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# International Workshop on Bioextractive Technologies for Nutrient Remediation Summary Report

by Julie M. Rose, Mark Tedesco, Gary H. Wikfors, Charles Yarish

August 2010

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10-16 *Stock Assessment of Scup for 2010*, by M Terceiro. July 2010.

10-17 *50th Northeast Regional Stock Assessment Workshop (50th SAW) Assessment Repor*t, by Northeast Fisheries Science Center. August 2010.

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# INTRODUCTION

On December 3 and 4, 2009, the Long Island Sound Study (LISS) brought together an international roster of experts to discuss new and innovative technologies to address the management of eutrophication and hypoxia in the Long Island Sound. The workshop explored the potential application of extractive aquaculture technologies of macroalgal and shellfish cultivation for nutrient mitigation in the nearshore estuarine environments of the Sound. Nutrient bioextraction is defined here as "an environmental management strategy by which nutrients are removed from an aquatic ecosystem through the harvest of enhanced biological production, including the aquaculture of suspension-feeding shellfish or algae." These emerging technologies would complement existing nutrient source control programs. The workshop program was designed to bring experts in macroalgae and shellfish cultivation, integrated multi-trophic aquaculture (IMTA), resource economics and coastal modeling together with local partners to discuss the potential benefits of these technologies to the Sound and other urban estuarine environments. Goals of the workshop included: increasing awareness of alternatives for nutrient management on the part of federal/state/municipal agencies and coastal managers; an assessment of the local feasibility of this approach including suggestions for pilot projects and locations; and the identification of opportunities for economic incentives for nutrient bioextraction through nitrogen credit trading or other practices.

The workshop was co-sponsored by the Long Island Sound Study (a partnership of federal and state agencies, user groups, concerned organizations, and individuals dedicated to restoring and protecting the Sound), Environmental Protection Agency, National Oceanic and Atmospheric Administration, New England Interstate Water Pollution Control Commission, and University of Connecticut, and was held at the University of Connecticut's Stamford Campus. Over 100 people were in attendance each day. Participants represented a variety of organizations, including local, state and federal agencies, shellfish growers and industry representatives, academics and non-profits. Invited speakers were as follows:

1) Bela Buck, Alfred Wegener Institute for Polar Research, Bremerhaven, Germany;
2) Alejandro Buschmann, Universidad de Los Lagos, Puerto Montt, Chile;
3) Stephen Cross, University of Victoria, Victoria, British Columbia, Canada;
4) Hauke Kite-Powell, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA;
5) Dale Kiefer, University of Southern California, Los Angeles, California, USA;
6) Richard Langan, University of New Hampshire, Durham, New Hampshire, USA;
7) Odd Lindahl, University of Gothenburg, Sweden;
8) Robin Miller, HydroQual, Inc., New Jersey, USA;
9) Roger Newell, Horn Point Laboratory, University of Maryland, Cambridge, Maryland, USA;
10) Robert Rheault, East Coast Shellfish Growers Association, Wakefield, Rhode Island, USA; &
11) Kurt Stephenson, Virginia Tech, Blacksburg, Virginia, USA

The structure of the workshop was a series of dynamic presentations on the first day and morning of the second day. The entire afternoon of the second day was devoted to a panel

discussion by experts in aquaculture and local environmental laws and regulations. The panel was moderated by Charles Yarish from the University of Connecticut. Panelists were as follows:

1) Jeanette Brown, Executive Director of the Stamford Water Pollution Control Authority and advisory board member of the Connecticut Nitrogen Credit Exchange Program, Stamford, CT, USA
2) David Carey, Director of the Connecticut Department of Agriculture, Bureau of Aquaculture, Milford, CT, USA
3) Curt Johnson, Senior Staff Attorney, Connecticut Fund for the Environment, New Haven, CT, USA
4) Paul Mankiewicz, Executive Director of the Gaia Institute, Bronx, NY, USA
5) Robert Rheault, Executive Director of the East Coast Shellfish Growers Association, Wakefield, RI, USA

## SPEAKER PRESENTATIONS

A Summary of Speaker Presentations (the presentations themselves can be downloaded from http://longislandsoundstudy.net/issues-actions/water-quality/nutrient-bioextraction/

1. Bela Buck, "The European Experience in the North Sea: from Theory to Reality"

   Buck discussed integrated multi-trophic aquaculture in the North Sea and his work designing and implementing the combination of mussel and kelp mariculture with offshore wind farm technologies in Germany's coastal waters. Aquaculture siting, and marine spatial planning in general, are currently important issues in the North Sea because of intense and competing uses for limited space. This multi-use approach is intended to maximize the benefit of offshore areas. Buck reviewed the technologies proposed for the North Sea, the species evaluated, the partner organizations involved, and policy/management issues.

