SEAWEED AQUACULTURE: BIOEXTRACTION OF NUTRIENTS TO REDUCE EUTROPHICATION

GEORGE P. KRAEMER, JANG K. KIM, AND CHARLES YARISH

Like many other estuaries and coastal regions, Long Island Sound suffers from anthropogenic eutrophication. This phenomenon, the addition of nutrients to the system as a result of human activities, is a consequence of the human alteration of the nitrogen cycle on a global scale. In coastal waters and estuaries primary production by phytoplankton, seaweeds, and seagrasses is generally limited by the availability of dissolved inorganic nitrogen, present as nitrate, nitrite, and ammonium. The sources of the inorganic nitrogen added into coastal waters and estuaries are several: fertilizer run-off from residences, agriculture, septic seep into groundwater, fossil fuel combustion, and wastewater treatment plant discharges.

Left: Gracilaria harvest after 2 weeks of growth at the Bronx River Estuary site (in foreground Purchase college Student, John Delgado and background Rocking the Boat student, Gianmarco Bocchini). Photo credit: J.K. Kim and C. Yarish.

The ecological consequences are also varied. Eutrophication can lead to blooms of harmful (toxin-producing) microalgae, and the onshore accumulation of excess seaweed – one need only think back to the sailing events of the 2008 Olympics in Qingdao, China for a an example of this impact[1]. In addition, the sinking of algae to the bottom in shallow waters delivers biomass to microbes, with decomposition consuming oxygen, leading to hypoxia and anoxia. This has become a regular late summer feature of estuaries in the U.S., including Long Island Sound, Chesapeake Bay, Neuse River, and along coastal areas throughout the U.S. The "Dead Zone" off the mouth of the Mississippi River is the most famous example of this. In all cases, ecological impacts also translate into economic impacts, from reductions in fisheries yield to man-hours consumed cleaning beaches of accumulated seaweed.

Estuaries and coastal zones are some of the most important regional economic drivers. Long Island Sound, for example, contributes eight to nine billion dollars in revenue each year to the local economies[2]. Coastal resource managers have become increasingly drawn into watershed management in efforts to reduce eutrophication and its concomitant impacts, and protect coastal economies. In many areas of the northeast, a high degree of development and high population densities preclude large scale land use changes that could reduce nutrient inputs. Within 50 miles of its shores, Long Island Sound is home to more than 20 million people[3].

These high population densities translate into large eutrophication pressures. Strategies for reducing nutrient input include programs to educate homeowners to the action-at-a-distance effects of over-fertilization of suburban lawns, conversion of septic systems to sewerage, and upgrading of wastewater treatment plants to augment microbial denitrification prior to water discharge. These efforts all cost money, and though demonstrably effective in reducing inorganic nitrogen inputs over the past 25 years, have not eliminated hypoxia in the western arm of the Sound.

In 2013 hypoxia covered roughly 81 mi2 for a period of more than two months, the second smallest hypoxic area during the past 27 years[4]. It is likely that sediments at the bottom of Long Island Sound contain a reservoir of nitrogen that maintains the elevated nutrient status and occurrence of hypoxia[5]. What are needed are additional tools in the suite of approaches to nutrient and consequently eutrophication reduction.

An additional strategy to mitigate nutrient levels in estuaries and shallow coastal waters is seaweed aquaculture. Seaweeds have been a part of the human diet for ca. 14,000 years[6], and have a long and important history in Asian countries, including Japan, China, and Korea. These aquatic primary producers remove nutrients from water to fuel growth and reproduction in a process termed bioextraction. The same function occurs on land when wetlands and riparian plants[7] act as "sponges" absorbing nutrient from ground and surface water. Through growth of seaweeds, dissolved nutrients are removed and concentrated in algal biomass which is then harvested, effectively removing nutrients from the aquatic system.

Bioextraction is not envisioned as a replacement for any of the current nutrient or eutrophication mitigation strategies. Rather, it gives another point of attack, and is an approach with subsidiary benefits. Once harvested from aquaculture systems, algal biomass has the potential for many uses. Depending on the species cultured and siting of farm systems, biomass may be sold

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[1] http://www.nytimes.com/2008/07/01/world/asia/01algae.html

[2] http://longislandsoundstudy.net/about-the-sound/by-the-numbers/

[3] Latimer et al. (2014). Long Island Sound: Prospects for the Urban Sea. Springer. New York. 558p.

[4] http://www.ct.gov/deep/lib/deep/water/lis_water_quality/hypoxia/2013_season_review.pdf

[5] e.g., Lai & Lam (2008) Marine Pollution Bulletin, Vol. 57, Issues 6–12, pp. 349–356

[6] Dillehay et al. (2008) Science, Vol. 320 no. 5877 pp. 784-786.

