Marine Extension Bulletin

Jan 2014

Woods Hole Sea Grant Program
Cape Cod Cooperative Extension

Shellfish, Nitrogen, and the Health of our Coastal Waters

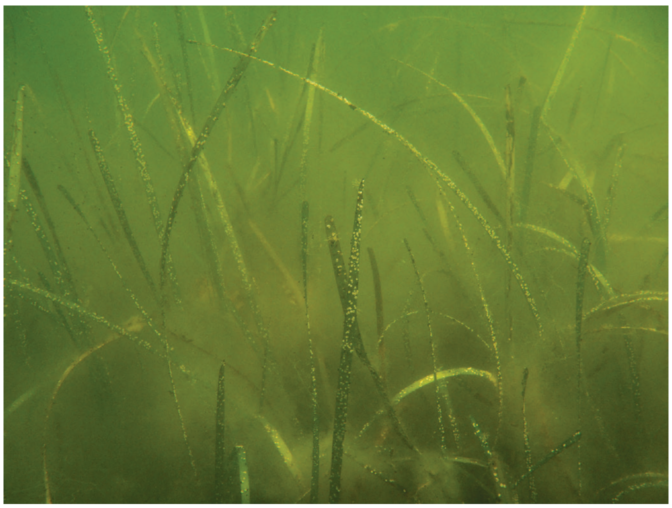

Figure 1. Eelgrass competing with macroalgae or seaweed in nutrient rich waters. Eutrophication will often cause eelgrass to decline as algae takes over, one way in which marine habitat may be altered.

Our coastal water bodies and estuaries are essential habitat for many species and are also important to the economic health of coastal communities. While nitrogen (N) is a vital nutrient to the marine environment, in excess it causes eutrophication or an increase in the rate of supply of organic matter to a system (Nixon 1995). Eutrophication can lead to a series of negative consequences and thus nitrogen can be a root cause of habitat degradation (Howarth 2008). Reducing nitrogen to thresholds identified as important to maintain ecosystem health is the approach being examined throughout coastal Massachusetts. Strategies being considered for reduction of nitrogen include centralized or improved wastewater treatment, stormwater treatment, increased tidal flushing, enhanced attenuation via wetlands, and others (Dudley 2003).

The propagation of shellfish is another strategy that is currently being considered as a method to reduce nitrogen in coastal waters, with several municipalities scaling projects for this effect. Bivalve shellfish, including commercially important oysters (*Crassostrea virginica*) and quahogs (*Mercenaria mercenaria*), live in coastal water bodies and derive their nutrition by filter feeding on available algae or phytoplankton in the water column. The productivity of nearshore waters has sustained a long history of economically important shellfish harvest through commercial and recreational fishing as well as more recently through aquaculture. These filter feeding shellfish are also important ecologically. They provide food and habitat for other marine and estuarine species, and promote the cycling of nutrients by grazing upon phytoplankton blooms.

Since bivalve shellfish obtain nutrition from their local environment and are an integral part of the ecosystems in which they live, managing shellfish populations has become an important part of managing a healthy water body. Unfortunately, due to a number of factors most of our nearshore shellfish populations are in decline. In fact, it has been estimated that 85% of oyster reefs have been lost globally, with U.S. Atlantic coast oyster reefs classified as poor or functionally extinct (Beck et al. 2011). With declines in natural populations and increased recognition of ecosystem services lost, communities are increasingly interested in examining the potential for propagation and/or restoration of shellfish to help remediate a portion of increasing nutrient inputs.

Figure 2. Quahog seed being grown through a municipal shellfish program.

