Final Programmatic Report

Project Name and Number: Maine Shellfish R&D Assistance to Mollusk Restoration to Increase Habitat and dO Around a wastewater Treatment Plant 2010-0920-001 (23897)

Recipient Organization/Agency: Maine Shellfish R&D, Carter R. Newell, Ph.D.

Date Submitted: Revision May 13, 2013

1. Summary of Accomplishments

In four to five sentences, provide a brief summary of the project's key accomplishments and outcomes that were observed or measured.

This project resulted in a series of field studies investigating the feasibility of using ribbed mussels, *Geukensia demissa*, and mussel raft aquaculture techniques to increase habitat and improve water quality around a wastewater treatment plant of Hunt's Point in the East River/Bronx River estuary in New York Harbor. We utilized intertidal and subtidal seed collection and the socking and tubing of wild ribbed mussels from nearby salt marsh to populate a mussel raft moored at a permitted site in the study area. Poor settlement of native ribbed mussels and competition by native and introduced tunicates and blue mussels made the use of ribbed mussels at this site not feasible. Studies by project partners indicated relative low filtration rates and energy acquisition of the ribbed mussels due to the high loads of sediment and low phytoplankton levels in the estuary. Using mussels collected from Jamaica Bay, and using the observed filtration rates (1.6 l h^{-1}) and dried suspended particulate matter (SPM, 13.7 mg h^{-1} from Hunt's point) standardized to a gram of dry tissue, for each meter of rope the ribbed mussels filtered 41.0 liters per hour and removed 351 mg of SPM per hour. The total seeded area (200 feet or 8 ropes) resulted in a measured filtration rate of 59,865 liters per day (=15,830 gallons per day) and the removal of 513.4 grams of SPM per day. If we were able to obtain seed mussels at the site, and fully populate the 20x20 foot raft, the total estimated filtration rate of the mussel raft would have been about 720,000 liters per day (about 190,000 gallons per day) and a suspended solids removal rate of 6.16 kg per day. One acre of surface area of a ribbed mussel culture operation would then be expected to filter 19 million gallons per day, and remove 616 kg per day of suspended particulate matter**.** . By comparing mussel feeding and assimilation of plankton, and nitrogen contained therein, between Hunts Point and Milford Harbor (a more classically eutrophic location with high phytoplankton biomass), we conclude that ribbed mussels have better potential for use in nutrient bioextraction in locations with lower silt loads and higher plankton production than exist at Hunts Point.

However, excellent growth and nitrogen absorption of a marine alga, *Gracilaria*, was noted on ropes suspended from the mussel raft mooring buoys. Gracilaria grew very well up to 16.5% d^{-1} (July, 2012) at the Bronx River Estuary (BRE) site during 2011 and 2012 summer and fall growing seasons. In 2011, the estimates of nitrogen removal by Gracilaria were 640 (July), 370 g (Sept.) and 314 g N $month^{-1}$ from 100 m longline (Oct.). In 2012, the nitrogen removal by Gracilaria was 1270 (July), 1030 (Aug.), 390 (Sept.) and 220 g N $month^{-1}$ from a 100 m longline (Oct.). These results suggest that nutrients were rapidly assimilated and used to fuel the growth of new Gracilaria tissue at the BRE site. In a hypothetical nutrient bioextraction 1 hectare Gracilaria farm system with 2-4 m spacing between longlines, Gracilaria could remove 8 - 16 kg N ha^{-1} mon^{-1} in October to 33 – 66 kg N ha^{-1} mon^{-1} in July.

In addition, we observed excellent spatfall of blue mussels and strong recruitment of tunicates (also filter feeders) on the pegged ropes, especially when extra weights were added to them to keep them vertical in the

strong currents. The mussel ropes, and lines of ribbed mussels, provided an excellent habitat for over 37 species of marine invertebrates, including amphipods, mollusks, polychaete worms, and tunicates. The raft also survived two hurricanes!. Thus, at the Hunt's Point site, there is excellent potential for the removal of nitrogen using Gracilaria, potential for blue mussel culture, and potential for increasing the biomass and biodiversity of over three dozen invertebrate species on the culture ropes.

2. Project Activities & Outcomes

Activities

- Describe and quantify (using the approved metrics if one is referenced in your contract) the primary activities conducted during this grant.

The comprehensive project utilized existing aquaculture technology and engaged experienced scientific/industry/nongovernmental community based partners to perform feasibility studies at a site (located at 40° 48' 04.66" N and 73° 52' 16.38" W) to determine if project goals can be realized. The project results form the foundation for expanded bioremediation efforts in the Bronx River and other urban estuaries.

The P.I., Dr. Carter Newell, was asked to manage this project which was originally funded to the Gaia Institute. The original project proposed to use longlines, fuzzy rope, and natural spat collection of ribbed mussels (*Geukensia demissa*) to filter the water, resulting in improvements in water clarity, removal of nitrogen and suspended particulates. The revised project performed a pilot project, using a 400 square foot mussel raft (Figure 1) with 100 x 25 foot long pegged ropes, natural spat collection on the ropes and on intertidal coir mats and logs in the Bronx River, and ribbed mussels gathered from nearby salt marshes to perform the feasibility studies at a permitted site at Hunt's Point to see if the project goals could be realized. In addition to ribbed mussel intertidal spat collection and culture experiments on subtidal pegged ropes, *in-situ* biodeposition studies of ribbed mussels, seaweed (*Gracilaria*, kelp) culture trials, and environmental monitoring of the site were performed by project partners.

Figure 1. Raft near Hunt's Point.

A site was **permitted** (Figure 2) which has 26 feet of water at low tide, is out of the navigation channel, and near the mouth of the Bronx River. A 20x20 mussel **raft was assembled** at Rocking

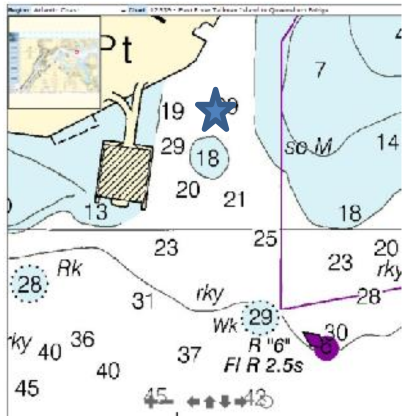

Figure 2. Location of permitted site near Hunt's Point.

the Boat, **deployed** (with the help of the nearby scrap yard, Figure 3) and **anchored** at the site for the spat collection, grow-out, water quality sampling, and seaweed growing experiments.

Figure 3. Lowering the assembled raft into the water.

In addition, permits were obtained to perform ribbed mussel **intertidal spat collection experiments** in the Bronx River using coir mats and logs (Figure 4). The coir mats and logs were placed just below a mid-intertidal rocky shore where ribbed mussels were abundant (Figure 5).

Figure 4. Loading up the boat with RTB interns and staff, and nets and logs after deployment.

Figure 5. Ribbed mussels at the mid-intertidal zone in the Bronx River.

In addition to placing mats and logs out for spat collection in May of 2011, once the necessary permits were obtained for the raft, ropes were hung out for **spat collection on the raft** in late summer and fall of 2011 to collect ribbed mussel seed.

In order to populate the raft with ribbed mussels for studies by NOAA in 2012, and for samples of mussel meat as a possible fish food, we obtained a permit to **collect wild mussels** which had been dislodged from salt marshes in Jamaica Bay. These were attached to pegged ropes and mesh socks in April of 2012. In addition, **spat collection studies** were continued to see if any mussels would be collected in the spring and early summer at the Hunts Point site. A total of 350 pounds of mussels were harvested on April 10 (Fig. 6) and they were declumped by hand, washed and attached to pegged ropes (using nylon binder) and filled in mesh socks (using a PVC pipe, Figure 7).

