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Monitoring Shellfish Aquaculture

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1. Background

This section describes recommended monitoring procedures for shellfish aquaculture. Shellfish aquaculture for nitrogen management involves setting up and maintaining shellfish aquaculture and harvesting operations for the purpose of reducing nitrogen concentrations in estuarine waters.

Monitoring of shellfish aquaculture will differ depending on the mechanism of nitrogen removal that needs to be documented for credit. There are two different mechanisms involved when shellfish are used to reduce nitrogen concentrations: direct uptake of nitrogen and denitrification. Both can be important and so a third mechanism would be to account for both.

1) Direct uptake of nitrogen into shellfish tissue and shells followed by harvesting. When shellfish filter-feed, they ingest organic particles containing nitrogen (e.g., algae, plankton, organic detritus) and this nitrogen is converted into shellfish tissue and shells. The nitrogen in shellfish tissue and shells is removed from the estuary when shellfish are harvested. The key removal mechanism is uptake of particulate nitrogen from the water column by shellfish. Research and pilot tests show that the nitrogen content of shellfish varies with species, size, salinity, and aquaculture configuration (i.e., on-bottom culture vs. floating culture). For more information on studies of nitrogen content in shellfish, see the References and Notes.

2) Microbial processes that favor denitrification. Living shellfish excrete nitrogen-containing wastes into the surrounding water and sediments. Microbial nitrogen-cycling processes (e.g., ammonification, nitrification, denitrification) convert the nitrogen into dissolved inorganic forms (ammonia, nitrate) and gaseous forms (primarily N_2) . Dissolved inorganic nitrogen re-enters the water column and can be used by algae. However, denitrification converts dissolved nitrate into gaseous nitrogen (N_2) which is not available to most algae and hence this nitrogen gas may be considered as nitrogen removed from the estuary. More research is needed to characterize denitrification rates in Cape Cod environments (Reitsma et al., 2014). The key removal mechanism here is denitrification, since only a small amount of nitrogen is permanently buried in sediments. It should be noted that shellfish may also decrease ambient denitrification rates if the loading of organic matter to the sediments is very high and especially if the shellfish aquaculture causes local oxygen depletion in bottom waters.

3) A combination of shellfish harvesting and microbial denitrification. Combining both of the above mechanisms should result in a larger net reduction in nitrogen in the estuary.

Monitoring methods will therefore differ depending on which nitrogen-removal mechanism must be documented in order to get credit. If the goal is to demonstrate direct uptake and removal of nitrogen by shellfish harvesting, monitoring will be relatively straightforward and based on routine observations; this type of monitoring is likely to be feasible for municipalities. However, if the goal is to demonstrate that denitrification or burial in sediment is removing nitrogen from the water column, more complex scientific monitoring is needed to analyze and quantify microbial nitrogen cycling and nitrogen removal processes. This requires scientific knowledge of microbial nitrogen cycling and scientific expertise to design and implement field and perhaps lab studies to address specific questions; this is likely to be best conducted by scientists or scientific consulting firms working with scientists. Finally, if the goal is to demonstrate that both mechanisms of nitrogen removal are operating, then both monitoring approaches would be used.

2. Shellfish uptake of nitrogen

Recommendations for monitoring of shellfish uptake of nitrogen fall into two categories: pilot testing for proof-of-concept and long-term implementation.

2.1. Pilot testing for proof-of-concept

For each location and aquaculture configuration being tested, monitoring parameters that are needed to estimate the amount of nitrogen removed by shellfish include:

a) Shellfish parameters:
- Number of shellfish in a standard harvested volume (e.g., bushel, peck, barrel, etc.), size classes present in the standard harvested volume, and numbers of shellfish in each size class (or weight of shellfish in each size class).
- Number of standard volumes of shellfish that are harvested at a given location in a given unit of time (e.g., year).
- For each size class, measure dry weights of shellfish tissue and shell separately, using a pooled sample of 10-20 animals.
- For each size class, measure the percentage of nitrogen (N) in tissue and shell separately, using a pooled sample of 10-20 animals (note that the shell has a low percentage of N but due to its weight can account for 25% or more of N removal);
- Geographic differences in N-uptake related to the particular estuary;
- Species-specific differences in N-uptake related to the shellfish species being tested.
- Survival and mortality rates (useful for determining if the site is suitable for growing shellfish);
- Frequency of monitoring nitrogen removal in harvested shellfish: annual.
- Calculations to perform:
  - Total number of shellfish grown and harvested (calculated by multiplying the total number of shellfish in a standard harvested volume by the number of volumes harvested).
  - Total number of shellfish in each size class harvested (calculated by multiplying the number of shellfish in each size class by the number of standard harvested volumes).

