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Best Practices for Healthy Beaches and Watersheds in Maine: Potential Bioremediation Strategies for Improving Water Quality

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in Maine

Potential Bioremediation Strategies for Improving Water Quality

By Elyse DeFranco

For Keri Kaczor and Maine Healthy Beaches

Background

Maine's watersheds face many challenges from human inputs, with pollution threatening the health of our beaches, rivers, and aquaculture operations. Maine's rural communities often lack the resources to update aging sewer infrastructure or to adequately maintain septic systems, and these sources of pollution impact watershed health. In addition to addressing sources of pollution, which can be difficult to ascertain and challenging to address when located, bioremediation practices have the potential to aid in clean-up efforts. New technological advances and research discoveries in creative forms of bioremediation are being developed and are producing promising case studies around the world. These new developments offer the potential to protect Maine's valuable natural resource heritage, tourism economy, and aquaculture operations.

Introduction

Bioremediation involves using natural processes to clean up pollution, often while simultaneously restoring native ecosystems and habitats. In recent years, research on the use of natural processes to clean water pollution has been increasing. This paper will discuss the bioremediation strategies most relevant to improving water quality in Maine: the use of algae, mussels, and oysters for filtering pollutants and bacteria. I have focused here on research most relevant to the goals of Maine Healthy Beaches as discussed with Keri Kaczor in September of 2017.

Microalgae

Phycoremediation is the process of employing algae for removing excess nutrient load from wastewater to diminish the pollution load. It is an alternative strategy of treating sewage wastewater, and is thought to have economic and environmental benefits compared to conventional treatment processes (Kshirsagar, 2013). A major problem with wastewater is that it is rich in organic compounds and inorganic chemicals such as phosphates and nitrates, which cause eutrophication (de Bashan et al., 2010). The introduction of microalgae, which feed on excess nutrients, has the potential to address this issue. This strategy not only removes excess nutrients from the wastewater, it also produces biomass which can be processed into biofuels. Wastewater remediation by microalgae is a creative and eco-friendly solution with no secondary pollution as long as the biomass produced in the process is reused, and there is potential for this biomass to be used in biofuel production. A range of microalgae has been experimented with, including *Chlorella, Scenedesmus, Phormidium, Botrycoccus, Chlamydomonas,* and *Spirulina*, and results have been promising. Research has shown that using 15 native algal isolates removed over 96% of the excess nutrients in treated wastewater (Chinassamy et al., 2010). About 64% of the algal oil obtained in this study was useful for conversion to biodiesel, and there was a rapid decrease in the level of metals, nitrates, and phosphates in the wastewater (Chinassamy et al., 2010). Table 1 shows various algae species and their wastewater cleanup uses.

Table 2
Microalgae contributing to the degradation of environmental pollutants.

S. no	Microalgae	Aquatic microalgae	Types of wastewater	Reference
1	*Prototheca zopfii*	Fresh water	Degraded petroleum hydrocarbons found in Louisiana crude and motor oils waste	[106]
2	*Chlamydomonas* species	Fresh water	*Meta* cleavage in wastewater	[107]
3	*Chlorella pyrenoidosa*	Fresh and brackish	Degradation of azo dyes wastewater	[108]
4	*Chlorella* sp.	Fresh and marine water	Anaerobic digested dairy waste	[109]
5	*Ankistrodesmus* and *Scenedesmus* *Scenedesmus quadricauda*	Fresh water	Olive oil mill wastewaters and paper industry wastewaters.	[38,51,52,101]
6	*Spirulina platensis*	Freshwater and brackish water	Domestic wastewater treatment	[110]
7	*Chlorella sorokiniana*	Freshwater	Wastewater treatment under aerobic dark heterotrophic conditions	[71]
8	*Botryococcus braunii*	Freshwater	Secondarily treated sewage in batch and continuous cultures	[111,112]
9	*Scenedesmus*	Freshwater	Removal of ammonia from anaerobic digestion effluent containing high levels of ammonium and alkalinity	[1,113]

Table 1. Sourced from Rawat et al. (2011). Algae species and their wastewater cleanup uses.

