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Development of guidelines for using bioextraction technologies to manage nutrients in New Hampshire's estuarine waters

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FINAL REPORT

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Project goal: Provide the knowledge base needed for further development of technologies involving biological uptake and removal of nutrients (bioextraction) for application to the Great Bay/Piscataqua River estuarine system.

Background: There is growing literature on bioextraction approaches to managing nutrients in coastal waters, and it includes studies using a variety of species. Bivalve mollusks and macroalgae have received the most attention for several reasons, but perhaps foremost because of their aquaculture potential. A December 2009 workshop at the University of Connecticut, which included speakers from several countries, indicated overall that although bioextraction approaches hold substantial potential there are still many unanswered questions. The present review takes a "what we know/what we need to know" perspective, and focuses on aquaculture. For some taxa (e.g., eastern oyster), wild populations occur in New Hampshire which provide substantial nutrient bioextraction. The associated processes that result in nutrient removal from the ecosystem, however, are generally more complicated and much more difficult to unambiguously quantify except when actual harvest data are available. Therefore, the present review focuses on aquaculture, and it is restricted to those taxa (plants and animals) that occur in New Hampshire.

It should be noted that the present project is associated with a recently completed project (funded by the Piscataqua Region Estuaries Partnership [PREP]) consisting of a field experiment designed to provide empirical data on nutrient uptake by oysters. The final report for this project represents the starting point for future research that will more completely characterize the bioextraction potential for oysters in New Hampshire (see discussion of Grizzle and Ward 2011 below).

Methods: The present report is a literature review, including published and unpublished sources. The overall aim was to glean information that is applicable to managing nutrients in New Hampshire's estuarine waters. The major objectives of the project were: (1) identify the major potential species (plants and animals) occurring in New Hampshire that have potential for bioextraction technologies; (2) identify aquaculture and other related activities (e.g., restoration of natural shellfish populations) that might be appropriate; (3) quantify the bioextraction potential of different combinations of species and methods; and (4) compare the effectiveness and costs of the new bioextraction technologies to traditional engineering-based nutrient removal methods.

Results and Discussion

Species with bioextraction potential

Several bivalve mollusks and macroalgae with bioextraction potential occur in New Hampshire's estuarine and coastal waters: eastern oyster (*Crassostrea virginica*), blue mussel (*Mytilus edulis*), northern quahog/hard clam (*Mercenaria mercenaria*), softshell clam (*Mya arenaria*), several species of red algae (*Gracilaria tikvahiae*, *Chondrus crispus* [Irish moss], and *Porphyra* spp. [nori]), and two species of kelp (*Saccharina latissima* and *Laminaria digitata*). At present, only the eastern oyster and blue mussel support aquaculture operations in New Hampshire. And of these two, only the eastern oyster is farmed in estuarine waters. Therefore, this review will focus on oysters, but will include selected relevant literature on other taxa.

The effects of oysters on water quality have been demonstrated in studies ranging from laboratory experiments (Jordan 1987; Riisgard 1988; Newell and Koch 2004) to field studies over natural reefs (Cressman et al. 2003; Nelson et al. 2004; Grizzle et al. 2006, 2008). Overall, the oyster research corroborates what has been demonstrated for many suspension-feeding bivalve taxa: when occurring in sufficient numbers, they can dramatically reduce suspended particulates in the overlying water column, thereby strongly affecting water quality (see reviews by Dame 1996; Dame et al. 2001). Thus, it is to be expected that oysters, which typically occur in large numbers on natural reefs and oyster farms, have the potential to improve water quality. This fact coupled with concerns over water quality degradations in many areas has led to more attention being paid to what role oyster aquaculture might play in water quality management.

In New Hampshire, the major estuarine water quality problem is increasing nitrogen concentrations (Trowbridge 2010). Shellfish aquaculture has the potential to contribute to nitrogen management goals (Langan 2009). Two recent studies represent the current literature on nutrient bioextraction by farmed oysters (Higgins et al. 2011, and Grizzle and Ward 2011). The table below summarizes the available data on bioextraction of N and C by the eastern oyster.

Table 1. Summary of data from Grizzle and Ward (2011) and published literature on C and N content relative to oyster size.

