Incorporating Shellfish Bed Restoration into a Nitrogen TMDL Implementation Plan

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ABSTRACT

The ability of oysters and other shellfish to filter the water column as well as to remove nitrogen from the water are well documented. However, the use of shellfish as a tool in a TMDL Implementation Plan is a novel idea. The use of shellfish as a tool in TMDL implementation plans can be accomplished through nutrient trading credits. By using nutrient trading credits, both public and private aquaculture can be enhanced and subsidized.

KEYWORDS
TMDL, Implementation Plans, Nitrogen, filtration, oysters, nutrient trading

NUTRIENT OVER-ENRICHMENT AND TMDLS

Section 303 of the Clean Water Act, requires each state to produce a Total Maximum Daily Load (TMDL) report for each of its bodies of water that are impaired by pollutants. This report identifies the pollutants; the current level of the pollutants; and the level which the pollutants must be reduced. In addition, strategies must be identified to accomplish the goal of pollutant reduction.

For many coastal water bodies, the main pollutant issue is Nutrient Over-Enrichment. Nutrient pollution causes an increase in algae and phytoplankton in the water body. This increase serves to block sunlight to the lower depths of the water body. The decrease in sunlight eventually kills plant life on the bottom of the water body, causing eutrophic conditions.

The demise of plant life decreases the amount of dissolved oxygen in the water as well as decreases critical habitat for fin fish, shellfish, etc. In addition, when the algae and phytoplankton die, their remains sink to the bottom of the water, where they are consumed by bacteria. This consumption further decreases the level of dissolved oxygen, leading to hypoxia.

"Excess inputs of nutrients and contaminants are currently impairing coastal waters throughout the world with nutrients currently having the largest impact. Excess nutrient enrichment leads to excessive production of algal biomass, loss of sea grass habitats and depletion of dissolved oxygen….(it is) estimated that 60% of the estuaries in the NE were moderately or highly eutrophic." (Giblin & Bliven, 2005)

NUTRIENT POLLUTION AND BUZZARDS BAY

As with many coastal waters, the waters of Buzzards Bay have been negatively impacted by nutrient pollution. Buzzards Bay is located in southeastern Massachusetts bordered on the south by the Elizabeth Island chain and to the east by Cape Cod. The Bay contains approximately 228 square miles of surface water with a watershed nearly twice that size.

More than half of Buzzards Bay’s harbors, coves, and tidal rivers are suffering from nutrient pollution, due to a great extent to the large increases in population within its watershed area. As with most coastal waters, human activities and development have nutrient levels to highly critical levels.

The principal sources of nitrogen in Buzzards Bay include septic systems, wastewater treatment plants, stormwater runoff, lawn and agricultural fertilizers, and acid rain – all coming from a growing population and increasing, poorly-planned development throughout the Bay’s watershed. Today, more than ½ of the bay's harbors and coves are degraded due to nitrogen. (Haupert and Rasmussen, 2003)

“Due to nitrogen pollution’s destructive impact on marine ecosystems, this increasing problem is regarded by scientists as the greatest long-term threat to the health and vitality of Buzzards Bay. As the health of the Bay declines, additional negative impacts occur, such as murky waters, bad odors, and loss of marine plants and animals like eelgrass and shellfish. Nitrogen-related water quality degradation is focused in the Bay’s nearshore, shallow areas – the same areas that support the majority of the Bay’s recreational and economic uses.” (Haupert et al., 2003)

In the next three to five years, Total Maximum Daily Load (TMDL) reports for the Bay’s waters will be completed. These reports represent the start of the process nutrient removal process in the embayment waters in compliance with Section 303 of the Clean Water Act.

Traditionally, nutrient pollution in water bodies can be reduced by upgrading wastewater treatment plants, reducing N inputs from septic systems, reducing runoff from farm lands, etc. These techniques are commonly used in the TMDL implementation plans.

OYSTERS AS FILTER FEEDERS AND NUTRIENT REMOVERS

One of the groups monitoring the TMDL process for Buzzards Bay is the Coalition for Buzzards Bay, a citizens’ advocacy group. In anticipation of the TMDL reports and subsequent implementation plans, the Coalition for Buzzards Bay is reviewing the possibility of using shellfish, primarily oysters, as a nutrient removal tool.

Since the 1980s, scientists and aquaculturists have been advocating the benefits of shellfish aquaculture in cleaning water from the effects over nitrification. A number of these groups have gone as far as suggesting that shellfish aquaculture could be included in the implementation plans for TMDL compliance.