   - Calculate the total amount of nitrogen taken up by harvested shellfish as follows: for each size class, calculate the amount of nitrogen taken up by shellfish tissue by multiplying the number of shellfish harvested by the average nitrogen concentration of shellfish tissue for that size class. Do this for all size classes. Repeat this for shell for all size classes. Sum the amounts of nitrogen in shellfish tissue and in shell for all size classes.
   - If the total weight of shellfish in each size class is going to be used to calculate nitrogen uptake, the total wet weight of shellfish (shell and tissue) in each size class must be converted to a dry weight and then multiplied by the % of nitrogen for that size class, to obtain the total amount of nitrogen removed by that size class. This is repeated for all size classes.

b) Water quality parameters:
- Water clarity (Secchi disc, total suspended solids);
- Total nitrogen;
- Particulate nitrogen;
- Dissolved oxygen, at several depths in the water column (at a minimum, in the surface layer, mid-water-column, and near-bottom);
- Chlorophyll a;
- If more than one shellfish species are being tested, monitor for species-specific differences in the above parameters.
- Frequency of monitoring water quality; Initially water quality should be monitored every two weeks for all parameters except dissolved oxygen. For dissolved oxygen, continuous monitoring of near-bottom water would be best as dissolved oxygen can vary a great deal on a daily basis.

c) Sediment quality parameters, as necessary (see Section 3 below).

d) Duration of pilot testing: For each location where shellfish aquaculture is being considered, pilot testing should be conducted for at least two (2) years in order to generate enough useable data to evaluate feasibility.

e) For multiple locations that are being tested, geographic differences in the above parameters should be evaluated.

2.2. Long-term implementation

Once pilot testing demonstrates that sufficient shellfish uptake of nitrogen occurs consistently and is otherwise feasible, then long-term monitoring parameters include:

For each location and aquaculture configuration where shellfish aquaculture is being used:
- Annual shellfish harvest data:
   - Number of standard volumes of shellfish harvested,
   - Average number of shellfish per standard volume, based on samples,

  - The total number of shellfish harvested, based on multiplying the two numbers above;
  - Size classes present in standard volumes, based on samples,
  - Number of shellfish in each size class, based on samples,
  - Estimated amount of nitrogen removed by each size class, summed over all size classes (calculated as described above under Pilot Testing),
- As water quality changes, monitor nitrogen concentrations in shellfish tissue and shell, by size class, every few years;
- Occasional sediment quality data (e.g., every 2-3 years – see Section 3 for parameters);
- Occasional water quality monitoring of pond for dissolved oxygen, total nitrogen, and chlorophyll a (e.g., 4 times a year).

In order to ensure that shellfish harvesting meets nitrogen removal targets, institutional processes should be in place to track and record shellfish harvests as described above. If shellfish harvesting cannot be completed for some reason (e.g., closure due to red tide, oil spills, or other reasons) then the amount of nitrogen that is not removed needs to be accounted for.

3. Monitoring shellfish denitrification and burial of nitrogen

Recommendations for monitoring of shellfish denitrification and burial of nitrogen fall into two categories: pilot testing and long-term implementation.

3.1. Pilot testing

Monitoring for the pilot test should include monitoring at both the reference station(s) and sites where shellfish aquaculture is being tested. Baseline monitoring to establish pre-treatment conditions should be conducted for at least one (1) year prior to the installation of the test shellfish aquaculture plots.

For each location, monitoring parameters include:

- Changes in sediment N removal via denitrification and other possibly sediment impacts due to increased organic matter deposition to the sediments.
- To document benthic communities, their biomass and nitrogen content, conduct rapid surveys of benthic animal community (grabs) within proposed aquaculture operation and then at some suitable reference sites, upstream and downstream of farm. Frequency: annually.
- Sediment water oxygen demand (SOD) and benthic nutrient fluxes should be monitored within 5-8 cores within proposed shellfish aquaculture or shellfish bed area. At the reference site, 5-10 cores should be monitored. Frequency: 3 to 4 times a year initially (May, July, Aug, Oct) and in the first few years.
- Measurements of sediment denitrification via a whole core method (i.e., not potentials) using either isotope pairing or N_2/Ar). 3-5 cores within beds and at a nearby reference site. Frequency: 2-3 times during spring-fall, with at least one mid summer.

- Sediment percentage of nitrogen (% N) and organic carbon (% C): measured at 5 sites within and outside of the beds, once a year.
- Bottom water oxygen, before and after farm put in, within bed area and at least one other location outside in reference area. Ideally this would be continuously logged from May-October; and
- If more than one shellfish species are being tested, monitor for species-specific differences in the above parameters.