2. Alejandro Buschmann, "Seaweed Use to Mitigate Aquaculture Induced Eutrophication Processes in Chile"

   Buschmann reviewed the recent dramatic increases in aquaculture production around the world and particularly in Chile. Increased aquaculture in Chile has largely centered on finfish, which has contributed to coastal eutrophication through nutrient release in waste streams. Buschmann discussed land-based and open-water IMTA systems that use macroalgae to absorb inorganic nutrients released from fish production. He also presented results from a 20-hectare pilot farm that combines salmon, oyster and macroalgal cultivation. Buschmann highlighted current challenges, including increasing economic value of seaweeds, and valuation of the environmental benefits of seaweed-based local nutrient reductions.

3. Stephen Cross, "Sustainable Ecological Aquaculture (SEA) Systems: Building a Business Case for Bioextraction"

   Cross discussed the current state of aquaculture in British Columbia, which is dominated by finfish production, and the environmental impacts of waste streams from these farms. Cross highlighted the social, environmental, and economic benefits of sustainable, ecological aquaculture. He presented his designs and showed his operating sustainable finfish production systems, which include a fed component (finfish), organic extractive components (filter and deposit feeders including the Asian scallop and sea cucumbers), and an inorganic extractive component (kelp).

Cross included an evaluation of potential biomass production and profitability for each component in the system. He concluded with results from studies of seafood safety suggesting that potential contaminant streams from finfish are not being retained in the long term by downstream filter feeders or the kelp.

4. Dale Kiefer, "Modeling Fish Farm Operations and Impacts"

   Kiefer described a model he designed for assessing the impacts of fish farms on the local environments including Puget Sound. The model is intended for site selection of restoration and intervention and defines the parameters of sustainable operations. He reviewed user interface options and ran simulations that were developed for the Juan de Fuca Strait, WA and Gokasho Bay, Japan. Kiefer described components of the model in detail and presented results of model validation from Atlantic salmon farms in the Gulf of Maine.

5. Hauke Kite-Powell, "Aquatic Carrying Capacity and Economic Considerations for Shellfish Aquaculture"

   Kite-Powell reviewed the ways in which different types of carrying capacity (physical, production, ecological/ecosystem and social) currently limit aquaculture activities, highlighting his view that social carrying capacity is currently the primary limiting factor in the United States. Kite-Powell described results from a case study in Waquoit Bay, MA, examining the cost and efficiency of a variety of management options to reduce eutrophication. He determined that increased shellfish aquaculture was more cost-effective than reducing fertilizers or improving wastewater treatment. A cost-benefit analysis of shellfish aquaculture and social carrying capacity estimated maximum net benefit at 4% of the bay area devoted to aquaculture. Kite-Powell concluded by highlighting the importance of community outreach by shellfish growers and the value of collaboration between scientists and growers.

6. Richard Langan, "Hypothetical Case Study for Using Extractive Technologies for Meeting Nutrient Criteria Goals for the Great Bay Estuary, New Hampshire"

   Langan reviewed the extractive technology options for the Great Bay Estuary, New Hampshire, including oyster culture, mussel-seed production, and oyster restoration. Using these numbers, he was able to estimate total nitrogen removal, if these combined technologies were applied at maximum potential. Langan also discussed possibilities for microalgal biomass/biofuel production in this region, including siting, production potential, and cost. He estimated the economic opportunities and constraints from bioextraction in Great Bay and reviewed environmental, regulatory, and social constraints that would likely be imposed on expanded aquaculture in this region.

7. Odd Lindahl, "Bioextraction in Practice: A Case Study for Shellfish Cultivation, Experiences from Sweden"

   Lindahl described ongoing problems with coastal eutrophication off the west coast of Sweden, and the potential benefits of combining agricultural best management practices (e.g. spring cultivation, catch crops) with mussel farming in regions with large agricultural operations. He also highlighted a pilot study in Lysekil, Sweden, in which the town greatly increased mussel biomass in local waters in lieu of a costly sewage treatment plant upgrade. The deployment was successful but insufficient markets were identified for the mussels in advance; therefore, large amounts of biomass have yet to be harvested. Lindahl spoke about the potential use of mussels

as fish feed and in biogas production, and cited ongoing research programs investigating these options.