[7] e.g., Likens (2010) River Ecosystem Ecology: A Global Perspective, Elsevier Pub., 424 p.

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for direct consumption as human food[1]. In addition, biomass may also become part of a feed for fish, shrimp, chicken, cattle, etc. Biomass unsold for consumption has potential use as a source of cosmeceutical and nutraceuticals compounds, and cell wall phycocolloids (agars, carrageenans or alginates). Anything remaining has potential value as feedstock for organic fertilizers and/or biofuels. These ancillary revenue sources help make seaweed bioextraction a more attractive, economically viable option.

Right: Bren Smith, owner of the Thimble Island Oyster Co. harvests sugar kelp grown at a site off the Thimble Islands, Branford, CT. Smith is the first commercial seaweed grower in Long Island Sound. Photo credit: R. Gautreau.

Seaweed aquaculture is not a "one size fits all" strategy. Native seaweed species differ in phycocolloid chemistry and quantity, ability to sequester nitrogen, growth rate, and life history malleability[2]. In fact, seasonality of growth varies among species, necessitating a sort of crop rotation. *Gracilaria tikvahiae*, for example, is a red, agar-producing seaweed that grows well during warmer months (water temperature greater than 15°C) in temperate ecosystems. Under optimal conditions, this species may grow at more than 16% per day, and accumulate nitrogen at up to 6% per gram of dry tissue. The sugar kelp, *Saccharina latissima*, is a brown, alginate-producing seaweed growing when temperatures are less than about 15°C. After out-planting juvenile kelp (<1mm), the sugar kelp can grow up to 3.0 m in length with a yield of over 18 kilograms fresh weight per meter of line after 5 months (December-May). The sugar kelp accumulates nitrogen up to 3% on a dry weight basis, depending on location.

Recent studies in the Long Island Sound and the Bronx River estuaries, supported by the Connecticut Sea Grant College Program, the U.S. EPA Long Island Sound Study's Long Island Sound Futures Fund, New York State Attorney General's Bronx River Watershed Initiative Grant Program and National Fish and Wildlife Foundation estimated that the biomass yields of Gracilaria tikvahiae and the sugar kelp were up to 21 and 62 metric tons fresh weight per hectare, respectively.

The aquacultured *Gracilaria tikvahiae* in a hypothetical one hectare farm can remove up to 145 kilograms of nitrogen during a 120 days growing season (July – October). Since these estimates only encompass part of the full May-October growing season, total realized bioextraction would be much greater. The greatest extraction, a function of ambient temperature, light, and N concentration, will likely occur during May-July. The sugar kelp can remove up to 183 kilograms nitrogen per hectare, during the winter spring growing season. The economic value of N removal, if incorporated into a N trading program[3], would be as high as $1,600 per hectare for *Gracilaria tikvahiae* and $2,020 per hectare for the sugar kelp. These values would represent additional income for seaweed aquaculturalists beyond the value of seaweed products.

The bottom line is that seaweed aquaculture removes inorganic nutrients from seawater in a fashion similar to land-based wetlands; nutrients that could otherwise fuel the growth of potentially harmful microalgal and nuisance macroalgal blooms. And, since a fraction of biomass eventually reaches the base of the water column, bloom prevention through bioextraction will help reduce bottom water hypoxia, and eventually draw down nutrients stored in the sediment reservoir. Seaweed aquaculture could be a cost effective, affordable and equitable solution to remove inorganic nutrients in urbanized coastal systems. Seaweed aquaculture, therefore, could be included as part of a suite of management tools to minimize nutrient impacts in urbanized coastal waters, while providing a new business opportunities for seaweed aquaculturalists in the United States[4].

George P. Kraemer, Professor
Department of Environmental Studies
Purchase College
735 Anderson Hill Road
Purchase, NY, 10577, USA

Jang K. Kim, Assistant Research Professor
Department of Marine Sciences
University of Connecticut
1 University Place
Stamford, CT, 06901, USA

Charles Yarish, Professor
Department of Ecology and Evolutionary Biology
University of Connecticut
1 University Place
Stamford, CT, 06901, USA
(203) 251-8432
charles.yarish@uconn.edu

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[1] http://today.uconn.edu/blog/2013/08/from-the-lab-to-the-dinner-table-kelp/

[2] http://seagrant.uconn.edu/publications/aquaculture/handbook.pdf

[3] http://www.ct.gov/deep/lib/deep/water/municipal_wastewater/nitrogen_report_2012.pdf

[4] http://water.epa.gov/resource_performance/performance/upload/OW_End_of_Year_BPFY2012_Report.pdf