Mussels

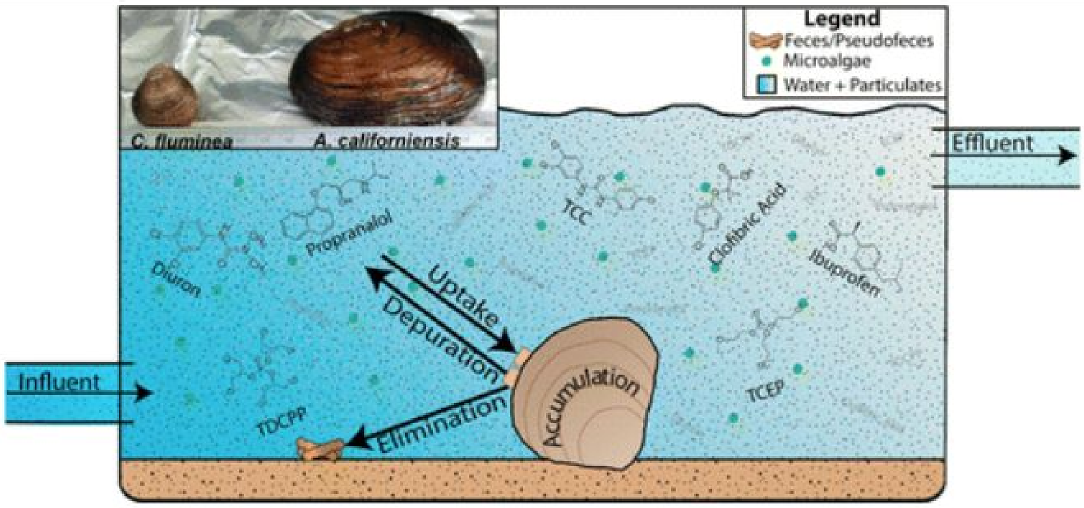


Figure 1. Graphic demonstrating filtering abilities of mussels (Source: Ismail et al., 2014)

Non-point source contaminants from urban and agricultural runoff as well as specific inputs from industry and municipal treatment plants can negatively impact aquatic ecosystem health. A primary contributor to poor water quality near human settled areas is the effluent from wastewater treatment plants and septic systems, which release organic material that can result in eutrophication and reduced dissolved oxygen levels (Chambers et al., 1997). Nearly 70% of the freshwater mussel species in North America are endangered, threatened, or in decline. Wild freshwater mussels collected downstream in urban rivers have exhibited significantly higher concentrations of lead, aluminum, copper, nickel, and zinc than reference sites upstream in the same river. As benthic filter feeders, mussels are exposed to contaminants through multiple ways, including the water column, sediment, and pore water.

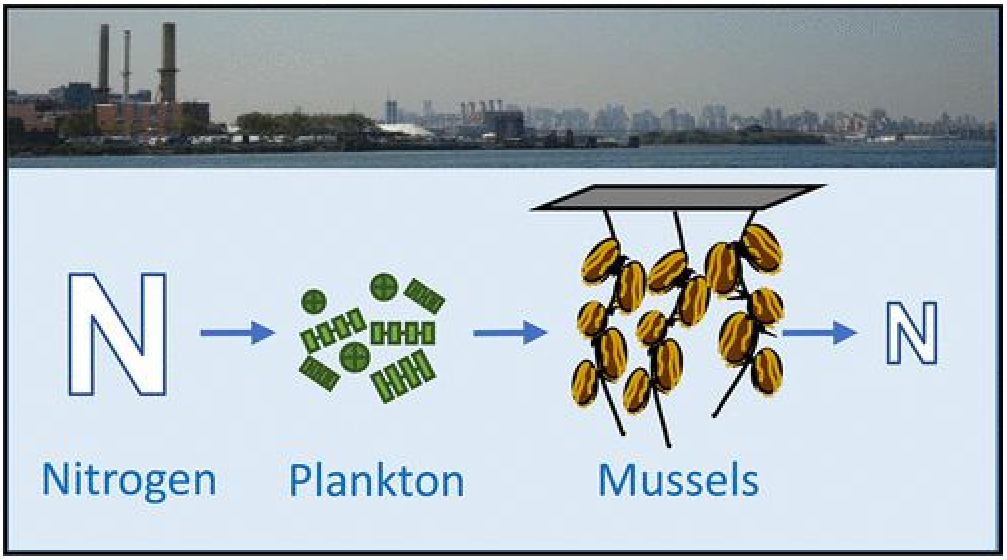


Figure 2. Mussel rafts remove excess nitrogen from the water.