8. Robin Landeck Miller, "Applying the System Wide Eutrophication Model (SWEM) for a Preliminary Quantitative Evaluation of Biomass Harvesting as a Nutrient Control Strategy for Long Island Sound"

   Miller reported the results of model runs in which the existing Long Island Sound SWEM model was refined to assess potential improvements in summertime dissolved oxygen if large-scale shellfish and seaweed aquaculture were implemented. She reviewed existing water-quality standards and model predictions showing that, even after TMDL implementation, dissolved oxygen levels will not be in compliance at all times and in all places, underscoring the need for additional management action. Miller described bioextraction-related enhancements in detail, including biomass, functioning, and placement of both seaweed and shellfish. Results of the model runs indicate substantial improvements in summertime dissolved oxygen over the post-TMDL baseline. Miller concluded that these preliminary model runs showed very promising results, warranting further evaluation.

9. Roger Newell, "The Influence of Eastern Oysters on Ecological Processes in Chesapeake Bay: Insights from Modeling Studies"

   Newell highlighted the possible effect that major declines in oysters in Chesapeake Bay over the last century may have had on water quality. He summarized results from studies that demonstrate the significant impacts that large populations of oysters can have on sediment biogeochemistry, benthic primary production, and benthic-pelagic coupling in estuaries. Newell emphasized the importance of suspension feeding bivalves, such as oysters and mussels, in making nutrients available in particulate form to other benthic organisms, increasing benthic dissolved oxygen concentrations and reducing turbidity. Newell presented results from several different ecosystem models developed to explore the effects of increased oyster populations *versus* nutrient reductions on various components of the Chesapeake Bay ecosystem as a whole and as regional segments. He concluded by stressing that, although bivalves can make significant contributions to nutrient remediation in estuaries, bioextractive technologies should be implemented in concert with (not in lieu of) reductions in nutrient loading. For further information, please see references at the end of the document.

10. Robert Rheault, "Ecosystem Services Provided by Shellfish Aquaculture"

    Rheault reviewed the problems with coastal eutrophication that have accompanied the development and widespread use of commercial fertilizers. He described the benefits provided by shellfish aquaculture to the local environment, including removal of nutrients, reductions in turbidity, and improved quality of habitat for other organisms. He discussed his experiences in Point Judith Pond, RI, in which he examined the ecosystem effects of his oyster farm. Rheault showed the results of studies on shellfish cages which showed significant increases in fish and crustacean biomass and diversity around his operation over a non-vegetated, benthic control site and a nearby eelgrass bed suggesting that aquaculture gear shares many attributes of essential fish habitat. Rheault emphasized that shellfish aquaculture alone cannot

solve the nutrient problem in the coastal environment, but that it is a cost-effective, sustainable and an environmentally beneficial option.

11. Kurt Stephenson, "The Economics of Nutrient Harvest: Overviews of Alternatives and Challenges to Creating Incentives"

    Stephenson discussed the estimation of nutrient removal costs from bioextractive technologies and compared these costs to those of agricultural and urban stormwater best management practices. He highlighted the advantage of bioextractive technologies in that nitrogen removal is easy to quantify relative to BMPs (which require model estimates of nutrient removal). Stephenson reviewed available ways to incentivize nutrient harvest, including nutrient credit trading, public sector purchase, voluntary private sector offsets, and donations and market development of related products. He concluded with his view that substantial administrative and regulatory barriers need to be overcome to create financial incentives for bioextraction at a large scale, but if this can be accomplished, bioextractive technologies provide relatively certain nitrogen removal and ancillary benefits, at possibly reasonable costs.

# PANEL DISCUSSION

Moderator Charlie Yarish reviewed the opportunities in the Sound for the aquaculture of macroalgae as the key inorganic extractive component. Each panelist spoke for a few minutes about their activities and interests related to nutrient bioextraction. Jeanette Brown (Stamford Water Pollution Control Authority and Connecticut Nitrogen Credit Exchange Program) spoke about her considerable experience in wastewater treatment working on denitrification processes and reducing point source nitrogen inputs into the Sound, as well as her ongoing work with nitrogen credit trading in Connecticut. David Carey (Connecticut Bureau of Aquaculture) discussed his involvement in the permitting and regulation of aquaculture in Connecticut waters of Long Island Sound. Curt Johnson (Connecticut Fund for the Environment) spoke about his experience as an attorney dealing with legal issues surrounding the environmental management of Long Island Sound. Paul Mankiewicz (Gaia Institute) related his extensive on-the-ground experience with restoration projects in and around the waters of New York City. Bob Rheault (East Coast Shellfish Growers Association) talked about his experiences as a longtime shellfish grower in Rhode Island, as well as his political efforts on behalf of the ECSGA.