A total of 4 x 25 foot pegged ropes (100 feet) and 5 x 20 foot mesh sock (100 feet) for a total of 200 feet was seeded (Fig. 8) with an average biomass of 1.5 pounds of mussels per foot (yielding 300 lbs of mussels). Samples from the ribbed mussels (NOAA) yielded a mean length of 60.7 mm and a dry tissue weight of 0. 70 g (and a std. error of .54 and 0.02, respectively, n=100). With a count of 90 mussels per pound and 1.5 pounds **per foot, there was an average dry tissue biomass of 120 x .70 = 84 g dry tissue weight/foot or rope (or 25.6 g** m^{-1}). Using the observed filtration rates (1.6 l h^{-1}) and dried suspended particulate matter (SPM, 13.7 mg h^{-1}) standardized to a gram of dry tissue, for each meter of rope the ribbed mussels filtered 41 liters per hour and removed 351 mg of SPM per hour. The total seeded area (200 feet or 8 ropes) resulted in a **measured filtration rate of 59,865 liters per day (=15,830 gallons per day) and the remover of 513.4 grams of SPM per day.**

If we were able to obtain seed mussels at the site, and fully populate the 20x20 foot raft, the total estimated filtration rate of the mussel raft would have been about 720,000 liters per day (about 190,000 gallons per day) and a removal rate of 6.16 kg per day. **One acre of surface area of a ribbed mussel culture operation would then be expected to filter 19 million gallons per day, and remove 616 kg per day of suspended particulate matter.**

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Figure 6. RTB volunteers collected ribbed mussels in Jamaican Bay.

Figure 7. Hand declumping, filling mesh socks and hand winding of binder on pegged ropes.

Between April and August, 2012 the raft has was monitored, a mooring was reset after the winter, and a spatfall of wild blue mussels was noted in July by NOAA and RTB staff. The status of these ropes (coiled seed collectors, uncoiled ropes, ribbed mussel pegged ropes and ribbed mussel mesh socks) were monitored by Dawn of RTB on August 29, 2012 (Figures 9,10).

Figure 8. Mussel sock (mesh) and pegged rope (hand socked) 5 days after socking on April 16, 2012.

Figure 9 Mesh sock with ribbed mussels and blue mussel spatfall (left) and pegged rope with ribbed mussels (right) on August 29, 2012.

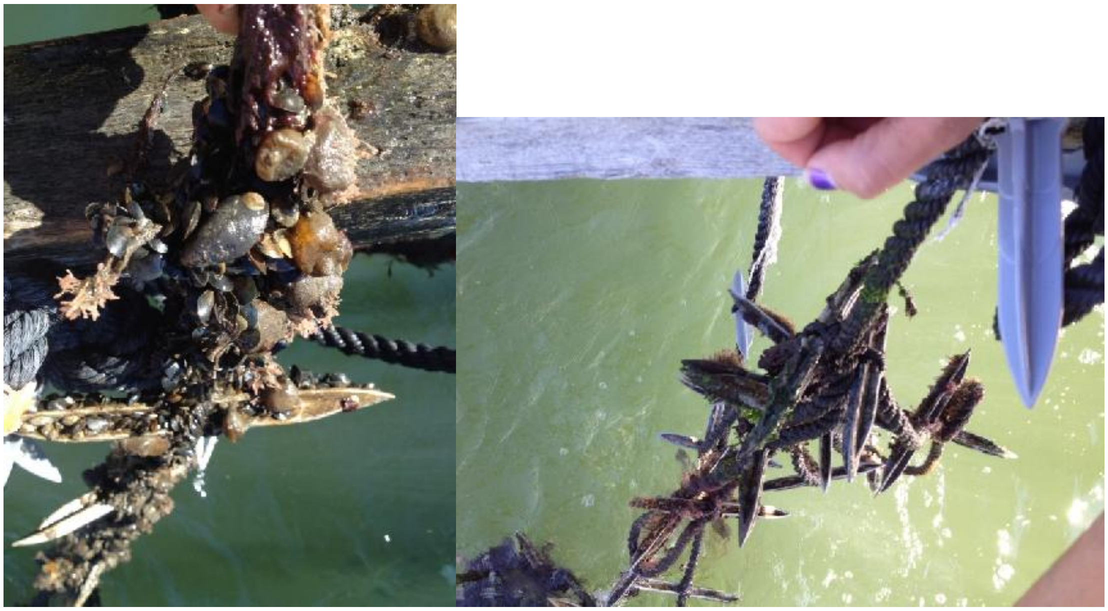

Figure 10. Pegged rope (uncoiled) collector with wild blue mussel spatfall and much less tunicate biomass, and pegged rope (coiled) with less spatfall on August 29, 2012.

Throughout the study in the fall (2011 and 2012), samples were taken from the mussel ropes or socks and analyzed for invertebrate species composition and biodiversity (Figure 11).

Figure 11. Taking samples of collector ropes for biodiversity and species composition.

Ribbed Mussel Results:NOAA

1) To evaluate the reproductive cycle, ribbed mussels were collected from natural populations along the Bronx River shores monthly from June 2011 to May 2012. Mussel gonads matured by June. Nevertheless, there was no evidence of spawning until July, although the biggest spawning period occurred in August. These histological observations of the ribbed mussel reproductive cycle are relevant to results from attempts to collect mussel seed described elsewhere in this report.
2) The ability of the ribbed mussel, an intertidal organism, to survive and function normally when submerged constantly beneath the aquaculture raft was investigated in a laboratory study. Filtration activity was measured in mussels submerged for 8 weeks and in mussels moved from the intertidal zone into a constantly-submerged condition. Results, published in Galimany et al. (2012), showed "… that mussels taken from the intertidal population had significantly higher filtration than the submerged population initially, but after 3 days of submersion in the aquaria, this difference disappeared." Thus, the ribbed mussel quickly adapted filtration and feeding to constant submersion in standard suspension-culture gear used for other mussel species".
3) As a non-commercial species, the ribbed mussel has not been the subject of studies describing the details of filtration, feeding, and assimilation of suspended particles that have been accomplished for blue mussels and other commercial and aquacultured bivalve species. To describe and quantify these behavioral and physiological functions of ribbed mussels at the Hunts Point site, we used the biodeposition method, employing a new apparatus developed by Galimany and co-workers (2011) and compared mussels at Hunts Point to mussels at Milford Harbor in Connecticut, a less-urban site. Seston characteristics at the Hunts Point (6 dates) and Milford (7 dates) sites contrasted radically, and this contrast provided an important opportunity to evaluate the potential for ribbed-mussel aquaculture to succeed at Hunts Point.

   Seston characteristics at both sites are summarized in Fig. 1 (from Galimany et al. in press).

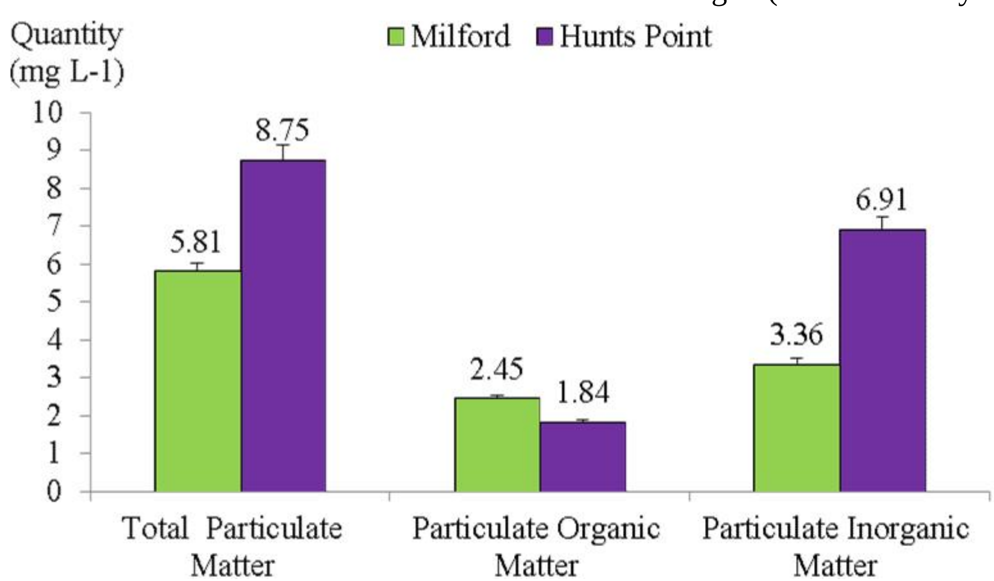

Figure 1. Seston characteristics at Milford and Hunts Point sites. Mean and standard error values are presented.

