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# Developing an environmentally and economically sustainable sugar kelp aquaculture industry in southern New England: from seed to market

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**Title:** Developing an environmentally and economically sustainable sugar kelp aquaculture industry in southern New England: from seed to market

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# PROJECT SUMMARY

The long-term goal of this proposed project was to promote development of a sustainable sugar kelp industry that can help revitalize working waterfronts, and increase employment and economic opportunities for seafood production, processing, and distribution services in Southern New England and New York. To achieve this goal, we have transfer cultivation techniques of Saccharina latissima (sugar kelp) from academic laboratories to commercially viable farms, introduce processing techniques, and provide templates for business plans.  An additional benefit of this study are the ecosystem services afforded by sugar kelp farming. Kelp aquaculture will remove carbon and nitrogen (as well as phosphorus) from the marine ecosystem, and may be useful to restore impacted natural communities of kelp by providing a natural source of seed.

This study directly addressed two of NIFA's four program priorities: Design of environmentally and economically sustainable aquaculture production and Economic research for increasing aquaculture profitability. Supporting objectives to address these program priorities included 1) expanding seedstock nurseries to provide sustainable seedstock of sugar kelp to new growers; 2) transferring open water cultivation technologies to new sugar kelp growers; 3) developing a mobile seaweed processing facility for fresh and frozen products; 4) providing market analysis, a financial model, and a business plan template for sugar kelp; and 5) developing and completing educational workshops and best management practices for all existing and potential sugar kelp growers in Southern New England and New York, as well as explaining this growing industry to the general public.

**Objective 1.** Expand seedstock nurseries to provide sustainable seedstock to new sugar kelp growers at a scale of at least 150 m per grower (Year 1 and 2);

### 1.1. Expansion of kelp nurseries in Southern New England.

Previously, UCONN and BRASTEC had a seed production capacity of approximately 2,000 m. During the project period, the PIs have worked closely with The Noank Aquaculture Cooperative and GreenWave to develop an industrial kelp nursery system with proper environmental controls (*i.e.* light intensity and photoperiod, water temperature, water filtration, water circulation, water chemistry, etc.). During year 1, the kelp nursery cultivation technologies had been successfully transferred to The Noank Aquaculture Cooperative (NAC), Noank, CT. NAC was the first private sector organization to set up a kelp nursery system in southern New England. NAC had produced over 500 m of seedstring in year 1 and extended its capacity to 1000 m in year 2. The kelp seed production capacity during the project period was expanded to over 3,000 m at UCONN (> 2200 m), BRASTEC (> 800 m; Fig. 1) and NAC (>500 m) nurseries during year 1. During year 2, the production capacity was further increased to over 5,300 m (UCONN, > 2,500 m; BRASTEC, > 1,600 m and; NAC, > 1,000 m). The UCONN's kelp nursery technology in the third year now has been transferred to GreenWave, Fair Haven, CT (http://greenwave.org/). The PIs continue to work with GreenWave with the expansion of an industrial scale kelp nursery system with a capacity of over 18,000 m (Fig. 1).

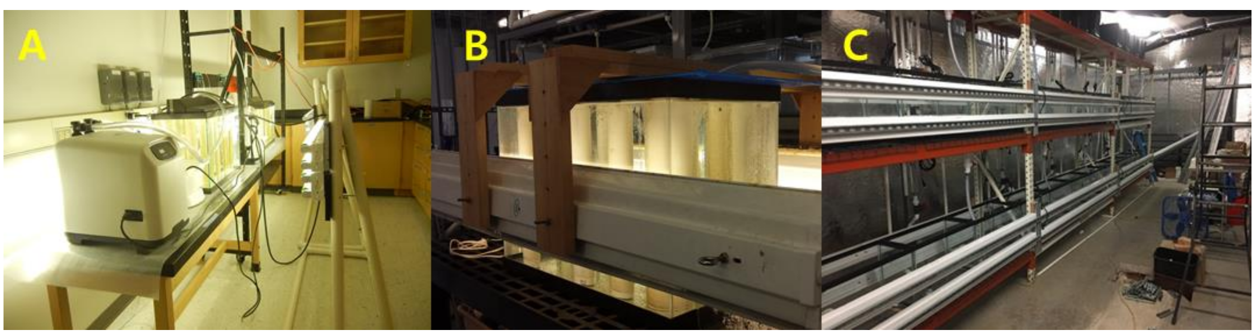



Figure 1. The kelp nursery systems at UCONN Stamford (A), BRASTEC (B) and GreenWave (C).

