Water Quality and Benthic Impacts of Marine Aquaculture in Maine

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There is no debate that, at various times and places, aquaculture has caused undesirable, even unacceptable, changes to the environment. Nor is there argument that as aquaculture expands and evolves, there will be need to continually assess risks and monitor impacts associated with aquaculture. All aquaculture is based on an underlying requirement for a clean environment for two very practical reasons. First, the product must meet high standards of quality for human consumption and second, production is highest when environmental stress to the cultured organism is minimal. Whether related to pollution or carrying capacity, to a large extent, aquaculture is self-limiting (Braaten et al., 1983). Much has been written about impacts of aquaculture in other countries and regions of the world. But for the Governor's Task Force on Marine Aquaculture, the immediate issue at hand is "What is happening here in Maine?" and "What can the Task Force do to ensure that aquaculture in Maine is practiced in a environmentally acceptable fashion?"

Water Quality Law and Regulatory History

By definition, aqua"culture" involves manipulation of the natural environment. Under state water quality laws and the federal Clean Water Act, alteration of the natural environment is acceptable, as long as the "chemical, physical, and biological integrity" of a waterbody is maintained. What sets aquaculture apart from other uses of public water is that it is a direct and productive use of the resource that is itself vulnerable to water pollution. Virtually all other users of water (e.g. industrial and municipal discharges) use the public waters either to carry away wastes or for consumption. Also unlike aquaculture, most other users of water pre-treat incoming process water and do not depend on naturally clean water.

In 1984, the Maine Legislature formally designated aquaculture a protected use of coastal waters while holding it to water quality standards (Title 38 MRSA §465-B). When the state began to issue permits, it became clear that the state discharge permitting process for aquaculture was neither effective nor appropriate. As a result, in 1989, the Legislature exempted finfish aquaculture from having to obtain a State issued Water Discharge Permit from the Maine Department of Environmental Protection (DEP) as long as water quality standards were attained. Monitoring was conducted by aquaculturists and data submitted to the DEP. However, several problems were quickly realized:

- monitoring reports by operators were of inconsistent quality
- the cost of monitoring disproportionately affected small operators
- state regulators were unfamiliar with the industry and environmental impacts

To address these problems, in 1991 the Legislature created the Finfish Aquaculture Monitoring Program (FAMP), funding it through a penny a pound tax on industry production (Maine State Office of Policy and Legal Analyses. 1990; Parametrix, Inc, 1990). With FAMP, Maine was held as a national leader for emphasizing environmental results over "paper permitting." Further, unlike any other discharge in the Maine (and most of the rest of the U.S.) where the discharger collects the data and reports to the state, monitoring was under the direct control of the State. Not only did this provide the quality assurance and statewide standardization that was formerly lacking, it involved and educated the regulatory agency staff. Moreover, by scaling monitoring costs based on the magnitude of risk, one disincentive for small aquaculturist was removed.

FAMP results were annually reported to state and federal agencies and the conditions at each aquaculture operation reviewed (e.g. MDMR, 1992) Where environmental conditions did not meet water quality goals, companies were notified and remedial steps taken. Conkling and Hayden (1997) concluded in a report commissioned by Environmental Defense that

> "Maine has escaped many of the environmental problems that have beset marine aquaculture elsewhere in the world. Maine is fortunate to have high tides and high energy storms that flush wastes from farms. Moreover, implementation by Maine government officials of a variety of regulations, including conservative siting criteria, extensive pre and post lease site evaluations and long-term monitoring requirements have apparently helped to prevent serious environmental degradation by aquaculture."

In the ensuing years, FAMP methods were reviewed every two or three years by state and federal scientists (DEP, DMR, USEPA, USFWS, ACOE, and NMFS) to satisfy state and federal water quality goals.

Then in January 2001, federal Clean Water Act authority for all water discharge permits (National Pollutant Discharge Elimination System, NPDES) was delegated to Maine. As part of the delegation agreement between Maine-USEPA Region I, permits for finfish aquaculture would now be required[1]. In June 2003, after over 3 days of public testimony and deliberations, the Board of Environmental Protection promulgated a salmon aquaculture permit containing extensive monitoring requirements and water quality standards (in Task Force briefing booklet and at http://www.maine.gov/dep/blwq/docstand/aquaculture/MEG130000.pdf). In September, 2003 the first viable federal discharge permit[2] was issued to a finfish farm in Maine.