Total particulate matter was higher at Hunts Point than at Milford Harbor, but the organic content was higher at Milford than at Hunts Point, indicating there was more food available to mussels in Milford Harbor water (more details provided below). This difference in seston resulted in local mussel adaptation through adjustments to filtration and feeding activities as they attempted to optimize energetic gain from the small amount of organic matter present in the seston at Hunts Point. (Table 1., reprinted from Galimany et al. in press).

Table 1. Ribbed mussel filtration and feeding activities at Milford and Hunts Point. Mean (± standard error) of all experiments conducted in 2011.

		Clearance Rate (L h^{-1})	Filtration Rate (mg h^{-1})	Rejection Prop. (%)	Absorption Rate (mg h^{-1})	Absorption Efficiency
Milford (CT)	Average	2.38±0.10	12.50±0.46	35.62±1.50	3.25±0.18	0.71±0.01
Hunts Point (NY)	Average	1.61±0.10	13.68±0.93	59.84±1.97	1.39±0.09	0.71±0.01

The ribbed mussel appears to be capable of processing 13-14 mg of seston per hour (filtration rate). The high inorganic load at Hunts Point requires the mussels to reject nearly 60% of the particles captured (rejection proportion), limiting clearance rate to ~1/2 of the water volume cleared at Milford (clearance rate). The amount of organic matter (food) obtained by mussels (absorption rate) at Hunts Point is, thus, less than half that obtained by mussels at Milford. Despite the scarcity of food at Hunts Point, the ribbed mussels there were able to prolong gut transit time (how long food is kept in the digestive system) to maintain an absorption efficiency equal to that found in Milford mussels. This unexpected adaptation to maintain efficiency only partially compensates for the low proportion of useful food in Hunts Point seston, making Hunts Point a poor location for ribbed mussel aquaculture.

4) Approximately 300 lb (135 kg) of mussels harvested from the Hunts Point raft in October of 2012 were frozen and shipped overnight to the NOAA Fisheries Service facility in Seattle, WA, where evaluation of possible use in alternative finfish feeds is ongoing at the time of this report.
5) Twice, once in April and once in July 2012, 100 mussels were measured for size and weight, numbered, and placed in pearl nets suspended beneath the mussel raft to monitor for growth. Both times, the pearl nets disappeared, either as a result of natural processes or vandalism. Accordingly, we do not have growth data for mussels, except for a short period in April and May when growth was negligible.

NOAA Hunts Point Water Results

Figure 2. Water temperature showed expected seasonal variation, but only slight diel and tidal signals were found in the YSI sonde data

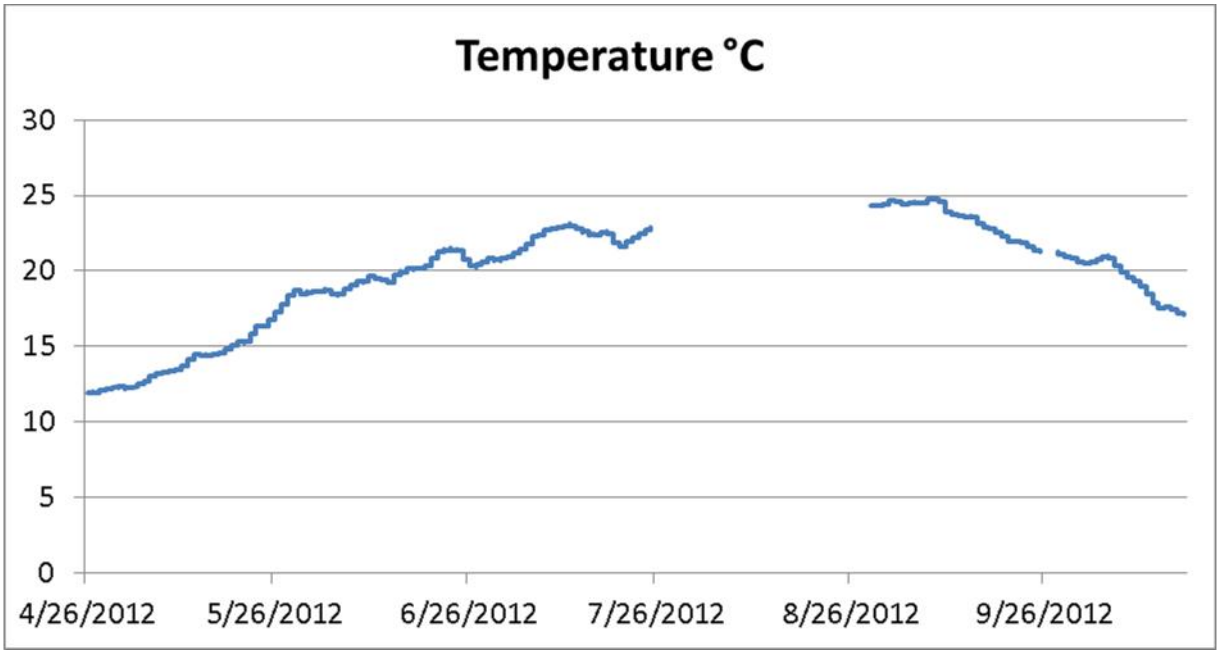

Figure 2. Temperature 1 M beneath the mussel raft at Hunts Point.

Figure 3. Salinity would be characterized as "brackish," responding as expected to local rain events. No diel cycle was apparent, and only a small tidal cycle in salinity was found.

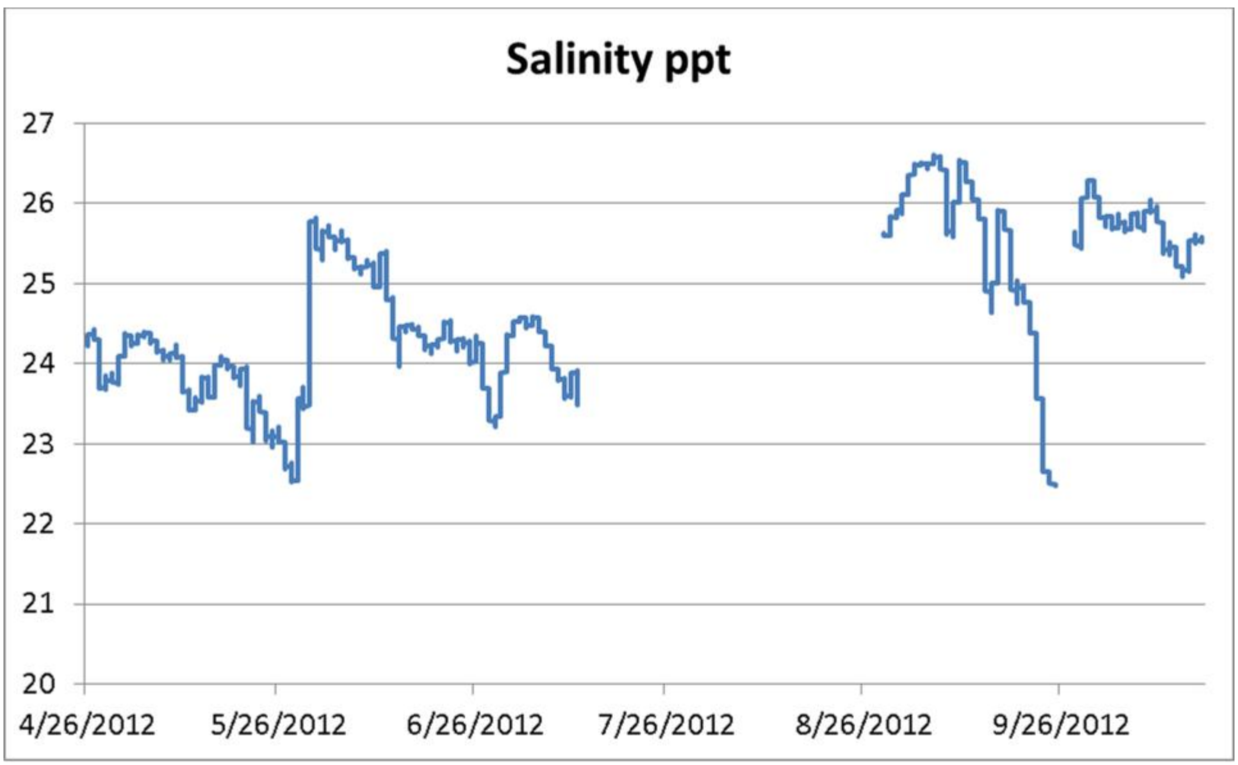

Figure 3. Salinity 1 M beneath the mussel raft at Hunts Point.