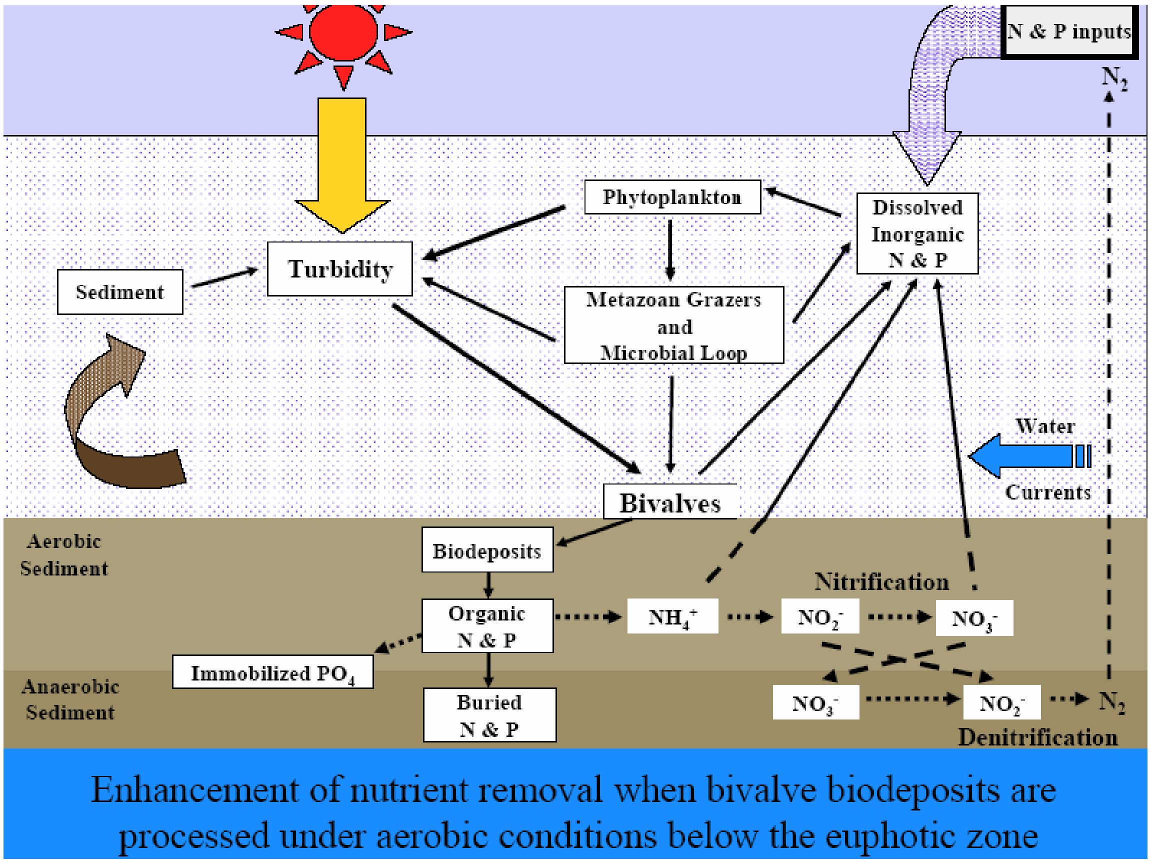
Roger I. E. Newell (1988) hypothesized that the oyster population in the Chesapeake Bay was large enough in the 1890s to turnover the water in 3 days as opposed to the present 350 days. This led to further studies on the filtering abilities of oysters which have estimated that each adult 3” oyster filters between 30 to 50 gallons of water per day.

Newell further hypothesized that there was a direct link between the increase in nutrient-related pollution (algae and phytoplankton blooms and related eutrophic and hypoxic conditions) in Chesepeake Bay and the decline of the Chesepeake Bay's oyster population. The subsequent invasion of zebra mussels in the Great Lakes and the resultant increase in water clarity added support to this theory.

Oysters (and other shellfish) consume the byproducts of over-nitrification, namely algae and phytoplankton. "Filter feeding oysters enhance water clarity and either assimilate the nutrients or deposit them on the benthos as fecal strings bound in mucus. Many researchers have compared the cumulative filtration capacity for a population of bivalves with the tidal exchange and concluded that bivalves can exert a significant and controlling influence on particulate matter in many shallow coastal systems (reviewed by Dame, 1996). The reduction in turbitity increases light penetration, which can allow eelgrass to recolonize areas wehre it has struggled due to eutrophication, excessive nitrogen and inadequate light levels (Cohen et al. 1984, Nelson et al. 2004, Newell and Koch 2004, Rheault 2004, Rice 2001)." (Rheault, 2005)

The nitrogen absorbed into the flesh and shell (biomass) has been measured in a number of studies, and is universally accepted at 0.5 grams per oyster. So, in round numbers, it would take approximately 20 oysters to remove 1 gram of N at the time of harvest.