			Soft Tissue		Shell		Whole Oyster		
Shell Height (mm)	Shell DW (g)	Soft Tissue DW (g)	%C	%N	%C	%N	Total C (g)	Total N (g)	Source
7.8	n/d	0.03	32.12	7.71	n/d	n/d	n/d	n/d	Grizzle & Ward 2011
12.7	n/d	0.20	37.62	9.10	n/d	n/d	n/d	n/d	Grizzle & Ward 2011
35.7	n/d	0.06	27.58	6.52	n/d	n/d	0.585*	0.013*	Grizzle & Ward 201
55.6	n/d	0.24	32.85	7.86	n/d	n/d	3.082*	0.065*	Grizzle & Ward 2011
76	150	1	n/d	7	n/d	0.3	n/d	0.52	Newell et al. 2005
43.6	**4.8**	0.20	43.30	8.15	**11.84**	**0.18**	0.647	0.025	Higgins et al. 2011
64.8	**24.3**	0.80	44.30	8.06	**12.36**	**0.19**	3.391	0.112	Higgins et al. 2011
85.5	37.6	1.58	45.10	7.28	12.43	0.17	5.375	0.176	Higgins et al. 2011
117.8	71.9	3.00	46.20	7.37	12.04	0.26	10.011	0.394	Higgins et al. 2011

*NOTE: These values were calculated using data from Grizzle & Ward (2011) for soft tissue and shell data from Higgins et al. (2011) shown in bold.

Because shell material was not analyzed by Grizzle and Ward (2011), literature values for shell were combined with soft tissue data from the Great Bay oysters to arrive at total whole animal C and N content. Oysters with mean shell height of 35.7 mm contained 0.6 g of C and 0.01 g of N; oysters with mean shell height of 55.6 mm contained 3.1 g of C and 0.07 g of N. These size classes, however, are well below the typical harvest size oyster. Higgins et al. (2011) contain the only available data C and N levels in farmed eastern oysters; their data (shaded in blue in Table 1), indicate that typical bioextraction potential for farmed oysters would be 0.2 to 0.4 g of N and 5 to 10 g C per oyster.

Although I am aware of no reports on the other mollusk species listed above that represent potential farmed species in New Hampshire, it should be noted that percent N and C composition similar to the eastern oyster (Table 1) would likely be expected. Blue mussels are farmed in open ocean waters in New Hampshire, and juveniles commonly occur in estuarine areas. Thus, if for example, hard clam or blue mussel aquaculture operations in estuarine waters were to be developed in New Hampshire, bioextraction rates of N and C similar to oysters would likely occur.

Several seaweeds also have potential for aquaculture in New Hampshire's estuarine waters, though at present no such operations exist. The kelps (*Saccharina latissima, Laminaria digitata*) have potential as a biofuel source, a sea vegetable, and as a direct feed source for urchin aquaculture. Kelps are very robust and wave-tolerant, and over a period of 6 to 9 months can attain a length of several meters. Kelps can be grown on horizontal lines and requires very little tending during grow-out. These characters make kelps a good candidate for incorporation into multi-species systems (Yarish & Pereira, 2008; Chopin *et al.* 2008).

Irish moss (*Chondrus crispus*) is another seaweed with substantial aquaculture potential, and thus nutrient bioextraction potential. Irish moss is a good source of carrageenan (kappa- and lambda-), and is used as a thickening and stabilizing agent in foods and cosmetics. Another market is as a specialty food product. For example, Acadian Seaplants Ltd. in Nova Scotia has been very successful marketing color variants of *Chondrus* to gourmet food markets in Asia. Acadian Seaplants grows *Chondrus* in land-based tank systems, but it could be grown in coastal systems as well. A final candidate for its bioextraction potenital is *Gracilaria tikvahiae*, a common warm temperate species found throughout the Great Bay Estuary (see more discussion below).

General methods for enhancing nutrient bieoextraction

The two mollusks currently farmed in New Hampshire─blue mussel and eastern oyster─involve different methods and different general locations. Both blue mussel farms are in coastal open ocean waters and are deployed using "longline" methods. Juvenile mussels can be caught in estuarine waters, particularly the lower Piscataqua River, but must be moved to the offshore longlines for growout in more saline waters. Thus, mussels have some potential for bioextraction but more research is needed. This research might focus on methods and locations for capturing mussel larvae as they settle from the water column, characterization of nutrient concentrations in mussels of different size and age, and assessing the potential for growout in estuarine waters.