Potential ways for shellfish to be used in nitrogen remediation

Shellfish do not absorb nitrogen directly from their environment but act as a first order consumer as they graze on phytoplankton (primary producer). The microscopic plant life shellfish feed upon assimilate dissolved nitrogen available directly from the surrounding waters, which can be transferred to the shellfish following consumption and digestion. As shellfish graze

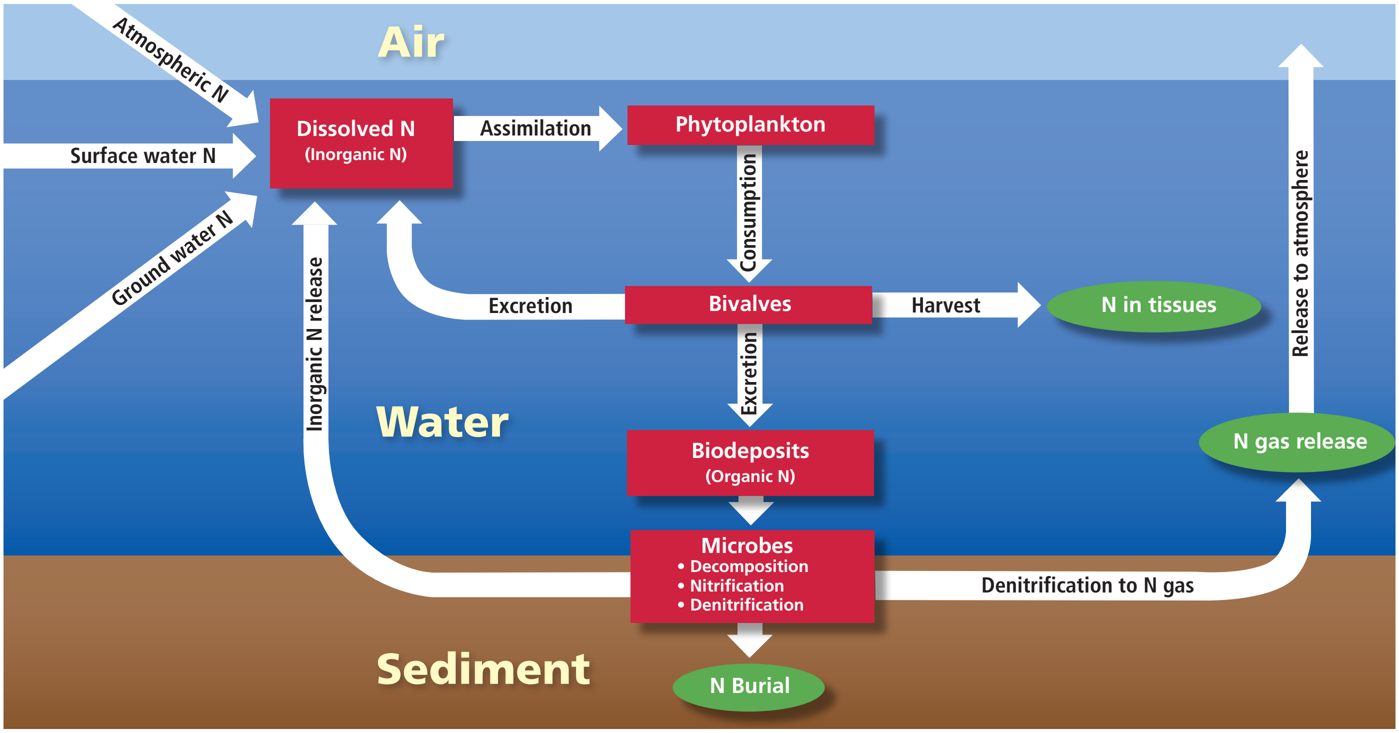

Figure 3. An overview of how bivalves interact with the marine nitrogen cycle, and potential ways in which nitrogen may be removed in green. Adapted from Newell et al. 2002 and http://oyster.agecon.vt.edu

and grow they incorporate an increasing amount of nitrogen from the local waters into their tissues. Overall, the filter feeding activity of shellfish affects the marine nitrogen cycle through incorporation of nitrogen in shellfish tissues and the cycling of nitrogen through the particulate waste (feces and pseudofeces), collectively called biodeposits (Figure 3).