"A weekly harvest of only about 200 oysters can compensate for the nutrient inputs of a typical waterfront homeowner on a properly functioning septic system (Rice et al. 2001). A commercial weekly harvest of ~10,000 oysters contains about 13.6 kg of nitrogen and 1.4 kg of phosphate, and can result in the removal of 100kg of N per year! In simple terms an oyster farm of about 1 ha can compensate for the nitrogeneous wastes of 40-50 coastal inhabitants. (see Newell et al. 2003)" (Shumway, Davis, Downey, Karney, Kraeuter, Parsons, Rheault & Wikfors, 2003)



Enhancement of nutrient removal when bivalve biodeposits are processed under aerobic conditions below the euphotic zone

Wickfors (2006)

Harvesting of these oysters would have the additional benefit in that the harvest product can be sold to the public, either directly at seafood markets or indirectly via restaurants and other food-service establishments. This creates both environmental as well as economic benefits to coastal communities.

The question remains, however, can shellfish be integrated into the TMDL process? An obvious way would be through the establishment of nutrient trading credits based upon the filter-feeding/nutrient removal abilities of oysters.

NUTRIENT TRADING

EPA Guidelines for Nutrient Trading

The US EPA, environmental groups, and state governments have been advocating the development of nutrient trading regimes as a method of compliance to the Clean Water Act, and as a strategy to be employed in the implementation plans of TMDLs. Nutrient trading may allow waste water treatment facilities the option to achieve TMDL nutrient reduction goals by funding other more cost-effective nutrient reduction measures rather than paying for costly expansions and upgrades to their waste water treatment facilities. Trading is not a substitute for a regulatory framework, but rather it is a policy tool that can be used alongside regulation.

Reviewing EPA's water quality guidelines, a justification can be established which would allow oysters to be used in a nutrient trading process.

"EPA supports implementation of water quality trading by states, interstate agencies and tribes where trading:

A. Achieves early reductions and progress towards water quality standards pending development of TMDLs for impaired waters.

B. Reduces the cost of implementing TMDLs through greater efficiency and flexible approaches.

C. Establishes economic incentives for voluntary pollutant reductions from point and nonpoint sources within a watershed.

D. Reduces the cost of compliance with water quality-based requirements.

E. Offsets new or increased discharges resulting from growth in order to maintain levels of water quality that support all designated uses.

F. Achieves greater environmental benefits than those under existing regulatory programs. EPA supports the creation of water quality trading credits in ways that achieve ancillary environmental benefits beyond the required reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains and wildlife and/or waterfowl habitat. (author's italics)

G. Secures long-term improvements in water quality through the purchase and retirement of credits by any entity.

H. Combines ecological services to achieve multiple environmental and economic benefits, such as wetland restoration or the implementation of management practices that improve water quality and habitat." (author's italics) (US EPA, 2003)

Using shellfish restoration as part of a nutrient trading scheme would fulfill items F and H in the EPA's Nutrient Trading Objectives, as shellfish de-nitrification would provide greater benefits in the form of shellfish habitat restoration as well as multiple economic and environmental benefits.

State Nutrient Trading Programs

A number of states have established nutrient trading programs which comply with EPA's guidelines. The most ambitious of these programs is the program in the Chesapeake Bay which involves the states of Pennsylvania, Maryland, and Virginia as well as the District of Columbia. This program allows nutrient trading amongst the states that border the bay or are part of the bay's watershed.

The question becomes how can oysters be used in a nutrient credit trading scheme? Nutrient trading involves units which can be clearly defined and measured. The issue with using shellfish (presumably oysters) is how can one satisfactorily define and measure nitrogen removal by oysters?

CAN OYSTERS BE EMPLOYED IN A NUTRIENT TRADING PROGRAM?