Note – rapid surveys of benthic communities and measurements of sediment denitrification via a whole core method are expensive and may not need to be done every year. After the initial assessment sediment oxygen demand (SOD) could be a indicator of sediment changes and 1 and 3 may not need to be repeated unless SOD or water column O_2 changes.

For multiple locations that are being tested, geographic differences in the above parameters should be evaluated.

3.2. Long-term implementation

Once pilot testing demonstrates that sufficient shellfish denitrification and/or burial of nitrogen occurs and is otherwise feasible, then long-term monitoring is conducted using many of the same monitoring parameters used for pilot tests, but monitored at a reduced frequency:

For each location where shellfish aquaculture is being used:

- Occasional monitoring of sediment quality data and water quality monitoring (e.g., dissolved oxygen, total N, chlorophyll a);
- Frequency of sediment quality monitoring: sediments could be monitored every 2-3 years for some parameters. Monitoring of denitrification may be repeated every 5-6 years or if water quality starts to deteriorate.
- Frequency of water quality monitoring: At least four times per year if the goal is to determine if shellfish aquaculture is successful.

4. Monitoring combined shellfish harvesting and microbial denitrification

Monitoring parameters for pilot testing and long-term implementation of combined shellfish harvesting and denitrification/burial will include combinations of the parameters described above.

5. Other monitoring

Shellfish diseases and seafood safety: For both pilot tests and long-term implementation, shellfish aquaculture will also require routine monitoring for shellfish diseases (e.g., Dermo, MSX) and shellfish safety (e.g., fecal coliform bacteria, Enterococcus bacteria, *Vibrio parahaemolyticus*, paralytic shellfish poison due to harmful algal blooms) as required by state and federal regulations. Research and outreach on new and emerging shellfish diseases and pathogens and methods to control these are critically important.

Harmful invasive species: Monitoring for harmful invasive species or predators such as green crabs should be conducted, followed by removal if feasible.

Ocean acidification: Ocean acidification due to increasing levels of carbon dioxide in the atmosphere and oceans could be a concern for shellfish aquaculture, wild shellfish populations and shellfish hatcheries alike. Excess carbon dioxide in the ocean causes carbonate concentrations in seawater to decrease, which impacts shell formation and larval survival (Washington State Fact Sheet, May 2014). In 2008 in the Pacific Northwest, increased upwelling of carbon dioxide-rich water contributed to ocean acidification which caused production at some oyster hatcheries to decline by as much as 80%. Adaptive measures included monitoring ocean acidity and shutting off seawater intake valves when acidity increased (NOAA, January 2012). However, ocean acidity varies regionally due to river inputs, upwelling, and other factors. This may be less of an issue in the Northeast, but scientific monitoring programs should continue and the results should be relayed to shellfish managers and regulators. Such monitoring is difficult and expensive and is beyond the scope of town monitoring programs.

6. Contingency plans

A contingency plan should address steps to take if shellfish aquaculture were to be impacted by a natural disaster or if harvesting were to be stopped or curtailed for some reason. The contingency plan should specify how backup removal of nitrogen will be provided if shellfish aquaculture or harvesting is partially or completely halted. In the event that shellfish are unsafe to consume (e.g., due to red tide, paralytic shellfish poisoning, or other causes) but are otherwise functioning to remove nitrogen, backup plans may include harvesting and proper disposal of inedible shellfish to prevent dead shellfish from re-entering the nitrogen cycle, switching to another method of nitrogen removal, or other measure.

7. Quality assurance and reporting

To ensure that quality data are collected, stored, properly utilized and reported, all of the monitoring procedures described above should be conducted according to standard protocols and procedures that are agreed-upon in advance. Typically this is done by developing and using a Quality Assurance Project Plan, or QAPP. The QAPP should specify the goals and objectives of the monitoring program, responsible parties and data quality objectives, and describe monitoring protocols (methods, equipment), data analysis, reporting, and addressing problems.

Existing QAPPs can likely serve as models for the development of a QAPP. Relevant QAPPs include those for monitoring water quality (Town of Falmouth Water Quality Monitoring Committee/SMAST) and sediment quality (MWRA) (see References for examples). A QAPP for monitoring shellfish aquaculture needs to be developed.

Wellfleet Audubon Sanctuary has developed a QAPP for monitoring shellfish bed restoration for the purpose of increasing biodiversity (see Faherty et al., 2011, under Shellfish Bed Restoration).