Key points discussed by panelists and participants were as follows:

- The opportunity that bioextractive technologies provide for addressing nonpoint source pollution was highlighted by the panel. There was agreement among panelists and participants that reductions in point source pollution need to continue in addition to potential water quality improvements provided by increased shellfish and macroalgal cultivation.
- The situation in Long Island Sound is different than in Chesapeake Bay, where the emphasis has traditionally been on restoration of historical beds and where shellfish are predominantly harvested by watermen. In Long Island Sound, aquaculture is the predominant industry for harvesting shellfish. David Carey reported that considerable acreage is left in Connecticut waters of Long Island Sound that are open to shellfish harvest and that the Bureau of Aquaculture supports expanding aquaculture activities into approved waters. He emphasized that public health is the number one priority of the

Bureau of Aquaculture, and as such, would not support the expansion of edible shellfish aquaculture into closed waters.

- Bob Rheault spoke of the importance of increasing awareness of the ecosystem services provided by oysters. He voiced the opinion that the actual monetary value of a nitrogen credit for nutrient bioextraction may be less important than the recognition at the state and federal level that shellfish aquaculture is good for the environment. He also emphasized the need to address significant existing regulatory barriers to increased aquaculture in many estuaries.
- There was discussion about what types of shellfish and macroalgal aquaculture would be best for the Sound. Currently the main focus is on oysters and oyster cultivation in Long Island Sound. The possibility of increasing the relative importance of clams was mentioned but not discussed in great detail. Key macroalgal species that would lend themselves for cultivation included the sugar kelp (*Saccharina latissima*) and the red algal species, *Gracilaria tikvahiae*. The kelp species would be a crop that would be grown from late Fall through late Spring and the *Gracilaria* would be a crop for late Spring into Fall. Each could be grown on long-lines provided there was a nursery source of "seedlings" for each species. A debate about the potential for increased mussel production ensued. An argument in favor was that mussels are more cost effective to produce than oysters, and the need for market expansion and economic incentives for mussel aquaculture in the United States was highlighted. The argument against increased mussel production centered on the problem of longline culture, because of potential spatial conflicts with recreational sailing and boating in the Sound. This relates back to the concept of social carrying capacity discussed in Kite-Powell's presentation: what the community sees and perceives trumps the ecological and biological reality. The argument was made, however, that typical mussel production involves lines that are located 30 feet below the surface, so the conflict with recreational boaters and local communities may be minimized.
- There was widespread agreement that, if the SWEM model predictions are correct, bioextraction of nutrients through aquaculture has the potential to result in significant improvements in water quality in the Sound. The results of model runs presented by Robin Miller indicate that increased shellfish and macroalgae harvests have the potential to increase summertime benthic dissolved oxygen in the western Sound by 1.5 mg/L.
- Curt Johnson stressed that given the promising nature of this technology, there is a need to come up with a plan of action for the Long Island Sound Study for the next year. He emphasized the need for refining model estimates and narrowing the range of predicted nutrient uptake by shellfish and macroalgae. He also discussed the need for public competitive funding and the importance of involvement at the municipal level. Johnson emphasized the need for accurately quantifying nutrient removal in these processes if these technologies are to be incorporated into a regulatory framework such as the TMDL or nitrogen trading program.
- There was an extensive discussion of the existing nutrient regulatory framework and steps/challenges to the potential future incorporation of bioextractive technologies. The question was raised whether or not bioextractive technologies qualify as "in stream treatment", which may cause legal problems related to the Clean Water Act. Curt Johnson questioned how regulators would set a baseline for existing aquaculture production in an ecosystem before beginning a nutrient bioextraction program. Paul