"Nutrient trading will allow aquaculturists, who can document the amount of N and P removed by their farms, to be paid by those industries that find it less expensive to purchase nutrient removal rather than upgrade their own facilities to meet the TMDL. The use of extractive animal and plant aquaculture is actually a unique solution to helping attain these water-quality standards because it offers the only opportunity to reduce nutrients once they have entered a receiving body of water." (Newell, 2004)

"In any nutrient trading scheme involving suspension-feeding bivalves, it will be relatively easy to account for N and P removed in shell and flesh based upon the annual harvest levels. Unfortunately, the factors that govern the magnitude of N removal and P immobilization (Newell et al. 2005) that are byproducts of rearing bivalves are too complex and variable to allow the use of fixed removal rates that can be applied across all shellfish aquaculture facilities." (Newell, 2004)

The nitrogen which is expended, is deposited in the sediment where some is buried. The remainder is consumed by bacteria and the nutrients are converted to N2 which returns to the atmosphere (denitrification).

The problem with using the nutrient removal via feces and pseudo feces is that it has been difficult to adequately quantifying the amount of N that is removed. The amount of N removal has been quantified in laboratory experiments. However, the behavior of oysters in laboratory experiments and the behavior of oysters in their natural habitat are different. One of the issues being the many variables which occur in the habitat (tidal action, currents, temperature, population of shellfish, etc.), while in lab experiments most of the variables are controlled. (Pietros & Rice, 2002)

Does this inability to measure the N removal via feces and pseudofeces automatically render oyster aquaculture unusable in a nitrogen trading scheme? The answer is no.

Nitrogen trading using oysters could proceed based solely upon the quantification of N removal via biomass at the harvesting of the oysters. N removal has been quantified and agreed to within the scientific and aquaculture community at 0.2 grams of N, or approximately 0.2% nitrogen by weight. Therefore, establishing the number of oysters to a nitrogen trading "currency" would be fairly straight forward. (Rheault, 2004)

The advantage of using solely the biomass is that nutrient trading could commence in a short time. Current restoration projects, governmental re-seeding/re-stocking programs, as well as current shellfish aquaculture operations could all be counted in the calculations which could be used in the TMDL implementation process. This would bring these activities into the pollution reduction programs almost immediately. The resulting biomass trading credits could be used to fund further projects or to subsidize existing projects.

The disadvantage would be that without counting burial and denitrification, an inefficient trading process would be developed. The biomass method would require more oysters than necessary to be deployed in an embayment. In turn, smaller water bodies, or those in highly utilized (recreational boating, swimming, residence) areas would be eliminated from candidacy as a site for oyster beds.

However, a grant project in the Chesapeake Bay region is attempting to develop a method of quantifying N removal via burial and denitrification so that nutrient trading credits can be established. The project is being conducted by Dr. Kurt Stephenson and Dr. Bonnie Brown. Their project, funded by a National Fish and Wildlife Foundation grant, proposes to create a method of measurement of the sediment in the areas beneath and surrounding an oyster bed to determine the amount of N buried in the sediment and released into the atmosphere for a given oyster population.

Their project proposes the following outcomes:

- Quantify nutrient removal associated with high density native oyster production, including identification and assessment of uncertainties
- Identify beneficial and adverse local water quality and environmental consequences of oyster production facilities;
- Develop estimates of the cost per pound to remove nutrients through assimilation services coupled with oyster harvest;
- Model regulatory language for state nutrient trading programs and other state nutrient reduction funding programs. (Stephenson, K. & Brown, B., 2006)

If the project is successful, the burial and denitrification method could be then translated into nutrient trading credits. This development would take the oyster nutrient trading to an entirely new level. Stephenson and Brown have estimated the burial and denitrification abilities of oysters to be up to 7 times greater than nitrogen removal through biomass alone. (Stephenson, et al., 2006).

Taking this estimate one step further and combining it with Newell's estimate that a commercial weekly harvest of ~10,000 oysters can compensate for the nitrogeneous wastes of 40-50 coastal inhabitants through biomass, then the total N removal (via biomass, burial and denitrification) could offset the nitrogeneous wastes of up to 500 coastal inhabitants.

Assuming that a waste water treatment plant for a community of 100,000 is operating at 90% efficiency in its N removal, then an oyster population of 100,000 oysters would be able to remove the remaining 10% N. A potential "rule of thumb" could be then generated for a target of 10% N reduction from point source pollution from a waste water treatment plant, of one oyster (during the course of a year) could remove the remaining N of one person (assuming that a waste water treatment plant was operating at 90% efficiency).