Nitrogen may be removed from the marine environment via shellfish in two general ways. Shellfish can be harvested directly thereby removing nitrogen accumulated in the tissues, or through the interaction of particulates released by shellfish and the surrounding sediment. In the biodeposition and sediment interaction, the particulate waste (biodeposits) generated by shellfish falls to the bottom and can either become buried or feed an active population of sediment microorganisms. Under the right conditions these microorganisms can process the biodeposits, resulting in the production of di-nitrogen gas (through the nitrification and denitrification processes) which is then released to the atmosphere thereby removing it from the marine environment (for more complete description see Newell et al. 2002, Kellogg et al. 2013).

The process of denitrification occurs naturally in coastal water bodies, and may be further stimulated by shellfish populations becoming a significant source of nitrogen removal from the water column cumulatively over the course of a bivalve's life (Newell et al. 2005). Oyster reefs in particular have been shown to have dramatically higher rates of denitrification compared to control sites (Kellogg et al. 2013), while the evidence is limited and a bit unclear relating the influence of shellfish aquaculture to these processes (Higgins et al. 2013, Nizzoli et al. 2006). Denitrification rates also vary seasonally based on levels of shellfish and microbial activity (Kellogg et al. 2013, Newell et al. 2005) and are also based largely on site and sediment conditions, including bivalve densities (Burkholder & Shumway 2011). Further complicating the assessment of potential rates of nitrogen removal through bivalve stimulated denitrification and/or burial is the fact that the analyses of these processes is challenging and expensive for practical purposes.

How much nitrogen can a shellfish hold?

Determining the amount nitrogen present in shellfish shell and tissues is less complicated and may provide the most direct approach to quantifying the amount of nitrogen that could be removed from a water body through shellfish production and harvest. Literature values are available for some species of shellfish but largely focus on eastern oysters in the Chesapeake Bay region where nitrogen enrichment is also a prominent issue. Fewer literature values are available regarding our other commercially important shellfish like the northern quahog (or hard clam). Available values for nitrogen content in oysters and quahogs (Newell 2004, Higgins et al. 2011, Carmichael et al. 2012, Sisson et al. 2011) are of a similar range, though display some variation between species, location, size, grow out method, and season of harvest.

Due to this variability in the available literature a study was undertaken to determine nitrogen content values for oysters and quahogs in Massachusetts. Both species were sampled from a variety of sites in southeastern Massachusetts , including both wild and cultured stocks, in both the spring and the fall.

Results from local oysters are similar to reported values from the Chesapeake region, though may be slightly higher on average, and quahog nitrogen values were all higher than those previously reported. The biggest differences or points of variation seem to be ultimately related to either size or amount of tissue contained. For instance, a 3 inch (76mm) wild Chesapeake Bay oyster (Newell 2004) was found to have more nitrogen by weight though this was due to a shell weight over 3 times higher than that reported for other groups of oysters (Table 1). Even among Massachusetts oysters the way in which the oysters were grown showed differences in shell mass corresponding to increased mass of nitrogen per animal. Likewise,

Table 1. Quahog and oyster data summary showing the average of spring and fall Massachusetts samples with literature comparisons, NS indicates values were not specified.
Adapted from Newell and Mann 2012.

	Shell Length (mm)	Shell DW(g)	Tissue DW(g)	Tissue %N	Shell %N	Total N(g)	Total % N(DW)
Quahogs from Cape Cod							
Wild	57.1	32.6	2.43	7.50	0.18	0.24	0.67
Cultured	55.0	29.6	1.99	7.90	0.17	0.21	0.66
Quahog average	56.1	31.2	2.22	7.69	0.18	0.22	0.67
Wild quahogs from Virginia (Sisson et al. 2011)							
	NS	NS	NS	5.96	0.15	NS	NS
Oysters from Cape Cod							
Wild	82.7	46.0	2.42	8.20	0.26	0.31	0.67
Cultured On-bottom	84.9	47.4	2.70	7.89	0.26	0.32	0.65
Cultured Off-bottom	83.1	35.7	2.36	7.95	0.21	0.26	0.70
Off-bottom Triploid	86.5	22.3	1.36	8.50	0.32	0.19	0.82
Oyster avgerage	83.8	40.9	2.43	8.01	0.24	0.28	0.69
Wild oysters from reefs in Chesapeake (Newell 2004)							
	76.0	150.0	1.00	7.00	0.30	0.52	0.34
Cultured floating cage oysters in Chesapeake (Higgins et al. 2011)							
	85.5	37.6	1.58	7.28	0.17	0.18	0.45

a harvestable oyster tends to weigh more and thus have more nitrogen than a "littleneck" sized quahog, the size most valuable and popular for quahog harvest.