Water Quality and Benthic Effects of Aquaculture in Maine

Of the three basic forms of aquaculture in Maine; finfish, shellfish, and sea vegetables, only finfish and shellfish are currently practiced. Environmental issues are distinct for each. To understand environmental impacts, it is helpful to ask at least the following 4 questions:

1. "What is the nature of change?
2. Where, when, and over what extent did it occur?
3. Is the change permanent? and
4. Is the change serious?"

Benthic Impacts from feces and unconsumed feed are primarily associated with finfish aquaculture, however shellfish farming can also result in organic buildup when shellfish fall from ropes or trays or pseudo-feces accumulate. In Maine, from our own observations and studies we have long known that the affected area is contained over a small footprint, generally immediately beneath the pens or rafts and is reversible in a matter of months (Findlay and Watling, 1994; Sowles et al.1994 ; and Panchang et al., 1997). Initial effects include an increase in infaunal abundance and species richness. If allowed to continue, build up of organic matter

[1] Prior to this, USEPA informed aquaculturists that as long as they submitted Notices of Intent (NOIs) to file for permits and as long as they participated in the FAMP, no enforcement action would be taken while Region I decided whether or not to issue permits.

[2] USEPA issued its only permit to Acadia Aquaculture in Blue Hill Bay in 2002. The conditions were unacceptable to the aquaculturist and its lease was voluntarily withdrawn.

can deplete sediment oxygen, eliminate sensitive benthic infauna, and produce methane and hydrogen sulfide gas. Such conditions have never been acceptable.

One objective of the monitoring program is to avoid allowing organic matter to accumulate and the key management tools are healthy benthic infauna and microbial communities to processes and recycle the organic waste. Here in Maine, Findlay and Watling (1994) concluded that infauna and microbial communities can account for complete breakdown of deposited wastes under a well managed farm as long as benthic oxygen consumption is in balance with oxygen supply. In any one year, about 5-10% of the farms in Maine are warned that they are approaching or have reached unacceptable localized benthic conditions. Upon notification and corrective management, the bottom and bottom community usually reverts to acceptable conditions in 6-12 months.

Water Quality

Nutrient enrichment of the water column from excretory products and waste feed has the potential to lead to oxygen depletion, ammonia toxicity and algae growth. Of feed consumed, over 80% of the nitrogen and 60% of the carbon is excreted through the gills as ammonia and carbon dioxide (Enell and Ackefors, 1992; Gowen and Bradbury, 1987; Silvert et al., 1990). Finfish aquaculture is the only form of aquaculture in Maine where a net increase in nutrient loading to a water occurs.

Waterbodies with poor flushing, that vertically stratify, and receive nutrient loads from non-aquaculture sources are more vulnerable to the effects of nutrients.   In Maine, where finfish aquaculture is practiced, 10 – 20 foot tides and strong currents generally preclude an accumulation of nutrients and chlorophyll.   And in Cobscook Bay, where finfish farms are most abundant, Phinney and Yentsch (2003) found that primary production is not even nutrient limited.

On the other hand, over concern for the potential for eutrophication in Blue Hill Bay, that does stratify and is not well flushed, the DMR delayed Acadia Aquaculture's lease hearing until an assessment was made of the projected nutrient discharge. A monitoring plan was developed with the Friends of Blue Hill Bay and Acadia Aquaculture and conducted in 2000 by DEP, DMR and Acadia Aquaculture. The study concluded that nutrient and chlorophyll concentrations in Blue Hill Bay are less than other coastal waters in Maine and that adding one more farm of the proposed size was reasonable as long as nutrient monitoring continued once farm operations commenced.

An issue that remains a concern, but for which no conclusions have been made, is the issue of nutrient stimulation of epibenthic marine algae.   A separate paper from the DMR aquaculture website (http://www.maine.gov/dmr/aquaculture/reports/GREEN%20SLIME.pdf) discusses our current thinking on this topic. In neighboring L'Etete, New Brunswick, where green algae is reported to be increasing, the biomass of salmon is up to 40 times that which is found in Cobscook Bay (New Brunswick Department of Agriculture, Fisheries and Aquaculture, 2003).