What would the cost for N removal be (and therefore the cost of N trading credits)? In his editorial entitled "Clean the Bay with Shellfish", Rheault (2004) estimates that the cost per pound of N would be between $40 to $79 per pound. Rheault's numbers are based only on biomass. Taking into account the associated N removal through burial and denitrification, that cost could drop to as little as \$5 to \$10 per pound. This cost is compatible with the nutrient trading credits established in the Commonwealth of Virginia's Pollution Discharge Elimination System which sets payments at \$11.06 per pound. (Commonwealth of Virginia, 2006). It is also well below the state of Maryland estimate of \$28 to \$54 per pound of N removed. (Rheault, 2004).

Another way of using oysters in the N removal process could be to compensate for non-point source or atmospheric deposition. In any TMDL report, quantifying N inputs from waste-water treatment plants and other point sources is fairly easy to determine. It is not so easy, however, to quantify the N inputs from certain non-point sources as well as from atmospheric deposition. This is why TMDLs also contain a so-called Margin of Safety or MOS.

"A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant and the quality of the receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements." (US EPA Region 3, 2007)

Oysters could be used as a method of N removal for the Margin of Safety alone, assuming a margin of safety was approximately 10 to 15% of the total N input into the body of water. The issue then would be how would the nutrient trading credits be funded, or how would the oyster beds be funded for MOS N removal.

There is a third option. Given the amount of nutrients removed by oysters via biomass, sequestration and denitrification and the costs associated with this (between \$10 to \$20 per pound of N removed). A process could be developed in which trading credits would be sold to point-source polluters which would allocate ½ of the nutrient credit to the point source polluter and the remaining ½ would be applied to the MOS for the water body. Effectively, the cost per pound of N removed would be \$10 to \$20 for the waste water treatment plant. However, the nutrient reduction within the MOS would then be subsidized by the remaining ½ credits.

Methods of Oyster Cultivation for Nutrient Removal

Three methods of oyster cultivation could be used in conjunction with a nutrient trading scheme: public re-seeding/re-stocking, private aquaculture, or private shellfish gardening. In Massachusetts, for example, the Commonwealth and local communities fund reseeding and restocking of oyster and other shellfish beds through tax dollars and revenue received through the issuance of local shellfish licenses (both recreational and commercial). Revenue raised through nutrient trading credits could be used to not only increase the acreage of reseeded and restocked beds, but also to begin to reseed and restock beds in areas where shellfish have not been traditionally grown.

The aquaculture industry would benefit from the revenue raised through nutrient trading credits which would help to subsidize new infrastructure, new equipment as well as the leasing of shellfish beds from state and local communities. The leasing of shellfish beds would, in turn, provide additional revenue to the states and local communities.

The final option would be to encourage private shellfish gardening. Virginia and Maryland as well as other states have created regulations allowing private individuals to grow oysters and muscles in containers which are suspended below docks.

The advantage of under dock oyster gardens is that racks and containers are placed in areas which are generally considered to be unusable or inaccessible, and by the nature of being located under the docks, are generally protected. These containers also have the advantage of being suspended within the water column and therefore the filtering effect of the oysters is at its maximum efficiency.

The disadvantage of the oyster garden is that there is the potential for oysters to become infected with diseases which cause illnesses in the humans who would consume the oysters. However, most states require that the oysters be periodically tested to ensure that they are safe for human consumption. The potential effect on the human population is limited by the prohibition of commercial sales of the oysters grown in oyster gardens.

In Virginia alone, there are over 2000 private oyster gardeners. Assuming that each of the gardeners employs just one Taylor float (a Taylor float will hold 500 adult oysters), that would mean that there would be 1,000,000 oysters potentially filtering the waters of the Chesapeake Bay. These oysters would have the potential of filtering up to 50,000,000 gallons of water per day. (Commonwealth of Virginia, 2006)

By using Newell's estimates of ~10,000 oysters' biomass removing the equivalent of nutrient output of 40 to 50 persons, then the Virginia Oyster Gardening program currently has the ability to remove the nutrient output of up to 5,000 persons through biomass alone.