Reporting results is essential for evaluating performance. Reports should follow the QAPP and identify successes as well as failures. Annual reports to regulatory authorities and the public are likely to be sufficient unless problems develop.

8. Adaptive approach to monitoring shellfish aquaculture for nitrogen management

The use of shellfish aquaculture to reduce or manage nitrogen in estuaries is a new approach to waste management. Scientific research to examine the effectiveness of shellfish in taking up and cycling nitrogen is also relatively new, and there are still many research needs. Some examples of research needs are:

- Determining the degree of variability in shellfish uptake of nitrogen and nitrogen cycling processes in different Cape Cod embayments and for different shellfish species (Reitsma et al., 2014);
- Methods of controlling shellfish diseases;
- Methods of controlling invasive species that prey on shellfish; and
- Monitoring the effects of ocean acidification on shellfish aquaculture and wild shellfish in Cape Cod waters.

As new information emerges, an adaptive approach to monitoring should be utilized. Therefore, these recommendations for monitoring should be periodically reviewed and updated as new information becomes available.

9. References

Falmouth Water Quality Management Committee. Quality Assurance Project Plan for Little Pond Shellfish Demonstration Monitoring. Posted at: http://www.falmouthmass.us/depart.php?depkey=waterq , or http://www.falmouthmass.us/waterq/qappyr1final.pdf . This QAPP incorporates the QAPP for the Massachusetts Estuaries Project (Howes, B. and R. Samimy. June 2003. Massachusetts Estuaries Project Quality Assurance Project Plan (QAPP), The DEP/SMAST Massachusetts Estuaries Project, Year One Final. 400 pp.).

> Note: The QAPP for the Massachusetts Estuaries Project is also known as "2003 Massachusetts Estuaries Project for Management and Restoration of 89 southeastern Massachusetts Embayments. Quality Assurance Project Plan. Final Report to MA Department of Environmental Protection and USEPA, 650 pp. Published by MADEP". It does not appear to be available from the Internet.

Karplus, A., personal communication. Nitrogen removal per acre of shellfish aquaculture, by size class and age.

Massachusetts Water Resources Authority: Examples of some QAPPs for monitoring the Boston Harbor Sewage Outfall:

Nestler, E.C., A.E. Pembroke and R.C. Hasevlat. 2011. Quality Assurance Project Plan for Benthic Monitoring 2011–2014. Boston: Massachusetts Water Resources Authority. Report 2011-07, 90 pp. plus Appendices. Posted at: http://www.mwra.state.ma.us/harbor/enquad/trlist.html .

Costa A., E. Larson, and K. Stamieszkin. 2014. Quality Assurance Project Plan (QAPP) for Water Quality Monitoring in Cape Cod Bay 2014-2016. Boston: Massachusetts Water Resources Authority. Report 2014-07. 94 p. Posted at: http://www.mwra.state.ma.us/harbor/enquad/trlist.html .

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NOAA National Marine Fisheries Service webpage. January 2012. NOAA's Science Supports Shellfish Aquaculture. Posted at: http://www.nmfs.noaa.gov/aquaculture/docs/shellfish/noaa_science_spprts_shellfsh_aq.pdf .

NOAA Fact Sheet. January 2013. State of the Science Fact Sheet on Ocean Acidification.

Reitsma, J., D. Murphy and A.F. Archer. January 2014. Shellfish, Nitrogen, and the Health of our Coastal Waters. Woods Hole Sea Grant Program and Cape Cod Cooperative Extension. 4 pp.

University of Washington and Washington Sea Grant. May 2014. Fact Sheet on Ocean Acidification in the Pacific Northwest. May 2014. Posted at: http://www.wsg.washington.edu/admin/pdfs/ocean-acidification/ocean-acidification-brochure.pdf .

Notes: Local research indicates that the percentage of total nitrogen in shellfish (including both tissue and shell) averaged 0.67% for quahogs from Cape Cod, 0.69% for oysters from Cape Cod, compared to 0.34% and 0.45% for wild Chesapeake oysters and cultured Chesapeake oysters, and that shellfish size is the most important parameter that determines the amount of nitrogen taken up by shellfish; that is, as shellfish get larger, they take up more nitrogen (Reitsma et al., 2014). A local pilot study in Falmouth confirmed the size-uptake relationship and measured nitrogen removal (e.g., 1,190,000 2-inch oysters per acre removed 58,482 kilograms of nitrogen when oyster bags were maximized (A. Karplus, 7/17/14).

Jo Ann 9/29/2014 12:04 PM
Comment [1]: I'll update this with new info from Sia's updated #s and Ann's graduate student.