The freshwater mussel *Diplodon chilensis* has been shown to remove algae, suspended solids and nutrients from fish farming effluents (Parada et al., 2008), coliform from polluted wells (Lara et al., 2002), and E. coli from the water column in laboratory exposures (Sabatini et al., 2011). Studies have also demonstrated that *D. chilensis* can be used to remove bacteria from sewage-polluted sediments and that adults can be relocated to sewage polluted areas for remediating affected water and sediments and maintain filtering capacities for many years. *D. chilensis* chronically exposed to sewage pollution has been shown to maintain filtering abilities and may even increase capacity to respond to higher bacteria load.

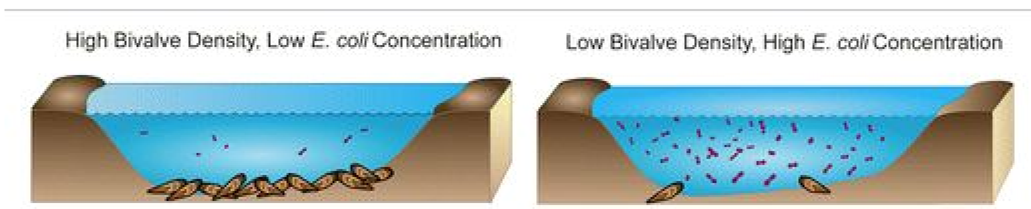
Researchers from the National Oceanic and Atmospheric Administration found that the ribbed mussel, *Geukensia demissa,* will feed on bacteria and therefore absorb excess nitrogen from rivers. By clearing the water of excess nitrogen, the mussels can help prevent eutrophication, which leads to an excess in plant growth at the water surface, blocking sunlight from the lower part of the river and preventing photosynthesis. The ribbed mussel is native on the East Coast, and can be used to effectively clean up watersheds that are threatened by human input. Researchers collected massive amounts of spat, which are the raw material for cultivating mussels, and then tracked their growth for a year in the Bronx River Estuary in New York.

Using mussels provides a way of targeting the excess nutrients in the river itself, which can be added to attempts of locating and stopping sources of pollution to help clean up waterways. As a native species, cultivating populations of ribbed mussels would also be a natural way of restoring the ecosystem. The potential exists for the mussels to be used for fertilizer or animal feed, which would use previously polluting nutrients in a positive cycle. The filtration experiments indicated that one raft of *G. demissa* has the potential to clear an average of 12 million liters of water daily, removing 160 kg of particulate matter from the water column. The raft could then be harvested, sequestering more than 62 kg of nitrogen in the mussel tissue and shell, comparing favorably to other resource management recovery methods aimed at addressing stormwater nitrogen sources (Galimany et al., 2017).

A Stanford study by Ismael et al. (2014) demonstrated similar filtering benefits for the native California floater mussel, *Anodonta Californiensis*, and the invasive Asian clam, *Corbicula fluminea*. This study examined the filtering abilities for "contaminants of emerging concern," (CECs), a term used for pollutants including pharmaceuticals, personal care products, herbicides, and flame retardants, which are a growing concern in waterways. Little is known about the ecosystem health impacts of these chemicals, though it is thought that they may be harmful to fish reproduction. The study demonstrated that both the native mussel and the clam species have the potential to remove CECs from the water in a matter of days: within 72 hours, up to 80 percent of some of the chemicals had been removed.

The use of shellfish to reduce bacterial levels has only been examined by the scientific community fairly recently. One team of researchers, originally at Stanford University, have published recent studies examining the efficacy of *E. coli* removal by the same native freshwater mussel, *Anodonta californiensis.* The first was performed in an urban lake in San Francisco. The bivalves maintained a 1-log removal of *E. coli* for the duration of exposure, and parallel laboratory experiments demonstrated that *E. coli* was inactivated with less than 5% of the initial colonies recoverable in mussel fecal matter or tissue (Ismael et al., 2014). This reduces concern for the use of the harvested mussels as fertilizer or animal feed.