### 1.2. **Preparation of sugar kelp seedstock for grow-out**.

Native *Saccharina latissima* seedstring was produced using the nursery rearing technology developed at UCONN. To develop seedstring of native *Saccharina latissima*, reproductive kelp plants were collected multiple times at many locations in southern New England to provide sufficient genetic variation and seedstring for growers. In 2014 (year 1), the reproductive plants (with sorus tissue) were collected on September 30th, October 15th, October 22nd, and November 6th at Pine Island (Groton, CT), Black Ledge (Groton, CT) and Ft. Wetherill (Jamestown, RI). In 2015, the sorus tissues of *Saccharina latissima* were collected on October 19th at Pine Island, on October 27th at Narraganset Bay, RI and November 2nd at Black Ledge. In addition, reproductive plants of another kelp species, native to southern New England *Laminaria digitata,* was also collected at Narragansett Bay on October 17th. In 2016, the sorus tissue was collected on September 16, and October 11, 18, 24 and 25 at Black Ledge (Groton, CT), on October 11, 17 and 31 at North Hill Point (Fisher Island, NY) and on November 8 at Orient Point (NY). Additionally, we developed induced sorus production of the kelp. The mature sporophytes of kelp (6 blades) was collected on September 6, 2016 from Black Ledge, Groton, CT. The blades were cleaned and processed, then transferred into half strength PSE medium following Pang and Lüning (2004). To begin the induction of sorus tissue, each of the six blades were kept at 18°C and a short day photoperiod of 8:16 L:D with a photon fluency rate of 90 µmol $m^{-2}$ $s^{-1}$. After two weeks, visible sorus material was observed on the blades. After an additional three weeks, one seed spool was inoculated with meiospores from the induced sorus tissue.

The collected sorus tissue from the reproductive plants was excised for sporulation and strain isolation. The strips of sorus tissue were scraped gently and cleansed of epibionts, immersed in a dilute solution of Betadine®, rinsed, and then wrapped in damp paper towels. The sorus tissue was then stored overnight at 10°C in darkness. The following day, sorus tissue was re-immersed in autoclaved natural seawater to stimulate the release of the flagellated meiospores (zoospores). After removing the spent sori, the spore-filled seawater was filtered through cheesecloth to remove potential contaminants (Brinkhuis et al. 1987). Spore concentration was determined with a hemocytometer under a compound microscope, and adjusted to a spore cell concentration of 4000 - 6000 cells per ml. These zoospores were seeded directly on seedstring (e.g. Korean type string: Guraron 24, 1 or 2mm) wrapped around 38 cm x 6cm PVC nursery spools and placed in seed containers containing 10°C sterilized half strength Provasoli's enriched seawater (PES/2) and 2ml/l of germanium dioxide ($GeO_2$). After 24 hours in the seed containers (dark, 10°C), the spools were then be transferred to grow-out tanks containing sterilized PES (half strength) treated with $GeO_2$ (during week one) and maintained at 10°C. Light levels were adjusted from 20-100 µmol $m^{-2}$ $s^{-1}$ (light levels increased as the sporelings increased in size) with a 12:12, L:D, photoperiod (Fig. 2).

Once all meiospore seedings were made at the UCONN nursery, the seedspools were transferred to all kelp nursery systems for cultivation using the nursery technologies developed at UCONN (Redmond et al. 2014). When plants reached 1-2mm in size, the seedstring was outplanted on longlines at the study sites.