Figure 4. Surface water dissolved oxygen (DO), measured at 1 meter depth by the YSI sonde probe, showed a steady, seasonal decline. A very slight cycle in DO was detected, indicating minimal

phytoplankton photosynthetic activity (consistent with low chlorophyll levels) re-charging the surface waters with oxygen during the day.

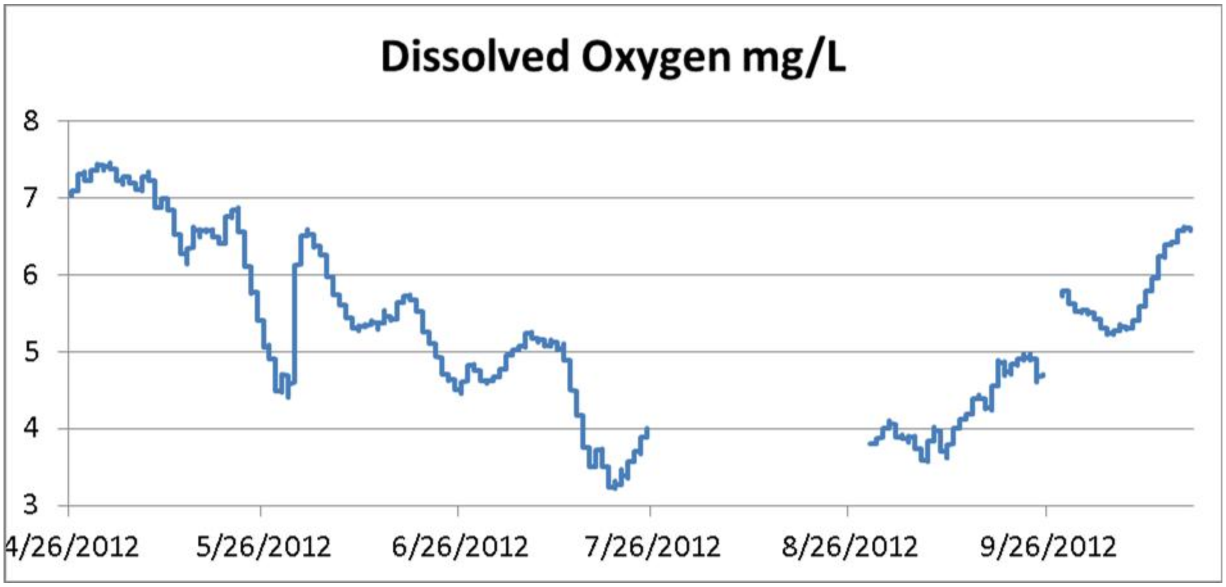

Figure 4. Dissolved oxygen i M beneath the mussel raft at Hunts Point.

Water currents in the vicinity of the raft were highly dynamic, with rapid changes in velocity, magnitude, and direction measured by Doppler current meter (data reduction is underway). This turbulence prevents settlement of suspended particles, results in consistent secchi depth of less than 1 m, and drives the high inorganic particle content observed in the water.

Dissolved inorganic nitrogen ranged between 20 and 70 μML^{-1} (micromoles per liter). There was no evidence of the seasonal cycle typical of Long Island Sound, in which high dissolved nutrients observed in winter are significantly depleted in spring and summer months.

Chlorophyll *a* content of the seston remained between 1-2 $\mu g\ L^{-1}$, an order of magnitude lower than the 10-yr average value of >10 μgL^{-1} for western Long Island Sound during the April-October study period.

The finding of high macronutrients and low chlorophyll in Hunts Point indicates that phytoplankton production is limited at the site, most likely because of either micronutrient deficiency or low light penetration into the water. Experiments at Hunts Point employing light manipulation and variable-fluorescence fluorometry confirmed that photosynthesis was light-limited throughout the season. Studies of microzooplankton grazing in Hunts Point water revealed high grazing rates on nanophytoplankton and heterotrophic nanoflagellates during summer, indicating an active microbial loop and high rates of respiration in the plankton community.

Summary of Milford Laboratory Findings: NOAA

Hunts Point is a challenging place for shellfish growth. High sediment concentrations in the water and low abundance of phytoplankton food force the mussels to process far greater volumes of seawater to obtain the same amount of food as in an algal-rich environment, resulting in a less-favorable energy balance for rapid mussel growth. Despite this challenge, ribbed mussels proved to be extremely resilient, feeding efficiently on the small amount of food available and growing over the course of the six-month season. The ribbed mussel was shown to be a good candidate species for use in nutrient mitigation projects because of its low public health risk, status as a species native to New York waters, ability to adapt to a wide range of environmental conditions and food availability, and continued growth when constantly submerged on the longlines below a raft. By comparing mussel feeding and assimilation of plankton, and nitrogen contained therein, between Hunts Point and Milford Harbor (a more classically eutrophic location with high phytoplankton biomass), we conclude that ribbed mussels have better potential for use in nutrient bioextraction in locations with lower silt loads and higher plankton production than exist at Hunts Point.

References

Galimany, E., M. Ramón, and I. Ibarrola. 2011. Feeding behavior of the mussel *Mytilus galloprovincialis* (L.) in a Mediterranean estuary: A field study. *Aquaculture* 314: 236−243.

Galimany, E., J.H. Alix, M.S. Dixon, and G.H. Wikfors. 2012. Short communication: adaptability of the feeding behavior of intertidal ribbed mussels (*Geukensia demissa*) to constant submersion. *Aquaculture International* DOI 10.1007/s10499-012-9608-3.

Galimany, E., J.M. Rose, M.S. Dixon, and G.H. Wikfors. In press. Quantifying feeding behavior of ribbed mussels (*Geukensia demissa*) in two urban sites (Long Island Sound, USA) with different seston characteristics. Estuaries and Coasts.

Rocking the Boat Activities

In May 2011, Apprentices helped Dr. Newell deploy coir mats and logs in two locations in the lower intertidal zone of the Bronx River where wild ribbed mussels had been observed: adjacent to an eelgrass bed and along rock rubble. In the first location, 30’ x 8’ coir mats were pinned to the mud, and three coir logs were pegged and tied to the sediment. The same process was undertaken in the second location with 70’ x 8’ coir mats and six coir logs. In August 2011, Apprentices assisted Dr. Newell in assembling the raft he had brought down to Rocking the Boat’s site in Hunts Point from Maine the previous winter. This entailed bolting steel separator beams to the parallel rows of floats and then adding a series of wooden cross-members to the raft to serve as walkways and support. The 20’ x 20’ raft was then lifted out of Rocking the Boat’s yard and into the water with a crane supplied by Rocking the Boat’s neighbor Sims Metal Management and was towed to the designated site near the outflow of the Hunts Point Wastewater Treatment Plant. There it was secured with four anchors, 50 feet of bar link chain, and 75 feet of mooring line. Nearly 60 seed collecting ropes, some coiled and some loose, were suspended from the raft with the aim of attracting ribbed mussels that would attach themselves to the ropes and help filter pollutants from the water. Two *Gracilaria* seaweed lines totaling 230 feet in length were fastened along the east and west sides of the raft.