Another study examined the ability of the same mussel, *Anodonta californiensis*, and an invasive freshwater clam, *Corbicula fluminea*, to reduce concentrations of *E. coli* in a coastal river affected by agriculture and grazing inputs. Results showed a significant inverse correlation between *E. coli* concentration and bivalve density, showing filtration of 1-1.5 log(10) reduction of E. coli over 24 hours. This calculated to about 1.2 to 7.4 L per hour for each bivalve. Though the study demonstrated that both the native and the invasive species were capable of filtering *E. coli* effectively, the use of native species is preferable as it integrates species and ecosystem restoration into management plans (Ismael et al., 2016). The results of these studies further support the use of native freshwater mussels for improving water quality and recovering freshwater ecosystems.



One benefit of mussels over oysters is that mussel rafts work in three dimensions, as they have long tendrils of mussels attached to them, working throughout the water column. Carter Newell, founder of Pemaquid Mussel Farms in Damariscotta, Maine, uses mussel rafts as large as 40 square feet. Newell, who has a Ph.D. in Marine Biology, states that his mussel rafts “can filter something like five million liters of water per hour.” These three dimensional rafts also provide excellent habitat. Newell notes that he has “counted 37 different species of invertebrates living among the mussels on their culture ropes” (Greenberg, 2013).

An additional advantage of mussels is that they are one of the easiest bivalves to grow, as large amounts of wild mussel seed (called “spat”) remain in our waters. Oyster spat used to be common as well, but since the collapse of oyster reefs, the spat is increasingly rare.

Mussels are also a resilient animal, responding well to storms that have been known to decimate oyster populations. “After [Hurricane] Irene there was just this incredible abundance of mussel larvae in the water and they set everywhere. Lobstermen were complaining that their traps were full of mussels. I realized all I’d have to do was provide the structure and I could have a mussel farm”, said Bren Smith, owner of Thimble Island Oyster Company in Connecticut. “[Hurricane] Irene completely buried my oysters and killed them. Sandy did too. The mussels- they were just hanging there on the ropes. They did fine.” (Greenberg, 2013).

Encouraging mussel aquaculture could also be made into an economic argument. Of the $108 million in mussels consumed in the U.S. in 2012, most of it came from Canada. Emphasizing the ecological advantages of culturing mussels is one way to expand the U.S. mussel industry, according to Gary Wikfors of NOAA. Carter Newell has utilized this strategy to foster support for mussel farming along the Maine coast. “Shellfish production is the economic argument for clean water. If you’ve established a shellfish farming area and then some real estate development wants to come in, it’s very hard for them to get permits if they reduce the water quality, because edible shellfish require very clean water.” (Greenberg, 2013).

Relevant Case Studies

Billion Oyster Project

The Billion Oyster Project (BOP) is an "effort to restore a sustainable oyster population and to foster awareness, affinity, and understanding of the Harbor by engaging New Yorkers directly in the work of restoring one billion oysters." Oysters historically had covered more than 220,000 acres of the Hudson River Estuary, providing valuable ecosystem services by filtering water and providing habitat for other species, and protecting the shorelines from storms. Oysters were severely over-harvested and impacted by dredging and pollution, and are today functionally extinct in the Harbor. The Billion Oyster Project aims to reverse this loss by restoring the oyster population and ensuring the long term integrity of the project while building community support and increasing awareness and education about the health of the watershed.

The oyster life cycle presents a challenging paradox for restoration, as oysters spend the first weeks of their lives as free swimming larvae. At the end of the larval period they settle out of the water column to the sea floor, where they need a hard surface to attach to- what would usually be a mat of other oyster shells. Due to the lack of existing oyster populations in the harbor, BOP needed to get creative, and they partnered with local restaurants to reuse previously discarded oyster shells (up to half a million oysters are eaten in NYC restaurants every week). BOP "cures" the discarded shells and uses them to grow new oysters- up to 20 per shell.

The reef construction and monitoring are done by students through hands-on restoration courses with the organization. BOP works with teachers to provide place-based science and math lessons taught through the lens of oyster restoration, and thousands of students have participated in the program thus far. They collect data on oyster growth and survival, water quality, and presence and diversity of other organisms at over 30 sites. Since the launch of the project in the Spring of 2014, it has successfully planted more than 25 million oysters in the harbor and reused 700,000 pounds of oyster shells donated by 70 restaurants. 107 middle and high schools have participated in the education program, with the participation of over 5,000 students.