Concern over lowered oxygen levels has also been studied. In waters adjacent to aquaculture pens and shellfish rafts, oxygen concentrations are slightly reduced due to respiration. Of the over 1,800 oxygen profiles collected by the FAMP, none have approached concentrations posing a biological threat.

Therapeutants and Toxic Contaminants

Experience in agriculture and human medicine has shown that misuse of antibiotics can promote antibiotic resistant strains of pathogens thus encouraging further disease. Antibiotics and pesticides can accumulate in sediments and surrounding biota resulting in a toxic effect on non-target organisms (Austin, 1985). Therapeutant usage is regulated by the Food and Drug Administration. In Maine, 4 therapeutants are approved for use and only two are used; the antibiotic oxytetracycline (Terramycin) and emmamectin benzoate (Slice) to control sea lice. Therapeutants are administered under supervision of a licensed veterinarian and both are administered via feed.

In practice, the industry has moved away from antibiotic treatment in favor of prophylactic vaccines. Weston et al. (1994) concluded that "...at realistic dosages, [antibacterials] had no effect on total bacterial density in sediments or on the rate of any of several microbially-mediated biogeochemical processes." Goldberg et al. (2003) concluded that "Antibiotic use in U.S. aquaculture does not significantly threaten the marine environment." Here in Maine, sediment samples collected in 2000 from under the larger and older finfish farms did not contain oxytetracycline residues (Sowles files) thus corroborating the findings of others that it does not persist long in marine sediments (Jacobsen and Berglind, 1988).

Management of sea-lice is important not only for the industry, but for the restoration of wild Atlantic salmon. The primary mode of control is through an Integrated Pest Management (IPM) Program overseen by Maine's Fish Health Committee and University of Maine Cooperative Extension Service. A successful IPM program, that includes single year class stocking, has reduced the need for chemical treatment overall. Emmamectin benzoate is currently registered as an Investigational New Animal Drug (INAD). Full registration is pending completion of final environmental risk assessment by the US Food and Drug Administration. Maine is participating in those studies. Early work done in France, Canada and Maine provided sufficient evidence to allow use of Slice while the risk assessment continues. Unlike previous lice treatments (baths), Slice is administered orally thus reducing the amount of chemical released into the environment. Monitoring under farms in Maine has detected Slice, however, concentrations are below those that pose risk to local fauna. Waddy et al. (2002) showed that in lobsters, Slice must be ingested at unrealistically high quantities before effects on lobsters are measured. Taken together (localized deposition, laboratory toxicity tests, and continued monitoring), the weight of evidence suggests that the risk of adverse impact on lobster populations from Slice are insignificant.

As a result of dietary zinc requirements, copper in antifoulants, and bioconcentration of chlorinated and brominated hydrocarbons in fishmeal and oil, concern exists over the accumulation of these toxic compounds in sediments beneath net pens. Brooks et al. (2003) concluded that heavy metal toxicity beneath finfish farms is not likely to result in a measurable biological effect. In adjacent Maritime Canada where sediments are similar yet salmon aquaculture practiced more intensively, Burridge et al. (1999), found that levels of metals and chlorinated hydrocarbons beneath pens were not likely to pose a biological threat. Although based on these and other works, we did not consider this issue a priority, due to public concern, in 2000, we and an industry member sampled sediments under salmon pens. Chlorinated hydrocarbons were not detected and metals were within the natural variability for the area of the coast sampled.

Aquaculture Monitoring
Environmental monitoring of aquaculture takes several forms. Not to be minimized, the first step is to monitor work by others and evaluate those results in the context of environmental conditions and industry practices here in Maine. If it appears that there is basis for concern or a new concern emerges for which no information is available, screening studies are initiated to assess those concerns before instituting formal monitoring. Where evidence suggests it is warranted, formal monitoring is conducted.

The FAMP has been the formal monitoring program for finfish aquaculture. The FAMP began in 1991 and has continually evolved to adapt to new knowledge and needs. To remain scientifically current and effective, the program has undergone at least 5 technical reviews since established. The most recent review with recommendations was in 2003 (Normandeau and Battelle, 2003) (http://www.maine.gov/dmr/aquaculture/reports/MaineAquacultureReview.pdf.)