After bi-weekly monitoring in October and November 2011 revealed no spatfall on the ropes of the raft and only light recruitment of ribbed mussels on the coir mats and logs in the intertidal zone, Apprentices spent a day collecting 350 pounds of ribbed mussels in Jamaica Bay, Queens. The mussels were transported back to the Bronx where Apprentices declumped and “socked” them onto line and filled net casings with them before attaching them to the mussel raft. A total of 100 feet of pegged ropes and 100 feet of mesh sock were seeded with the mussels with an average biomass of 1.5 pounds of mussels per foot.

Monitoring in July 2012 revealed a spatfall of wild blue mussels, which likely occurred in June. Spat were most prevalent onthe pegged ropes which had double weights (approx. 6 pounds) and extended to their full length (25 feet) as opposed to ropes that were coiled, and occurred on both the mesh socks and pegged ropes, which were seeded with ribbed mussels. In October 2012, Rocking the Boat, Dr. Newell, and project partner NOAA harvested all of the ribbed mussel ropes and mesh socks and mussels (approximately 300 pounds), which were separated, cleaned of barnacles, and shipped to a lab in Seattle for a nutritional content analysis. Samples were also analyzed to determine the diversity of species populating the ropesand water nutrient tissue chemical analyses were conducted by UCONN on samples of seaweed.

In addition to helping with the ribbed mussel culture, apprentices were given two seminars on mussel aquaculture and biology, as well as seminars by the NOAA team and UCONN on algae. It is estimated that a total of 500 hours of apprentice time was involved in the entire project.

- Briefly explain discrepancies between the activities conducted during the grant and the activities agreed upon in your contract.

We performed all the required activities. Because the permitting did not allow our raft to be put in place until August of 2011 (instead of May), we missed the early spatfall collection. However, we did some spatfall collection (which was mostly blue mussels) during the following spring when the mussel set in June.
Spat collection in late summer and fall in 2011 was not successful on the mussel ropes, and collectors on coir mats and logs in the intertidal zone yielded relatively low numbers of ribbed mussels by November of 2011. The collection of intertidal mussels from Jamaica Bay was not part of the original work plan.

- Small spatfall of ribbed mussels occurred on coir mats (80 per square meter), which grew to a mean size 5.3 mm by late November. Results are consistent with an early fall spatfall. Ribbed mussel size frequency on the mats is presented in Figure 12;
- Coir logs got dislodged in heavy rains and big tides;
- Mussel ropes got covered in sea squirts and other invertebrates (37 species) in the fall of 2011. Samples were taken and analyzed by Dr. Prezant for biodiversity and species composition .
- Most of the coir mats got buried in soft silt along the lower intetidal zone;
- If more seed collection were attempted in the future, placing mats higher in the intertidal zone (above the soft silt) might yield better results.

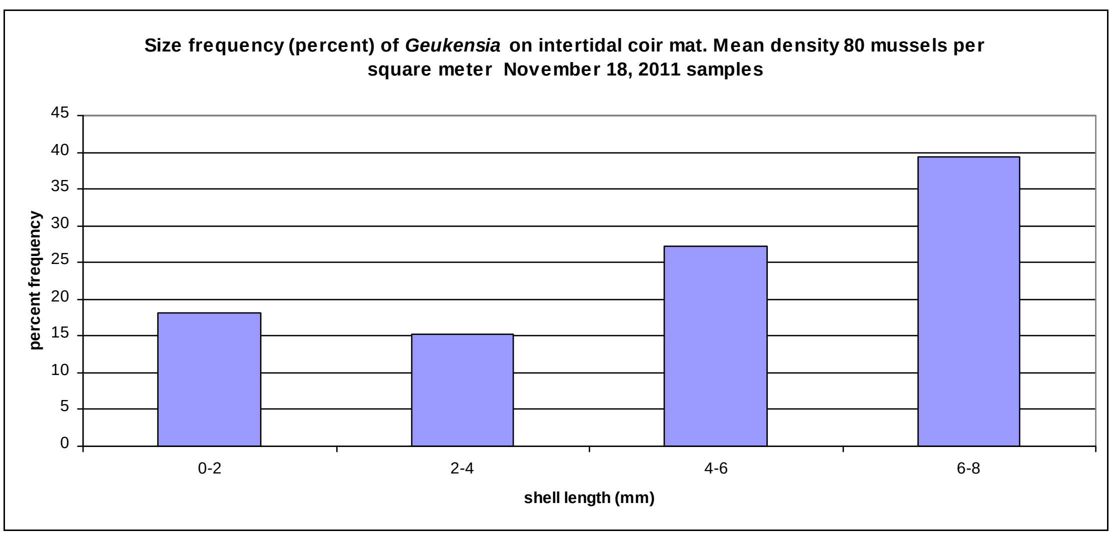

Figure 12. Size frequency of mussels collected on coir logs and mats in the intertidal zone in the Bronx River

Outcomes

- Describe and quantify progress towards achieving the project outcomes described in your contract. (Quantify using the approved metrics if one is referenced in your contract or by using more relevant metrics not included in the application.)

Our main goal was to generate a large population of ribbed mussels to filter the water in the Bronx River. However, we had difficulty obtaining sufficient mussels to provide a significant effect on the water quality there. The main biomass of invertebrates was tunicates and blue mussels settling on rope collectors at our site. Our secondary goal was to increase habitat and that was very successful. We found 37 species of invertebrates living on the ropes. The species list and biodiversity results are attached as an appendix. We did, however, obtain excellent information on the filtration rates and suspended solids removal by ribbed mussels, the uptake of nitrogen and growth rates of Gracilaria, and the permitting and operation of a bioextractive aquaculture operation in New York Harbor.

- Briefly explain discrepancies between what actually happened compared to what was anticipated to happen.

I had anticipated that this might happen since it had never been tried before and ribbed mussels are primarily an intertidal species. We had to eventually harvest and sock some ribbed mussels from salt marshes to get some to study during the 2012 study period. However, blue mussels and tunicates are feasible as filter feeders at this site.

During May and June of 2012, a blue mussel set occurred in June and was most prevalent on the pegged ropes which had double weights (approximately 6 lbs.) and extended to their full length (25 feet) as opposed to ropes that were coiled, and occurred on both the mesh socks and pegged ropes which were seeded with ribbed mussels. It is likely that if permits were obtained by May in 2011, we would have had a successful settlement of blue mussels to achieve the original project goals.

To mark the completion of the ribbed mussel component of the project, Dr. Newell, RTB staff and NOAA staff harvested all the ribbed mussel ropes and mesh socks on October 18, 2012, and mussels (approximately 300 lbs) were separated, cleaned of barnacles, and brought back to the NOAA Milford, Ct. lab to package for the fish feed portion of the project. Dr. Wikfors shipped them to a lab in Washington State to see if the mussel meat would be an acceptable component of fish food, with the idea of bioextraction of nitrogen from the Bronx River estuary from bivalve mollusk growth and harvest. The ribbed mussels did not grow very much (only about ¼ of an inch) from April to October, due to the poor water quality in the area, specifically a large quantity of suspended inorganic silt in the water from the East River. These data are summarized in the attached report and references from NOAA. However, the blue mussel spatfall observed in July and August resulted in nicely seeded ropes by the fall (Figure 13).

Figure 13. Blue mussel settlement on pegged rope collectors sampled on October 18, 2012.

Samples of coiled and uncoiled pegged ropes, pegged ropes with ribbed mussels, and mesh tubes with ribbed mussels were sampled on October 18, 2012 for density and biomass of mussels and other invertebrates. *Mytilus* and *Geukenssia* density (number per meter) on the collectors (coiled and uncoiled), and on the ribbed mussels put in mesh tubing and socked on pegged ropes in April, 2012 and sampled on October 18, 2012 is presented in Figure 14.