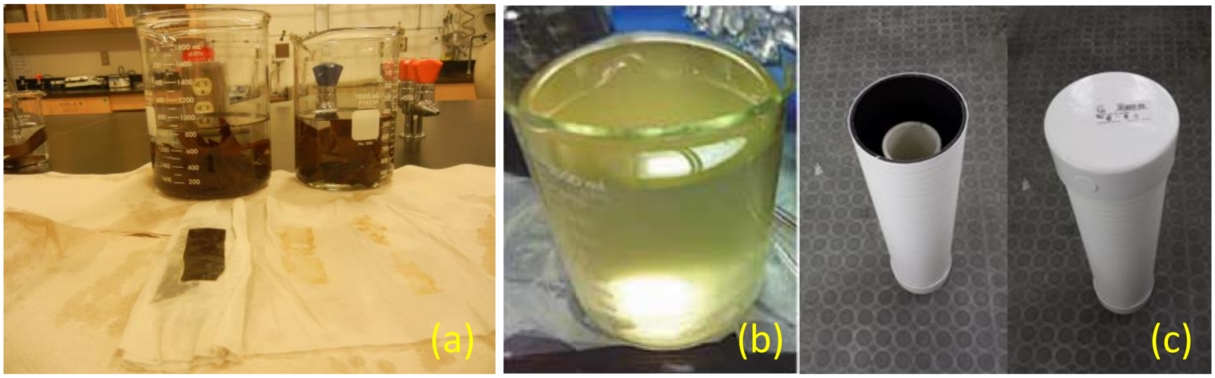



Figure 2. Sorus tissues started to release zoospores (a), spore solution (b) and seedspools in special containers used for seeding and transport to farms (c).

## Objective 2. Transfer open water cultivation technologies to new seaweed growers.

### 2.1. Recruitment of new sugar kelp growers.

In 2014-2015 growing season, six kelp farmers were recruited to grow the sugar kelp on their permitted seaweeds farms. The seaweed farms included Thimble Island Oyster Co. (now Sea Green Farms), Branford; DJ King Lobsters, Branford; and Bridgeport Regional Aquaculture Science and Technology Education Center (BRASTEC) seaweed farm, Fairfield) in CT, and Taylor Cultured Seafoods, Fairhaven, MA; Quissett Point Oyster Co., Woods Hole, MA; and the Marine Biology Labs (MBL) seaweed farm at Great Harbor, Woods Hole, MA.

In 2015-2016 growing season, total 10 seaweed farms participated in this project throughout southern New England and New York. The seaweed farms include: Sea Green Farms, DJ King Lobsters, BRASTEC and Norm Bloom & Son Oyster (Norwalk) in CT; Martha's Vineyard Shellfish group, Quissett Point Oyster Co., and MBL seaweed farm in MA: Walrus and Carpenter Oysters, D. Blaney & Son seaweed farm sites, Pt. Judith, RI: and Aeros Cultured Oyster Company (K. Rivara, Pres. and Secretary/Treasurer of the NOAA Aquaculture Cooperative) Southold, NY (Fig. 3). In 2016-2017 growing season. UCONN worked to transfer most commercial kelp seed production in southern New England to GreenWave and brought in

The Cornell Cooperative Extension (Southold, NY) as another grower for The Peconic Bays (NY).