Florida Oceanographic Oyster Restoration

A similar project to the Billion Oyster Project, the Florida Oceanographic Oyster Restoration (F.L.O.O.R.) project has restored over 60,000 square feet of oyster reef in the St. Lucie Estuary and Indian River Lagoon. This part of Florida experienced severe loss of oyster reefs primarily due to poor water quality and low salinity levels from fresh-water discharges. This program also actively engages the public in oyster restoration by partnering with restaurants to collect discarded oyster shells and utilizing volunteers to build reefs- to date, more than 2,400 volunteers have participated in the project. Local citizens in Martin County also grow oysters off of their private docks, which are eventually moved to historic reef sites in the estuary.

Piscataqua River and the Great Bay Estuary

The Nature Conservancy has been working on oyster restoration on the border of Maine and New Hampshire in the Great Bay Estuary and the Piscataqua River. The eastern oyster, *Crassostrea virginica*, had historically played a vital role in this region, covering more than 1,000 acres as late as 1970. With more than 90% of these oyster reefs now gone, this project is teaming with researchers at the University of New Hampshire to restore the habitat and the oyster populations. More than 18 acres of reef and 3.5 million oysters have been restored since the start of the program.

Conclusion

A single oyster can filter around 30 gallons of water per day. A single mussel can filter more than 2 Liters of water per day, and grows in even denser clusters than oysters. With the success of studies assessing the ability of bivalves to filter *E. coli*, particulate matter, heavy metals, and other pollutants from the water, the potential for targeted aquaculture to restore water quality seems evident. This strategy not only improves water quality, it also restores native ecosystems, provides habitat for other species, can be performed using volunteers and citizen scientists, and includes opportunities to reduce the waste stream by reusing discarded oyster shells. Existing projects demonstrate the potential for community involvement by partnering with restaurants to gather shells, or teaming with local residents to grow bivalves from private docks, producing a community-centered approach to water quality health.

In order to improve the health of Maine's beaches and decrease the bacteria and pollutant load, mussel rafts could be strategically placed near problem areas. When source pollution is difficult to identify or address, these rafts could be deployed to capture the pollutants in the river, before they move downstream and further impact water quality and beach health. This would not only make Maine's beaches cleaner and more tourist-friendly, it would also ensure cleaner water for commercial aquaculture operations downstream. There may be also be potential for the mussel rafts to produce economic benefits through partnership with a fertilizer production or animal feed company, which could then use the harvested mussels to recycle the captured nutrients.

It is difficult to imagine that there would be many community members opposed to this strategy, and including stakeholder involvement from the beginning stages of planning would help to ensure community buy-in. Native species should be used in order to ensure that ecosystem benefits are maximized and that scientists and conservation organizations support the effort. Theoretically, with nearly 70% of the freshwater mussel species in North America endangered, threatened, or in decline, restoration programs could potentially be used for species recovery, which would increase the availability of government grant funding. A mitigation program could also be started, which could provide the program with funding and resources (mitigation programs typically involve funding commitments for conservation projects from new developments and industry contributing to the decline of a species, or in this case, impacting water quality). As the placement of bivalves in upstream problem areas has the potential to produce cleaner water for commercial aquaculture production downstream, it may be possible to team with local aquaculture organizations who could provide materials and equipment, such as mussel rafts and spat. There is a lot of potential for these bioremediation strategies to produce wide-ranging benefits for Maine's water quality, community health, and aquaculture operations.

Resources

Dr. Niveen Ismael, Assistant Professor of Environmental Engineering at Smith College. Dr. Ismael's PhD work included the study of using native mussel species to remove *E. coli* from an urban lake in San Francisco.

Contact: nismail@smith.edu. 413-585-3900

Carter Newell, Founder of Pemaquid Mussel Farms in Damariscotta, Maine. Possible resource for mussel rafts and best practices for mussel aquaculture in Maine.

Contact: musselsandoysters@gmail.com, website: http://pemaquidmussels.com/

Billion Oyster Project. Executive Director Pete Malinowski. Good resource for information about outreach activities, partnering with restaurants to reclaim oyster shells, oyster aquaculture, and integrating education into the restoration program.

Contact: restore@nyharbor.org, pmalinowski@nyharbor.org

Website: https://billionoysterproject.org/about/our-team/

Maine Aquaculture Innovation Center at the Darling Marine Center

Christopher V. Davis, Ph.D. Executive Director

Contact: (207) 832-1075, cdavis@midcoast.com

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Video for presentation: https://www.youtube.com/watch?v=6p5VnFjV4q0