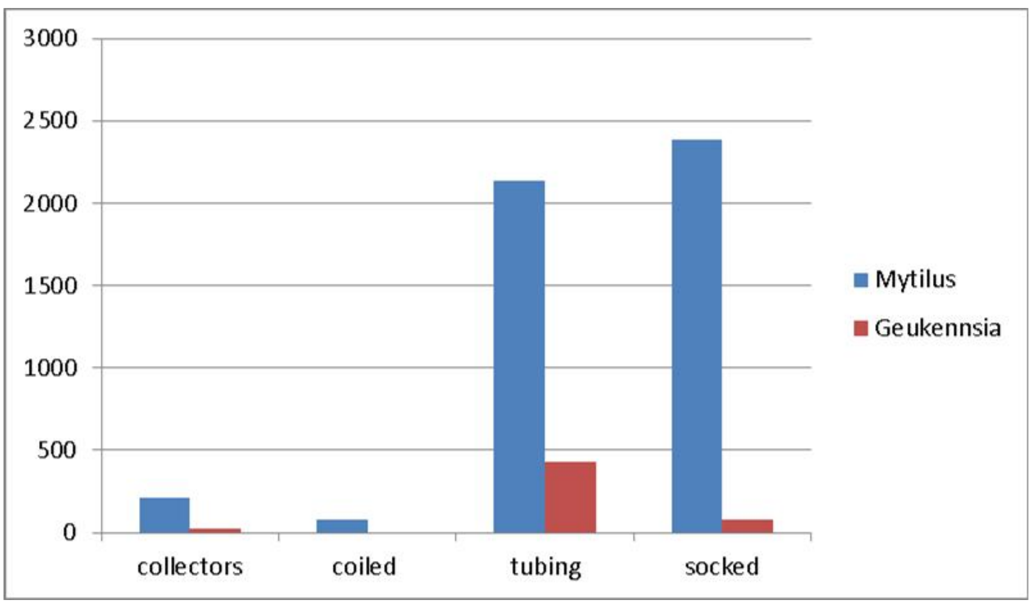

Figure 15. *Mytilus* and *Geukenssia* density (number per meter) on the collectors (coiled and uncoiled), mesh tubing and socked on pegged ropes on October 18, 2012. Note the high blue mussel recruitment to the collectors and especially ropes seeded with ribbed mussels. Also note the small amount of recruitment of ribbed mussels on the collectors, in comparison to the blue mussels.

- Provide any further information (such as unexpected outcomes) important for understanding project activities and outcome results.

3. Lessons Learned
Describe the key lessons learned from this project, such as the least and most effective conservation practices or notable aspects of the project's methods, monitoring, or results. How could other conservation organizations adapt their projects to build upon some of these key lessons about what worked best and what did not?

The main purpose of the project was to improve water quality by using filter feeders. At the Hunt's Point site, while it was not a good habitat for ribbed mussel growth or recruitment, blue mussel and tunicates have possibilities for achieving the same goals.

A comparison between the invertebrates identified from the Hunt's Point mussel raft, and samples taken from Soundview Park's oyster restoration project [1]indicate a number of common species, including amphipods, isopods, polychate worms (*Nereis succinea*), mollusks (*Crassostrea virginica, Mytilus edulis, Crepidula fornicate, Crepidula plana*), and tunicates (*Molgula manhattanensis*). This project has demonstrated that floating shellfish culture systems, such as mussel ropes on rafts, can generate a biodiverse and rich group of invertebrate species which provide benefits not only in water filtration and nutrient removal, but also important food items to fish such as striped bass. In fact the uncoiled pegged rope collectors with a good spatfall of blue mussels had the highest biodiversity (d = 3.55) of all the samples taken in this study.

The settlement of blue mussels indicated that the raft would be a successful biofilter using blue mussels naturally collected on uncoiled pegged ropes with two weights attached to them if the ropes were hung out in May. Furthermore, our results indicate better recruitment on ropes which are populated with some mussels initially. Gregarious settlement of bivalves has been widely recognized in previous studies.

4. Dissemination
Briefly identify any dissemination of lessons learned or other project results to external audiences, such as the public or other conservation organizations.

Presentations and Publications NOAA Staff

Rose, JM (2013) Using shellfish aquaculture for coastal nutrient remediation. Webinar for the NOAA Aquaculture Program seminar series.

Gary H. Wikfors, Eve Galimany, Julie M. Rose, Mark M. Dixon, Yaqin "Judy" Li, Shannon L. Meseck, Genevieve Bernatchez, Kelsey Boeff, Marguerite Petit, Daphne Belfodil, Carter Newell, Franck Brulle, Jason Krumholz, Aynur Lok, Sophie DeDecker, & Yann Reynaud. What we learned about ribbed mussels and Hunts Point. Oral presentation at Connecticut Sea Grant sponsored Workshop on Using Cultivated Seaweed and Shellfish for Nutrient Bioextraction in LIS and the Bronx River Estuary, 3 April 2013, Bridgeport, CT.

Rose, JM (2013) Shellfish aquaculture and coastal nutrient removal: blending ecology and resource management. Invited presentation at the Haskins Shellfish Lab, Bivalve NJ

[1] Oyster Restoration Research Project (ORRP) Phase I (2010-2012) Report, Hudson River Foundation.

Mark S. Dixon, Genevieve Bernatchez, Kelsey Boeff, Eve Galimany, Yaqin Li, Aynur Lok, Shannon L. Meseck, Marguerite Petit, Julie M. Rose, Gary H. Wikfors. The Atlantic Ribbed Mussel, Geukensia demissa, grown using standard aquaculture methods, has potential for use in nutrient bioextraction. Oral presentation at Northeast Aquaculture Conference and Exposition, 13-15 December 2012, Mystic, CT.

Gary H. Wikfors. Pollutant nitrogen ó nutritional protein: the symmetrical, alliterative poetry of bioextraction. Oral presentation at Northeast Aquaculture Conference and Exposition, 13-15 December 2012, Mystic, CT.

Mark S. Dixon. Shellfish Aquaculture and Environmental Interactions: Results of recent research. Oral presentation at Harvard University seminar series, 25 July 2012, Cambridge, MA.

Rose, JM; Bricker SB; Galimany, E; Tedesco, M; Wikfors, GH. (2012) Exploring the science and policy of using shellfish aquaculture for nutrient removal in the coastal environment. Oral presentation at the P/ICES Early Career Scientists Conference, Mallorca, Spain

Rose, JM; Wikfors, GH; Bricker, SB; Ferreira JG; Miller, R; Rheault, B; Tedesco, M; Wellman, K. (2011) An exploratory investigation of nutrient bioextraction opportunities in Long Island Sound. Oral presentation at the Environmental Management of Enclosed Coastal Seas Conference, Baltimore, MD

Rose, JM (2010) Nutrient Bioextraction: opportunities for additional nutrient management in Long Island Sound. Oral presentation at the Association of National Estuary Programs Meeting, Punta Gorda, FL

Rose, JM (2010) Nutrient Bioextraction: opportunities for additional nutrient management in Long Island Sound. Invited talk at the Sea Grant Nutrient Management workshop, New York City

Galimany, E.; Dixon, M.S.; Belfodil, D.; Wikfors, G.H.2012. Quantifying the feeding behavior of ribbed mussels in Long Island Sound for potential nutrient bioextraction use (oral communication) 32nd Milford Aquaculture Seminar; Westbrook, CT (USA). 2012

Galimany, E.; Dixon, M.S.; Rose, J.M.; Wikfors, G.H. 2012 Filter-feeding field studies of ribbed mussels in Long Island sound for bioextraction purposes (oral communication) 104th National Shellfisheries Association; Seattle, WA (USA).