Stacey emphasized that the TMDL needs to be considered, and that this is an opportunity to manage the nonpoint source pollution not regulated under the Clean Water Act. Charlie Yarish also pointed out that nutrient bioextraction currently is our only option for dealing with legacy effects of historical pollution within the watershed. Gary Wikfors spoke about the need to think separately about potential changes in dissolved oxygen predicted by the SWEM model from the TMDL-required reductions in nitrogen loading. Mark Tedesco indicated that there may be some flexibility in how we implement TMDLs under the Clean Water Act, but he noted that the challenge is to develop mechanisms for providing economic incentives for bioextractive technologies that function within the context of regulatory programs. Jeanette Brown echoed the view that point source polluters such as wastewater treatment plants would not be in favor of relying on living organisms (which are sensitive to toxins) to meet water quality requirements, but that nutrient bioextraction is potentially a good way to address stormwater-related nitrogen inputs. Paul Stacey reiterated the need to be able to certify the removal capacity of the bioextractive technologies if they are to be incorporated as part of the regulatory framework.

- There was agreement among the panelists that a pilot program is a necessary next step and that it is worth investing valuable time and resources into further exploration of nutrient bioextraction in Long Island Sound.

# ADDRESSING GOALS

The workshop was specifically designed to bring together a wide range of potential partners and interested parties. Three major goals for the workshop were established in advance, to help target discussions and prioritize future work. Progress on these goals is detailed below.

<u>Goal One: increasing awareness of alternatives for nutrient management on the part of federal/state/municipal agencies and coastal managers</u>

There was considerable discussion during both speaker presentations and the panel discussion about the importance of incorporating nutrient bioextraction and the use of bioextractive technologies into the federal nutrient regulatory framework. After the workshop, the EPA Long Island Sound Office was asked to provide a definition of Nutrient Bioextraction for inclusion into one of the versions of legislation that is being drafted to reauthorize the Long Island Sound Restoration Act, which is part of the Clean Water Act. The definition that was provided was "'nutrient bioextraction' means an environmental management strategy by which nutrients are removed from an aquatic ecosystem through the harvest of enhanced biological production, including the aquaculture of suspension-feeding shellfish or algae."

Nutrient bioextraction is currently being considered for incorporation into the revision of the LIS TMDL. Nutrient bioextraction is not seen as a replacement for nutrient control from watershed sources, but as part of an overall ecosystem strategy to attain water quality standards. Nitrogen trading as an element to attaining water quality objectives can be considered in the strategies that are developed to implement the TMDL.

The importance of increased shellfish aquaculture to help restore impacted estuarine ecosystems has also been recognized publicly at the highest levels within the National Oceanic and Atmospheric Administration. The recently released Strategy for Protecting and Restoring the Chesapeake Bay Watershed (Executive Order 13508) highlights the expansion of commercial aquaculture as a vital part of the ecosystem restoration process. The report states:

> "To provide economic alternatives for watermen, reduce fishing pressure on oysters and complement ecological oyster restoration efforts, NOAA will support state efforts to expand commercial shellfish aquaculture in the Bay. Oyster aquaculture improves water clarity, removes nitrogen and phosphorus pollution, keeps working waterfronts economically viable and reduces development pressure, creates jobs, and provides a locally grown, safe and sustainable food product. Oyster aquaculture also leverages private resources toward increasing the native oyster population. "

Goal Two: an assessment of the local feasibility of this approach including suggestions for pilot projects and locations

Local implementation of bioextractive technologies was the focus of the panel discussion on the second day of the workshop. There was general agreement during the panel that these technologies could be particularly effective for addressing nonpoint source nutrients. The ability of these technologies to be used to offset point source pollution directly was not as strongly supported. The major concern with this approach is that point source polluters have legal discharge limits and would be unwilling to use biological organisms (that are sensitive to toxins) to meet their water quality requirements.

Opportunities for the local expansion of aquaculture activities in Connecticut also were discussed during the panel. David Carey, the Director of the Connecticut Department of Agriculture Bureau of Aquaculture, expressed willingness to expand permitting into existing approved waters that are not leased currently. He emphasized that permitting agencies will not allow the expansion of commercial aquaculture into closed areas because of the human health risk from eating potentially-contaminated shellfish.

Since the workshop, discussions of a potential pilot study have begun as a collaborative effort from a variety of partner organizations in attendance at the workshop. Each partner in this group has identified a complementary area of expertise to contribute to a pilot program: The Gaia Institute with expertise in shellfish aquaculture deployment, gear maintenance and local permitting, NOAA's Milford Laboratory with expertise in shellfish physiology and environmental monitoring, EPA with expertise in regulatory context, NOAA's Center for Coastal Monitoring and Assessment with expertise in environmental modeling and economic valuation of ecosystem services, and UConn with expertise in macroalgal ecology and cultivation. A pilot program is in development and potential funding sources are being explored.