There are four oyster farms currently in production in New Hampshire. All are in Little Bay near the Oyster River. Thus, they are in estuarine areas with maximum nutrient bioextraction potential. All four employ the bottom culture method using some form of "rack-and-bag" set-up where the oysters are contained in mesh bags that are suspended just above the bottom on rope lines or in racks (see Flimlin et al. 2008 for review of methods used in the New England region). Some farmers in the region use bags for only the first year, then spread the oysters onto the bottom for final grow-out. At present, all four farms involve only oyster culture, but in 2012 hard clams will likely be placed on two farms on an experimental basis.

Bioextraction potential of different combinations of species

Integrated multi-trophic aquaculture (IMTA) approaches that couple shellfish with seaweeds likely have much greater potential than shellfish alone for removing nitrogen from the water column because both dissolved and particulate forms are removed. Development of IMTA approaches involving oyster aquaculture in temperate waters, however, is still in the early stages and very little attention has been paid to the effects on water quality (Barrington et al. 2009).

Although the potential benefits of coupling shellfish and seaweed in various IMTA arrangements has been demonstrated (e.g. Abreu et al. 2009; Mao et al. 2009), very little research has involved oysters. I am aware of two ongoing projects. Focusing on nutrient bioextraction, various arrangements of oysters and the red alga *Graciliaria* are being tested on an oyster farm in Rhode Island (Perry Rasso, pers. comm.). The Agriculture Experiment Station at the University of New Hampshire recently funded a project (Harris, Neefus, Berlinsky, and Grizzle) that is assessing the feasibility of integrated farming methods involving oysters, seaweeds, and sea urchins. Two experiments were initiated in 2011, and the first preliminary data are expected by 2012.

Comparison of bioextraction technologies with traditional nutrient removal approaches

There are four major sources of N inputs to the Great Bay estuarine system (Trowbridge 2010): wastewater treatment plant effluents, non-point runoff from watersheds, groundwater discharges, and atmospheric deposition. For the present analysis, only N removal from wastewater treatment plants and non-point runoff will be considered. In contrast to N removal by traditional land-based methods, oyster farming includes monetary income as well as production costs. Moreover, oyster farming also provides ecosystem services that scientists are only just beginning to understand and quantify (Pietros and Rice 2009; Brumbaugh and Toropova 2008). Thus, a comprehensive economic comparison of conventional N removal (for point and non-point sources) and bioextraction by oyster aquaculture is not possible given our current understanding. Nonetheless, some "best guess" comparisons from current literature can be made.

Table 2 summarizes the range of costs for N removal from point and nonpoint treatments and some economic considerations for oyster farming. There are many different conventional nutrient removal technologies and the present analysis is intended as a simplistic overview. No attempt has been made to consider the variety of wastewater treatment facilities or non-point runoff treatment methods in the Great Bay watershed. Nonetheless, cost estimates are available to provide at least a range of costs for N removal from wastewater and non-point sources (Kang et al. 2008). It should be noted that N extraction numbers for oyster farming only consider harvest of the oysters, and not denitrification or other processes associated with deposition of oyster feces and pseudofeces to bottom sediments (Newell et al. 2005). Thus, the data in Table 2 represent simplistic estimates at best.

Table 2. Summary of conventional N extraction (removal) methods and costs compared to oyster aquaculture in New England.

Method	Removal Cost Range	Removal Cost (average $/ton N)	Revenue Generated ($/ac/yr)[1]	Ecosystem Services ($/ac/yr)[2]	Tax Revenue Generated ($/ac/yr)[3]
Wastewater Treatment					
(various technologies)[4]	<$1 - ~$5/lb	$5,000	0	0	0
Agriculture Non-point Treatment[5]					
(various technologies)	$4 - 200/lb	$200,000	0	0	0
Urban Non-point Treatment[5]					
(various technologies)	$25 - >$1,000/lb	$500,000	0	0	0
Oyster Aquaculture					
Bottom Culture	?	?	$120,000	>>$6,700	$3,000

[1] Based on average annual production of 200,000 oysters/ac/yr and $0.60/oyster
[2] This estimate only represents secondary fish production; from Grabowski and Peterson (2007)
[3] Based on charge of $0.015/oyster sold (NH Adm. Rule Fis 807.11) and average annual production of 200,000 oysters/ac
[4] Kang et al. (2008)
[5] Stephensen (2009)

In addition to the actual data in Table 2, it should be noted that oyster aquaculture—in contrast to traditional N removal methods—results in substantial generated revenues from oyster sales as well as taxes. Moreover, the recent focus on ecosystem services provided by natural oyster reefs and oyster aquaculture adds another dimension to economic assessments (Brumbaugh and Toropova 2008; Northern Economics 2009). All this points to the complexities involved in trying to arrive at common economic parameters for comparing oyster aquaculture to other methods for N removal.