Galimany, E.; Ramón, M.; Ibarrola, I.; Wikfors, G.H. 2011.An approach to study the feeding behavior of mussels in the field (comunicación oral) 31st Milford Aquaculture Seminar; Shelton, CT (USA). 2011

Rose, J. M., Ferreira, J. G., Stephenson, K., Bricker, S. B., Tedesco, M., & Wikfors, G. H. (2012). Comment on Stadmark and Conley (2011)" Mussel farming as a nutrient reduction measure in the Baltic Sea: consideration of nutrient biogeochemical cycles". *Marine pollution bulletin*, *64*(2), 449.

UCONN seaweed work publications and presentations:

Publications:

Kim J.K., G.P. Kraemer and C. Yarish. 2013. Integrated Multi-tropic Aquaculture. *In* Greening the Blue Revolution: the Turquoise Revolution of Integrated Multi-Trophic Aquaculture (IMTA) (Eds. Chopin T., A. Buschmann, and A. Neori). In press.

Yarish, C., Redmond, S. and Kim, J.K. "*Gracilaria* Culture Handbook for New England" (2012).*Wrack Lines.* Paper 72. http://digitalcommons.uconn.edu/wracklines/72.

Yarish, C., Kim, J.K. and Redmond, S. "*Gracilaria* Culture Handbook (DVD) for New England" (2012). *Wrack Lines.* Paper 71.http://digitalcommons.uconn.edu/wracklines/71.

Presentations:

Yarish, C., J.K. Kim, G.P. Kraemer and J. Curtis. 2013. Bridgeport Regional Aquaculture Science and Technology Education Center's 1st annual Chef Event, Celebrating Seaweed. Key note speaker. May 1, 2013.

Yarish, C. and J.K. Kim. 2013. Exploring multi-trophic linkages through aquaculture systems: using ecological methods to integrate the cultivation of seaweeds and fish. 1st International Integrated Multi-trophic Aquaculture (IMTA) Symposium. (Invited speaker)

Kim J.K. and C. Yarish. 2013. Nutrient Bioextraction: an Application of Extractive Aquaculture in Urbanized Estuaries. 1st International Integrated Multi-trophic Aquaculture (IMTA) Symposium. (Invited speaker)

Kim J.K. and C. Yarish. 2013. Seaweed aquactulre for nutrient bioextraction and biofuel. Korea Institute of Ocean Science and Technology. Mar. 29, 2013. (Invited speaker)

Kim J.K. and C. Yarish. 2013. Seaweed Aquaculture: New opportunities for integrating seaweeds in Northeast America. Gangwon Sea Grant International Symposium, Gangwon Sea Grant / Gangneung Wonju National University. Mar. 26, 2013. (Invited speaker)

Kim J.K. and C. Yarish. 2013. Seaweed farming: a new industry in North America. West Sea Fisheries Research Institute. Mar. 19, 2013 (Invited speaker)

Kim J.K. and C. Yarish. 2013. Nutrient bioextraction (IMTA) for urban estuaries. Chungnam National University. Mar. 18, 2013 (Invited speaker)

Kim J.K. and C. Yarish. 2013. Nutrient Bioextraction, a potential opportunity in West Sea of Korea. Incheon National University. Mar. 15, 2013 (Invited speaker)

Kim J.K. and C. Yarish. 2013. Seaweed Aquaculture for nutrient bioextraction and sea vegetables. Sungkyunkwan University. Mar. 14, 2013. (Invited speaker)

Kim, J.K., G. Kraemer and C. Yarish. 2013. Nutrient bioextraction via seaweed aquaculture in Long Island Sound and the urbanized Bronx River estuaries. Northeast Algal Society Annual Meeting.

Kraemer, G. Y. Mao, J.K. Kim and C. Yarish. 2013. Comparison of LED and fluorescent lighting in the culture of wild and green mutant strains of *Gracilaria tikvahiae.* Northeast Algal Society Annual Meeting.

Kim, J.K., C. Yarish, G.P. Kraemer, J.J. Curtis and A. Green. 2013. Seaweed aquaculture: an opportunity for nutrient bioextraction in Long Island Sound and adjacent urbanized estuaries. Long Island Sound Research Conference.

Yarish, C., J.K. Kim and G. P. Kraemer. 2013. Nutrient bioextraction by *Gracilaria tikvahiae* and *Saccharina latissima* in Long Island Sound and the Bronx River estuary. Aquaculture 2013.

Yarish, C. and J.K. Kim. 2013. Seaweed aquaculture: an opportunity for nutrient bioextraction in Long Island Sound and adjacent urbanized estuaries. ASLO 2013 Aquatic Sciences Meeting.

Kim J.K., S. Redmond, G.P. Kraemer, J. Curtis and C. Yarish. 2012. Open water cultivation of *Gracilaria tikvahiae* and *Saccharina latissima* in Long Island Sound and the Bronx River Estuary. Northeast Aquaculture Conference and Exposition.

Yarish, C., J.K. Kim, C. Neefus and J. Curtis. 2012. An introduction to the cultivation of seaweeds: New opportunities for integrating seaweeds in Northeast America. Northeast Aquaculture Conference and Exposition.

Speirs, P., J.K. Kim and C. Yarish. 2012. Optimization of productivity by the CO_2 injection for *Gracilaria tikvahiae* nursery systems. Northeast Aquaculture Conference and Exposition.

Lindell S., E. Green-Beach, M. Peach, M. Beal, C. Jornlind, C. Yarish and J. Kim. 2012. Multi-cropping seaweed *Gracilaria tikvahiae* with oysters in Waquoit Bay, Massachusetts. Northeast Aquaculture Conference and Exposition.

Kim J.K. and C. Yarish. 2012. Nutrient bioextraction by *Saccharina latissima* and *Gracilaria tikvahiae* in Long Island Sound and the Bronx River Estuary. Annual Meeting of the Phycological Society of America.

Kim J.K., K. Kovtun, R. Stainton, and C. Yarish. 2012. Tolerance to hypo-osmotic stress and low temperature determines the spread of non-indigenous *Gracilaria vermiculophylla*. Annual Meeting of the Phycological Society of America.

Kim J.K., G.P. Kraemer, J. Curtis and C. Yarish. 2012. Oppurtunities for seaweed cultivation as an essential element for nutrient bioextraction in Long Island Sound and Bronx River Estuary. Northeast Algal Society Annual Meeting.

Cirino M., A. Bramante, J.K. Kim and C. Yarish 2012. Making friends with a Long Island Sounds invasive: novel evaluation of key resources of *Gracilaria vermiculophylla* relative to native *Gracilaria tikvahiae*. Northeast Algal Society 51st Annual Meeting.

Gong S., J.K. Kim, C. Yarish. 2012. Development of new culture media for *Gracilaria tikvahiae* cultivation. J. Shellfish Research 31: 217. Milford Aquaculture Seminar.

Kim J.K., G.P. Kraemer, J. Curtis and C. Yarish. 2012. Seaweed aquaculture for bioextraction of nutrients from LIS and Bronx River Estuary. J. Shellfish Research 31: 219. Milford Aquaculture Seminar.

Kovtun K., R. Stainton, J.K. Kim and C. Yarish. 2012. Effects of hypo-osmotic stress and temperature on the growth of *Gracilaria*. J. Shellfish Research 31: 221. Milford Aquaculture Seminar.

Kim J.K., G.P. Kraemer, J. Curtis and C. Yarish. 2011. Nutrient bioextraction (IMTA) for urban estuary of Bronx River and Long Island Sound. 50th Northeast Algal Symposium.

The work was shown on television http://www.cptv2.org/allthingsct/episode/savin-rock-west-haven, http://newyork.cbslocal.com/2012/08/21/commercial-seaweed-farm-coming-to-the-long-island-sound/
It was described in the newspaper http://www.theday.com/article/20120311/NWS01/303119895, http://ww2.ctmirror.org/story/14641/long-island-sound-legislation-stalled-washington-politics, http://www.ctpost.com/local/article/UConn-finds-seaweed-could-be-cash-crop-3805535.php, http://www.stamfordadvocate.com/local/article/UConn-finds-seaweed-could-be-cash-crop-3805257.php, http://www.thehour.com/stamford_times/news/uconn-stamford-professors-seaweed-farming-is-thewave-of-the/article_9c96b3b7-dcdf-5b69-9461-62fec52cbd63.html

We had a meeting at Rocking the Boat in May, 2012 and the agenda is below:

Meeting on May 16, 2012 at RTB.