Goal Three: the identification of opportunities for economic incentives for nutrient bioextraction through nitrogen credit trading or other practices.

Several of the workshop speakers highlighted the potential for economic benefit as a major factor favoring the widespread implementation of bioextractive technologies in the estuarine environment. The increased shellfish and macroalgal biomass could be sold if additional markets were identified and demand for these products is sufficient. In particular, Odd Lindahl's discussion of the recent problems with uses for increased mussel production in Lysekil, Sweden underscores the need to expand markets for shellfish and macroalgal biomass concurrently with implementation of bioextractive technologies. It is clear that successful application of bioextractive technologies requires a solid plan in advance for use of the enhanced biomass. EPA's Office of Research and Development, working with the EPA Region 1 and Region 2 offices, has approved funding to support an economic analysis of a proposed pilot

study in Long Island Sound. The discussion of funding sources and specific research needs is ongoing.

As discussed above, there was stronger support among workshop participants for the use of bioextractive technologies to offset nonpoint source rather than point source pollution. There was, however, discussion of the potential for bioextractive technologies to feed into a larger pool of nitrogen credits within a nitrogen trading program. This would allow both nonpoint source and point source polluters access to benefits from bioextractive technologies without dependence on biological organisms to meet discharge-limit requirements. This would also provide economic incentives for increased aquaculture activities.

On the whole, work related to economic incentives and valuation of ecosystem services was identified as a major gap during the workshop. This area has been identified as a priority for future development.

# POST-WORKSHOP UPDATES AND PROGRESS

During the workshop, the following data needs and gaps were highlighted as particularly important for future work:

- Economic analysis and identification of financial incentives for bioextractive technologies
- Identification of new and expanded markets for increased shellfish and macroalgal biomass
- Standardized methods for the precise and accurate documentation of nitrogen removal resulting from the harvest of increased shellfish and macroalgal biomass
- Improved estimates of nitrogen removal through sediment denitrification activities related to increased shellfish aquaculture.

Several presentations about the workshop and nutrient bioextraction in general have been given to continue to raise awareness at the local and regional level about these technologies and to reach out to potential partners. These have included:

- Milford Aquaculture Seminar, February 10, 2010, Shelton CT
- Long Island Sound Study Science and Technical Advisory Committee, February 19, 2010
- Sea Grant Nutrient Management Workshop, July 8, 2010
- Ongoing presentations among federal and state agencies responsible for implementation of the Long Island Sound TMDL.

As described above, after the workshop, the EPA Long Island Sound Office was provided with the opportunity to include a definition of Nutrient Bioextraction into draft legislation to reauthorize the federal Long Island Sound Restoration Act. Discussions are ongoing among NOAA, EPA, the Gaia Institute and UConn regarding implementation of a pilot study in Long Island Sound to examine the effects of a large-scale deployment of shellfish and macroalgae on local water quality. These organizations possess complementary technical skills to both deploy and maintain a large culture system and assess the effects of this system from a variety of perspectives, including direct and modeled impacts on the local environment and economic valuation of ecosystem services.

Eutrophication is among the most serious threats worldwide to the function and services supported by coastal ecosystems. Attempts to reverse coastal eutrophication have centered on reducing land-based sources of nutrients, such as fertilizer applications and wastewater treatment

plant dischargers. However, historical alterations in habitat quality, food webs, and community structure in coastal systems can alter nutrient processing, thus mitigating the ecosystem response to reduced nutrient loads. A systems approach that integrates watershed load reduction programs with enhanced nutrient processing in coastal systems may prove more effective at restoring ecosystem services at less cost than load reduction programs alone. Modeling analysis has shown that nutrient bioextraction can potentially be very effective in improving dissolved oxygen levels and in helping to attain water quality standards in a cost effective manner. Further economic, ecological and modeling evaluation of nutrient bioextraction through a coordinated pilot program is a necessary next step to facilitate further exploration of nutrient bioextraction in Long Island Sound.

# ADDITIONAL READING


Barrington, K., T. Chopin and S. Robinson. 2009. Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. In: D. Soto (Ed.)., Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. No. 529, Rome, Italy, FAO. Available at: http://www.fao.org/docrep/012/i1092e/i1092e00.htm

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