Until 2003, FAMP used a tiered approach focusing monitoring resources on worst-case times of year and locations. Monitoring was tailored to the unique conditions of each farm site. Follow-up monitoring occurred as indicated by initial monitoring results. The new DEP permit has largely replaced tiered and adaptive monitoring and requires monitoring regardless of threat or impact. All farms are now monitored as follows:

- Growers report monthly to the DMR number and weight of fish on site, amount of feed and medication used, mortalities and escapement,
- The bottom under each finfish site is inspected every fall and spring.
- Video transects are recorded along the axis of prevailing current
- Surficial sediment redox potential and sulfide is measured every fall and spring
- Benthic infauna communities, TOC, % moisture and grain size are analyzed at least every five years during the fall when market fish are on site
- Sediment chemistry for heavy metals, TOC, % moisture and grain size are analyzed every two years when market fish are on site
- Sediment chemistry for therapeutants are taken whenever therapeutants are used
- Dissolved oxygen profiles are taken in and outside the pens either weekly or biweekly depending on sensitivity of the area
- Secchi disk transparencies are taken in August and September
- Each site has a reference site to which results may be compared
- Samples are collected in triplicate

The permit also includes environmental impact standards, a summary of which follows:

- The discharge of human waste is prohibited.
- The discharges shall not cause a visible oil sheen, foam, or floating solids at any time that would impair the uses designated by the classification of the receiving waters;
- Discharges from the facility shall not contain materials in concentrations or combinations that are hazardous or toxic to aquatic life, or that would impair the existing or designated uses of the receiving waters;
- The discharges shall not cause toxicity, visible discoloration, turbidity or other effects to the receiving water that would impair the existing or designated uses of the receiving waters;
- The facility shall not discharge suspended or settleable solids that will have significant adverse effects on the quality or any uses of the receiving water body;

- The discharges shall not produce or result in harmful algae blooms that may be characterized by excessive growths of, but not limited to, the genera *Alexandrium, Dinophysis, Prorocentrum, Pseudonizschia, Phaeocyctis, Enteromorpha, Ulva or Aureococcus*; and
- Notwithstanding compliance with specific conditions of this General Permit, the discharge shall not cause or contribute to violations of water quality standards.
- Oxygen shall not fall below 6 mg/l inside the pen perimeter or below 85% or 70% (for Class SB and SC) 30 meters beyond the pen perimeter
- Redox is not to fall below –100 mVe or sulfides exceed 6000 uM
- Beggiatoa is not to cover more than 50 and 25% of the bottom under and within 30 meters, respectively.
- Changes to infauna community structure are controlled

Although no formal monitoring program for shellfish aquaculture exists, two shellfish leases have monitoring conditions that address concerns specific to those sites. The DMR is proceeding with general screening studies on a number of topics to assess whether or not routine monitoring is warranted. Topics the DMR is currently pursuing include the following:

- Assessment of benthic impacts of long-line mussel (*Mytilus edulis*) aquaculture
- The impacts of suspended oyster culture on Eelgrass (*Zostera marina*)
- The impact of small drags as harvest methods
- Determination of phytoplankton carrying capacity in small estuaries

In addition to field monitoring, DMR staff benefit from the latest information in the areas of sediment toxicology, therapeutant non-target toxicity, shellfish impacts, predictive modeling, monitoring protocols and regulatory approaches to help them remain knowledgeable of emerging issues. We maintain a close working relationship with scientists from Europe and Canada including the Department of Fisheries and Oceans in neighboring Maritime Canada with common concerns. We also integrate studies unrelated to aquaculture here in Maine to provide context of aquaculture impacts. Examples include baseline characterizations of water quality, habitat, sediment chemistry and tissue analyses. We author papers, serve on national and international working groups, and assist in peer reviews of aquaculture related work.

Summary and Conclusions

- Aquaculture is a designated and protected use of Maine coastal waters
- Changes to the marine environment are allowed under law.
- Impact by aquaculture are site specific and highly localized
- Impacts are not significant at an ecosystem scale
- Impacts noted to date are reversible.
- Many parties have scrutinized water quality and benthic impacts, regulations, and monitoring protocols for finfish aquaculture over the years.
- Water quality and benthic impacts are directly addressed by the DEP waste discharge permit
- Monitoring and research into the impacts of marine aquaculture continues in Maine as the industry evolves, and new issues emerge.

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