Mussels, Seaweeds, Oysters and Other Interesting Projects
Collaborative Discussion
Wednesday, May 16th

Rocking the Boat
812 Edgewater Road
Bronx, NY 10474
10:00 am – 4:00 pm

11:00 Welcome

11:10 Group Presentations (average 15 minutes each) - Goal is for the group to hear about relevant work in the Bronx River, NY Harbor and elsewhere (brief overview of projects and major findings) to provide a foundation for the group discussion on future research efforts and opportunities for collaboration

- Mussels
  - Gary Wikfors (NOAA)
  - Cater Newell – (Pemaquid Mussel Farm)
  - Julie Rose (NOAA)
  - Eva.Sanroma (NOAA)
  - Terry Doss (Biohabitats)
- Seaweeds
  - Jang Kim (UCONN)
- Oysters
  - Jim Lodge (HRF)
  - Brad Petersen (Stony Brook)
  - Chester Zarnoch (Baruch College)
  - Matthew P. Hare (Cornell - Tentative)
  - Jeff Levinton (Stony Brook - Tentative)

1:00 Lunch – At Rocking the Boat

1:30 Group Discussion

- Future Research Efforts
- Opportunities for Collaboration

2:30 Field Visits (optional)

- Bioextraction Raft
- Soundview Experimental Oyster Reef

4:00 Adjourn

The seaweed component of the project was presented at the NACE/MAS meeting in December, 2012, and at the WAS/NSA meeting in Nashville in February, 2013. The P.I. of this project will present a talk on the results of the study at the 2013 WAS meeting in Grand Canaria in November.

5. The Future
Briefly describe the next phase of this effort (e.g., continuation, expansion, replication, or termination).

The seaweed portion of the project has been extended to include studies of kelp (completed in June, 2012) and UCONN has applied for further studies using the moorings of the system for summer growth of various seaweed species. The raft will be removed in May. However, if it were to continue, it would be interested to use the existing raft with double weighted pegs to see if a good mussel spat (of blue mussels) could be obtained in June and then the project objectives (except with a different species) might be realized. A longline system in the shallow water east of the permitted site has potential for about 4 hectares of nitrogen removal by *Gracilaria*.

6. Project Documents
Include in your final programmatic report, the following:

- any photos from the project. Photos need to have a minimum resolution of 300 dpi;
- report publications, GIS data, brochures, videos, outreach tools, press releases, media coverage;
- any project deliverables per the terms of your contract.

Biodiversity Data:
The following species were observed in samples taken in the fall of 2011 and 2012 attached to the mussel ropes (2011), and to the mussel ropes and growing socks of ribbed mussels in 2012.

The species of invertebrates recruiting to the mussel raft are listed in Table 1 below. Most of the species on the ropes were found during both years samples (Nov. 2011 and October 2012). The presence of Chironomidae on the ropes indicates an influence from the sewage outfall nearby. The biodiversity results are presented in Tables 2 and 3.

Table 3. Species associated with mussel raft ropes.

Species	Group	2011	2012	Notes
Amphithoe valida	amphipod	x	x	
Batea catharinensis	amphipod	x		
Caprella linearis	amphipod		x	
Crassicorophium bonnelli	amphipod	x	x	
Elasmopus levis	amphipod	x	x	
Ericthonius sp.	amphipod		x	
Gammarus mucronatus	amphipod	x		
Gammarus palustris	amphipod	x		
Jassa falcata	amphipod	x	x	
Melita nitida	amphipod	x	x	
Microdeutopus gryllotalpa	amphipod	x	x	
Monocorophium	amphipod		x	

tuberculatum				
Paracaprella tenuis	amphipod	x	x	
Pleusymtes glaber	amphipod	x	x	
Doropygus laticornis	copepod		x	*commensal with *M.manhattensis*
Anthozoa sp.		x		
Campanullaridae	Hydroid	x	x	
Diadumene leucolena	anemone	x	x	
Semibalanus balanoides	barnacle	x	x	
Einhornia crustulenta	bryozoan	x	x	
Dolichopodidae	Chironomidae	x		
Tabanidae	Chironomidae	x		
Trombidiformes		x		
Sphaeroma quadridentatum	isopod	x		
Cyathura polita	isopod (Anthuridae)	x		
Synidotea laevidorsalis	isopoda	x	x	*Asian invasive
Tanystylum orbiculare	pycnogonidae	x	x	
Sesarma reticulatum	Brachyuran	x	x	
Pinnotheres maculatus	Brachyuran		x	
Pinnotheres ostreum	Brachyuran		x	
Eumida sanguinea	polychaete	x	x	
Lepidonotus sublevis	polychaete	x	x	
Nereis succinea	polychaete	x	x	
Polydora cornuta	polychaete	x		
Sabella microphthalma	polychaete	x	x	
Streblospio benedicti	polychaete	x	x	
Eteone lactea	polychaete		x	
Sabellidae sp.	polychaete		x	
Polycirrus sp.	polychaete		x	
Stylochus ellipticus	polyclad flatworm	x		
Botryllus schlosseri	Tunicate	x	x	
Molgula manhattensis	Tunicate	x	x	
Tenellia fuscata	opisthobranch mollusc	X	x	
Crepidula plana	mollusca	x	x	
Ecrobia truncata	mollusca	x	x	
Geukensia demissa	mollusca	x	x	
Mytilus edulis	mollusca		x	
Crassostrea virginica	mollusca		x	
Crepidula fornicata	mollusca		x	

Table 2. Biodiversity results from October, 2012 samples.

October 12, 2012 Hunts Point Samples	R	S-W Index	E = H/ln(R)	Margalef d=(R-1)/ln(N)
Mesh Bag; Bag Length 25cm	18	1.31	0.45	2.40
Coiled - no ribbed mussels; length 46cm, two stakes	18	1.87	0.65	2.76
Ribbed Mesh Tubing; length 32cm	17	1.30	0.46	2.30
Ribbed with sock; length 38cm, one stake	17	0.92	0.32	2.25
uncoiled, no ribbed; length 50cm, two stakes	18	2.00	0.69	2.94
uncoiled, no ribbed; length 50cm, two stakes	18	2.00	0.69	2.94
uncoiled, no ribbed; length 120cm, two stakes	29	2.31	0.69	3.55
ribbed w/sock; length 40cm, one stake	17	0.85	0.30	2.25

Table 3. Biodiversity data for the 11/18/2011 collections.

Sample	n	S	S-W	E	d (Margalef)
#19 11/18/11 Oct 3 Rep 3	101	10	1.6007	0.6952	1.9501
#11 11/18/11 June 1 Rep 2	437	15	1.5080	0.5569	2.3027
#1 11/18/11 Coil Mat South Rep 1	131	10	3.1459	1.3663	1.8461
#17 11/18/11 Oct 3 Rep 2	141	12	1.9109	0.7690	2.2228
#7 11/18/11 Coir Log 1 Rep 1	39	7	1.5066	0.7742	1.6378
#8 11/18/11 Coir Log 2 Rep 2	41	9	1.6548	0.7532	2.1543
#3 11/18/11 Coir Mat South	104	14	2.2690	0.8598	2.7991
#2 11/18/11 Coir Mat South Rep 2	72	10	2.0116	0.8736	2.1044
11/18/11 Aug 18 2011 Hunt's Point Rope Rep 1	555	13	1.6506	0.6435	1.8990
11/18/11 June 1 2011 Hunt's Point Rope Rep 1	2191	17	1.5067	0.5318	2.0801
11/18/11 Aug 18 2011 Hunt's Point Rope Rep 2	1298	16	1.6646	0.6004	2.0925

PDF reports from UCONN and Rocking the Boat are attached.