Pb levels of about 6 ppm were only found in *G. tikvahiae* and at the Bronx River Estuary site. This can possibly be attributed to a nearby scrap yard and previous industrial uses in the area. In most cases however, metal contents in tissue will be below international and US agency standards.

Rose, Julie M., et al. "A Role for Shellfish Aquaculture in Coastal Nitrogen Management." *Environmental Science & Technology*. vol. 48, no. (5), 2014, pp. 2519-2525.

Most nutrient management programs focus on removing nitrogen to reduce excess nutrients in estuaries and coastal ecosystems. This is because nitrogen is the primary nutrient phytoplankton require for growth. In Long Island Sound, nutrient reduction has been focused on improvement to wastewater treatment plants. Between 1988 to 2011 federal and state grants have accounted for $1.7 and $9.8 billion in nitrogen removal upgrades to wastewater treatment plants in Connecticut and New York. This has been an effort to reduce point source pollution. Point source pollution is when a source of pollution is single and identifiable, such as a pipe or a drain releasing pollutants directly into the water. However, as efforts to upgrade waste water treatment plants to reduce nitrogen succeed, total levels of nitrogen from nonpoint sources are increasing. Nonpoint sources of pollution occur over a wide area and the pollution is not easily identifiable to one source. Types of land use are identified as nonpoint source, such as fertilizer runoff from agricultural land or suburban lawns.

Rose et al. (2014) stated that the use of shellfish presents a potential opportunity to remove excess nutrients. Shellfish filter and consume phytoplankton and when shellfish are harvested from the system excess nutrients are as well. It should be used in conjunction with current land-based management approaches.

Rose, Julie M. et al. "Comparative Analysis of Modeled Nitrogen Removal by Shellfish Farms." *Marine Pollution Bulletin. vol.* 91, 2015, pp. 185-190.

Rose et al. summarized the Farm Aquaculture Resource Management (FARM) model and how it can be used by local governments to battle eutrophication. The FARM model estimates total farm production including nitrogen removal. Resource managers find this tool useful when optimizing culture practices, siting new farms, estimating impacts on eutrophication, and how shellfish aquaculture can contribute to nutrient management. The FARM model also determines growth and productivity outlook of the shellfish species to be used. The model requires information on aquaculture practices, suspended food entering the farm and environmental parameters. It is from these inputs that shellfish production, waste production and nutrient credit trading potential can all be determined. The FARM model will provide an estimation of shellfish density for the greatest sustainable yield. There are also calculations for the mass of carbon and nitrogen removed by the farm including net totals which account for waste matter and mortality.

In the study Rose et al. researched individual shellfish farms across 14 locations in 9 countries and 4 continents. Data using the FARM model was collected to give an idea on expected nitrogen removal rates. Removal rates varied from 105 lbs acre^{-1} year^{-1} (Chioggia, Italy) to 1,356 lbs acre^{-1} year^{-1} (Samish Bay, USA). The average nitrogen removal across all locations and species was 520 lbs acre^{-1} year^{-1}. This study found that nitrogen removal rates by shellfish farms compare very favorably to expected nitrogen removal by agricultural best management practices and stormwater control measures.

Sebastiano, Daria. et al. "Using a Shellfish Harvest Strategy to Extract High Nitrogen Input in Urban and Suburban Coastal Bays: Practical and Economic Implications." ***Journal of Shellfish Research*****. vol. 34, no. (34), 2015, pp. 573-583.**

In this study, Sebastiano et al. investigated the impact eastern oyster (*Crassostrea virginica*) has on decreasing urban and suburban bay nitrogen levels. The study was conducted in two estuaries that vary in the degree of eutrophication: Jamaica Bay, NY and Great South Bay, NY. Ninety-two percent of Jamaica Bay's nitrogen comes from wastewater treatment plants, combined sewer overflows, and subway dewatering. The Great South Bay receives the majority of its nitrogen from wastewater-derived sources and fertilizer.

Previous studies have estimated the ability of aquaculture bivalves to remove nitrogen from coastal bays. These estimates depend on accurate measures of soft tissue mass, shell mass and nitrogen contents of each. The value of nutrient bioextraction using shellfish also depends on the horizontal mixing of nutrients. This mixing is what allows nutrients to move around in a body of water and it gives shellfish access to nutrients that were released from a location further away.

The nutrient bioextraction potential for eastern oyster in Jamaica Bay for a 500-acre goal would extract 5% of nitrogen released into the system, however, 5,000 acres would extract nearly half of the nitrogen with an annual harvest. 5,000 acres is nearly 80% if the total potential oyster habitat. The bioextraction potential for eastern oyster in Great South Bay for a 50-acre lease area would result in a modest nitrogen removal; however, a 3,000-acre plan would remove nearly 90% of the nitrogen input.

The authors of the study concluded that the use of oysters as bioextraction tools may be very useful in removing nitrogen from nonpoint sources and should be used alongside waste water treatment plant upgrades.