The future?

There is substantial potential for further development of shellfish and other aquaculture activities in New Hampshire with a focus on nutrient management in coastal waters. An ongoing federally funded project aimed at enhancing shellfish aquaculture in estuarine waters in New Hampshire will be completed in 2012. At present, this study has identified those estuarine areas with the most potential for shellfish aquaculture (Fig. 1). This preliminary analysis was mainly based on a consideration of four potentially constraining factors: water classification relative to shellfish harvest; the extent of red tide toxicity observed historically; current eelgrass distribution; and bathymetry. The areas shown in yellow in Figure 1 represent those areas approved for harvest (except in cross-hatched areas), where red tide toxicity has not been observed or only at minimal levels, where no eelgrass occurs, and in subtidal waters shallow enough (between ~ -0.5m and -3m MLW) for current farming methods to be used. It is emphasized that there has been no assessment of the myriad of social factors that need to be considered. Thus, this preliminary assessment likely represents a mapping of the maximum or near-maximum potential for shellfish aquaculture in New Hampshire’s estuarine waters. The areas shown in yellow total about 234 hectares (577 acres).

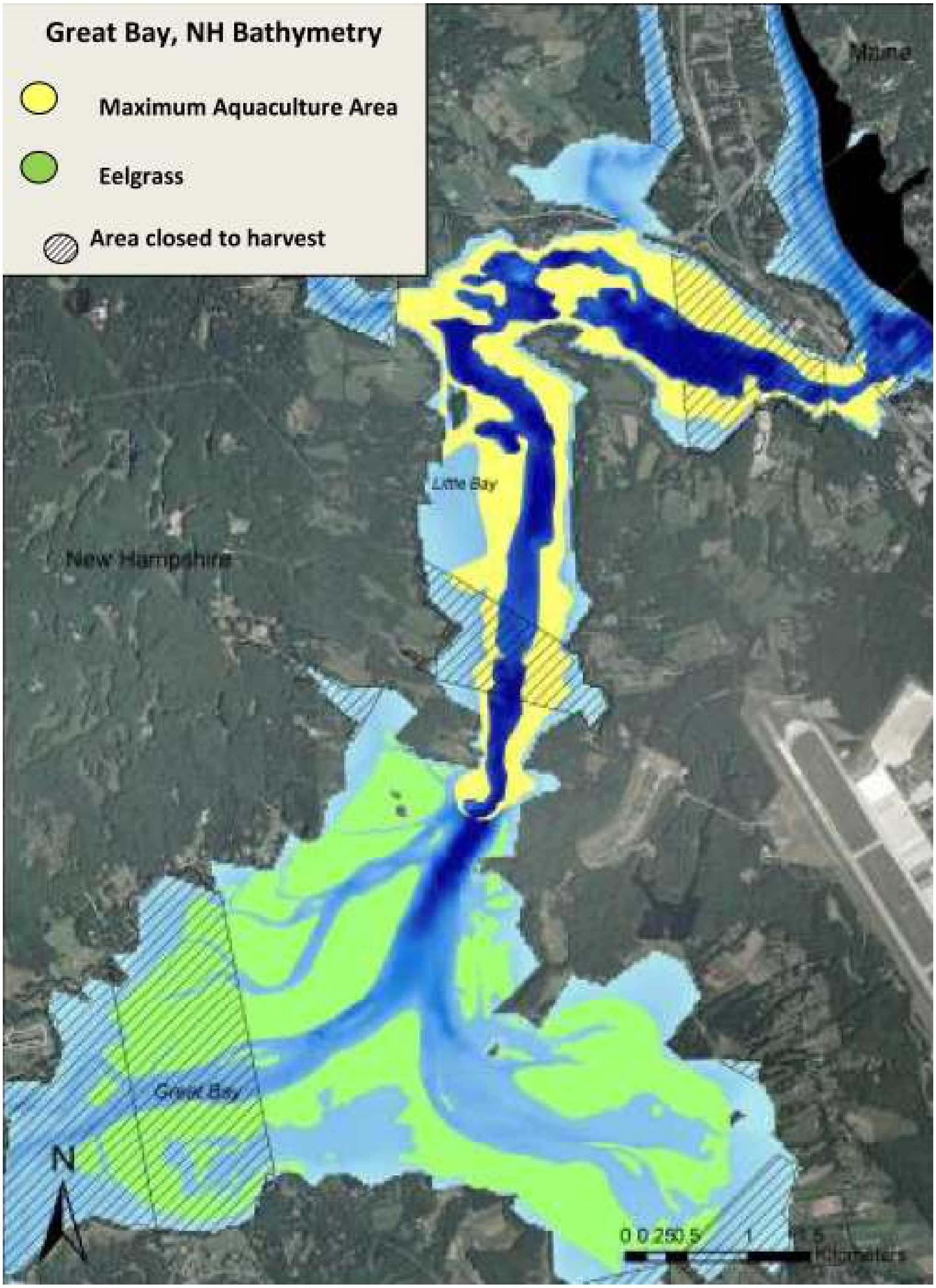

Fig. 1. *Preliminary maximum extent* for potential oyster aquaculture (yellow polygon) in the Great Bay Estuary (see text for details).

It should be noted, however, that all factors relevant to oyster aquaculture have not been fully assessed, nor have there been extensive conversations with all stakeholders. In particular, there has been no assessment of ecological or environmental carrying capacity for the oysters themselves. In other words, there has been no assessment of how many oysters could be grown given current water flows, seston concentrations, and other controlling factors. Certainly, the entire 577 acres could not be filled with oyster farms, but how much less than that would be feasible remains unknown. Nor has there been a complete assessment of social factors such as potential conflicting uses (e.g., recreational and commercial fisheries), or local regulatory policies. Nonetheless, some reasonable assumptions can be made to allow a preliminary assessment of the N bioextraction potential for oyster aquaculture in the state.