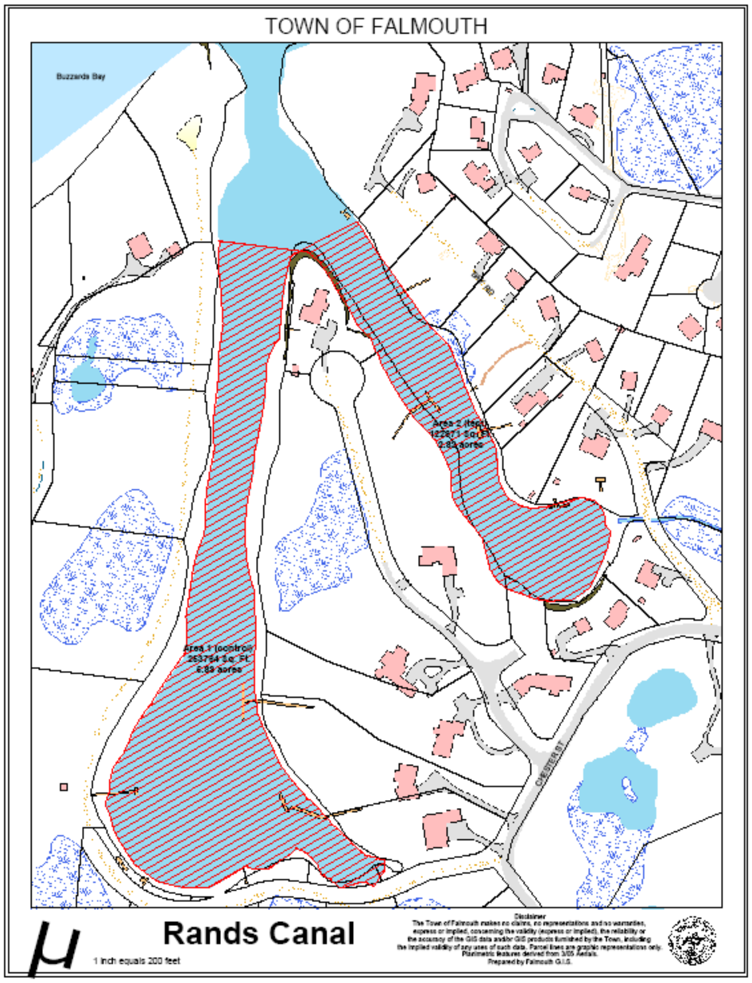
Traditionally, the oyster gardener purchased his/her own oyster spat and equipment, however, revenue received through nutrient trading credits could be used to subsidize these costs as well as to expand the program and its monitoring efforts.

BUZZARDS BAY PILOT PROJECT

The Coalition for Buzzards Bay is exploring the possibility of a test site to determine the feasibility of using oysters and nutrient trading in the waters of the Bay. Sites at Rands Canal and Rands Harbor are being investigated because both bodies of water flow into a common harbor, and Rands Canal will serve as the test site and Rands Harbor will serve as the control site.

The waters were chosen because of their nutrient loading is low and would mimic a body of water which has had nutrient input reduced through installation or upgrading of water treatment (point source) facilities. The Coalition has 10 year's worth of water quality data on the Rands Harbor/Canal areas, so a base-line has been established.

The measurement of nutrient removal through sequestration and denitrification may be conducted using the protocols and techniques developed by Drs. Stephenson and Brown. The testing and measurement would need to be conducted over a period of three years, and the data would be available in time for the majority of the TMDL reports for the bay area to be completed. If this project is successful, then the Coalition would have the basis to advocate oyster bed nutrient trading as part of the bay-wide TMDL implementation process.



CONCLUSION

It is clear, that the coastal waters and embayments of the United States suffer from both the negative impacts of nutrient pollution as well as a decrease in the population of native oyster and other shellfish stocks. These two issues are directly related to each other as shown through historical data, laboratory experiments, etc.

This paper has shown that not only does the scientific data support the theory that oysters can play an important role in removing the effects of nutrient pollution, but that oysters could be employed in a nutrient trading process.

By using oyster based nutrient trading, a cost-effective tool for nutrient removal can be developed. In addition, habitats can be restored and through the harvesting of oysters income and revenue can be created. Communities would receive two economic benefits, one through the revenues raised through the harvest of oysters and the other from clean waters in local embayments.

Oyster bed nutrient trading also has the potential of being a wonderful tool to build public awareness of nutrient pollution and its clean-up. It has been said that nutrient pollution is not a visible problem as pollution caused by an oil spill. Therefore, public awareness of nutrient pollution is not as great.

However, most people have had experience with oysters, mostly as a food source. Oysters are also a visible inhabitant of our coastal waters, as opposed to other shellfish species such as clams or quahogs. Because of this awareness as well as the visibility of the oysters in our waters, efforts to remove nutrients will be very visible to the public.

It is time for the links described in this paper and advocated by the aquaculture community to be put into practice as a TMDL nutrient removal tool. Nutrient removal by oysters is a cost-effective tool and provides benefits above and beyond clean water.

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