In terms of season, shellfish meats tend to be "lean" in the spring and "fatten" into the fall with extra storage in tissues for winter. In fact it was found that oysters in October had 98% more meat tissue compared to those of similar length in June. Over the same period, quahogs averaged a 63% increase in tissue, leading to increased quantities of nitrogen stored in biomass for fall harvests of both species.

Cultured and wild origin quahogs are not much different in terms of nitrogen content, but oysters did exhibit differences. Oysters of wild origin or those cultured on the bottom have thicker heavier shells which results in a higher nitrogen content than thinner shelled oysters grown off the bottom. Small differences between water bodies were seen but these differences were not as dramatic as the seasonal differences and it may be somewhat related to nutritional status of the shellfish at the time of sampling.

Variables affecting tissue mass such as size, season, or grow out method (for oysters) ultimately translate to varied quantities of nitrogen contained, an important parameter to keep in mind when considering nitrogen removal potential. This is increasingly important if shellfish are not harvested at uniform size. For example, a large chowder sized quahog weighing in at about a pound in whole live weight could contain the nitrogen equivalent of about eight littlenecks.

Summary

Local nitrogen content data indicate Massachusetts shellfish are indeed an important part of nutrient cycling in nearshore waters, and the harvest of their tissues may represent a method to directly remove nitrogen from enriched embayments. In addition to the habitat value of shellfish and the removal of nitrogen through harvest, there is potential for additional nitrogen removal through the processes of denitrification and burial though these numbers are more difficult to quantify. Quantification of nitrogen removal through shellfish harvest can be accomplished more simply and directly than quantification of denitrification. However nitrogen removal through harvest will potentially fluctuate as a result of seasonal variations in shellfish activity, a population's susceptibility to predation and disease, or extreme weather events. This method also requires

Figure 4. Varying morphology of oysters from different sources.

accurate quantification of numbers of shellfish being harvested from specific water bodies.

It is recommended if nitrogen removal is to be pursued and credited to shellfish harvest, the amount be quantified on a unit weight basis due to the fact that the amount of nitrogen contained in an individual shellfish is directly correlated to size (i.e. amount of tissue). Estimates based on the number of animals harvested may significantly under or overestimate nitrogen based on the value being used. Shellfish are an important part of our coastal ecosystems and properly managed propagation, restoration, and harvest of bivalve populations can be an important tool in mediating the growing nutrient enrichment issues faced in coastal Massachusetts waters. However, shellfish act at an ecosystem level with limitations; nitrogen management plans that include shellfish as mitigation should also adequately address nitrogen inputs to marine ecosystems.

If more detailed information and analysis of nitrogen content in Massachusetts oysters and quahogs is desired, a more complete report is available through the Cape Cod Cooperative Extension or Woods Hole Sea Grant.

This publication was prepared by J. Reitsma, D. Murphy, and A.F. Archer under NOAA Grant # NA10OAR4170083, Woods Hole Sea Grant Project # M/0-2s, through NOAA's National Sea Grant College Program, U.S. Dept. of Commerce; and was supported in part by Barnstable County's Cape Cod Cooperative Extension. It should be cited as follows: Shellfish, Nitrogen, and the Health of our Coastal Waters by J. Reitsma, D. Murphy, and A.F. Archer. We thank R.W. Fulweiler of Boston University and R. York of the Mashpee Shellfish Department for help in review of this document. The statements, findings, conclusions and recommendations are those of the author(s) and do not necessarily reflect the views of the aforementioned organizations.

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This document, a collaboration of the Woods Hole Sea Grant Program and Barnstable County's Cape Cod Cooperative Extension, should be cited as follows: Shellfish, Nitrogen, and the Health of our Coastal Waters by J. Reitsma, D. Murphy, and A.F. Archer.

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