If each oyster harvested represented a removal of 0.285 g N (=mean for two largest size classes of oysters in Table 1), and 200,000 oysters/yr were harvested from each acre (Table 2), then annual N bioextraction per acre would be 57,000 g (=125.7 lb; =0.0628 ton). If 200 acres were in production, the annual N removal from the estuary *from oyster harvest alone* would be 12.5 tons.

Oyster production from aquaculture in the past decade in New England has dramatically increased in some areas (e.g., Rice 2006), but with it has come concerns about environmental effects and potential conflicting uses (Costa-Pierce 2009; Forrest et al. 2009). Because shellfish aquaculture is typically regulated at the state level in the US, several states have taken steps to address the concerns of a broad range of stakeholders. For example, Rhode Island recently issued a detailed report addressing the major ecological and social issues that must be incorporated into planning and management of the state's rapidly expanding shellfish aquaculture industry (CRMC 2009).

Guidelines for using bioextraction technologies in aquaculture to manage nutrients in New Hampshire's estuarine waters also must be developed within the existing regulatory framework. Shellfish farming is regulated at the state level in New Hampshire by the Department of Environmental Services (DES), the Fish and Game Department (F&G), and Health and Human Services (HHS). F&G issues licenses for aquaculture activities, and HHS provides overview of the certification process for selling shellfish. The DES Wetlands Bureas requires a permit for farm sites. The DES Shellfish Program has responsibility for monitoring the harvesting waters and determining their suitability from a water quality perspective for harvest and human consumption of shellfish; the overall goal is to insure the state's compliance with National Shellfish Sanitation Program guidelines.

It was mentioned above that there are at present (2011) four oyster farms in New Hampshire. Two of the farms were initially permitted in 2010, and there is another farm currently in the permit process. Expansion of shellfish aquaculture in New Hampshire seems imminent. Moreover, there are ongoing experiments and pilot scale studies focusing on nutrient bioextraction involving shellfish alone as well as shellfish with seaweeds. Collectively, these ongoing efforts represent significant steps towards meaningful utilization of shellfish aquaculture as a management tool for nutrient pollution in our estuarine waters. Although we are far from such a goal, the process is underway.

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