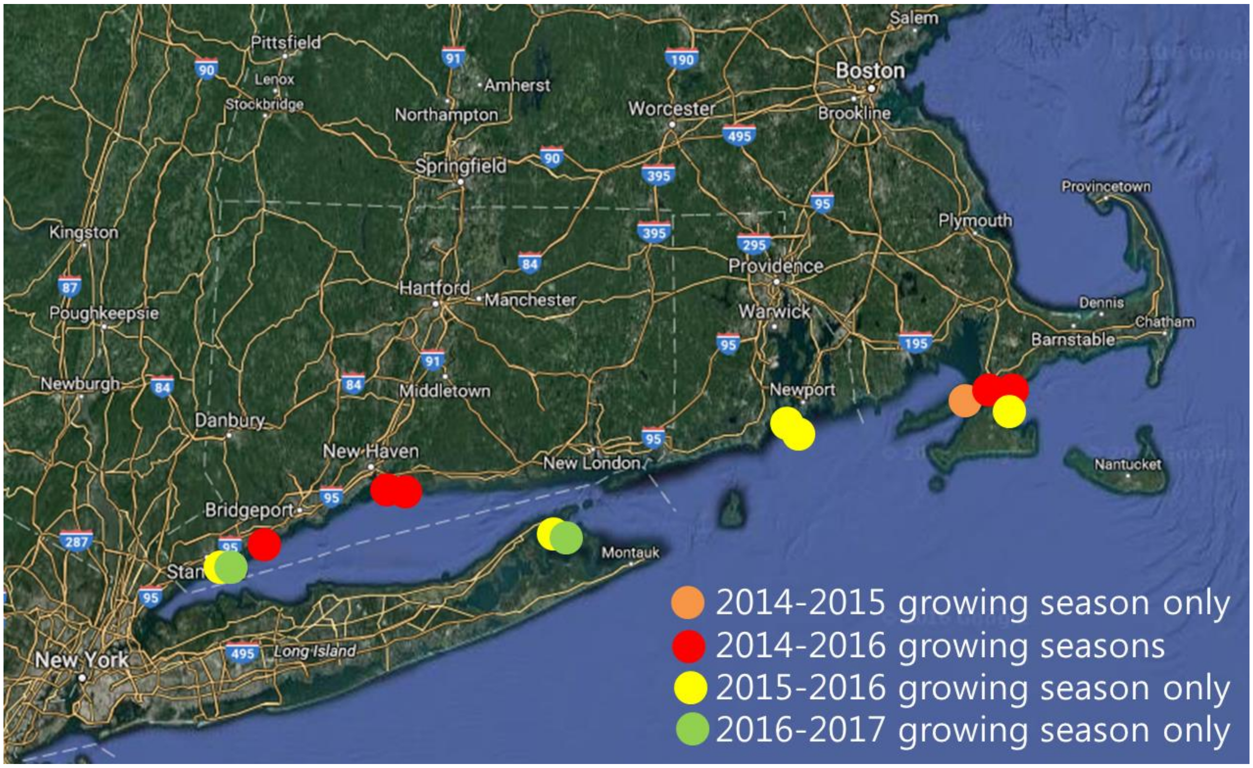



Figure 3. Seaweed farms in southern New England participated in the present project

### 2.2. Transfer open water kelp cultivation technologies to growers.

Open water kelp aquaculture technologies (seaweed farm design, seedstring deployment and maintenance) developed at UCONN were successfully transferred to all growers.

In year 1, we have provided seedstring to six kelp farms. Eleven deployments were made in 2014-2015 growing season, starting from Oct. 28th with the PIs assistance. Outplanting details are listed below

1) Oct. 28th, 2014: Sea Green Farms (200 m seedstring)
2) Oct. 28th, 2014: DJ King Lobsters (100 m seedstring)
3) Nov. 20th, 2014: BRASTEC (150 m seedstring)

4) Nov. 26th, 2014: Taylor Cultured Seafoods (100 m seedstring)
5) Nov. 26th, 2014: Quissett Point Oyster Co. (100 m seedstring)
6) Nov. 26th, 2014: MBL farm (50 m seedstring)
7) Dec. 1st, 2014: Sea Green Farms (200 m seedstring)
8) Dec. 10th, 2014: DJ King Lobsters (100 m seedstring)
9) Dec. 19th, 2014: Sea Green Farms (100 m seedstring)
10) Dec. 19th, 2014: BRASTEC (150 m seedstring)
11) Mar 17th, 2015: DJ King Lobsters (200 m seedstring)

During year 2, fifteen deployments were made from Nov. 24th.

1) Nov. 24th, 2015: DJ King Lobsters (70 m seedstring)
2) Nov. 27th, 2015: Sea Green Farms (350 m seedstring)
3) Nov. 30th, 2015: Sea Green Farms (420 m seedstring)
4) Dec. 2nd, 2015: BRASTEC (140 m seedstring)
5) Dec. 3rd, 2015: Quissett Point Oyster Co., Martha's Vineyard Shellfish Group's Oak Bluffs site and MBL seaweed farm (210 m seedstring in total)
6) Dec. 3th, 2015: David Blaney & Sons and Walrus and Carpenter Oysters (140 m seedstring)
7) Dec. 8th, 2015: Sea Green Farms (280 m seedstring)
8) Dec. 11th, 2015: Norm Bloom & Son, LLC (Copps Island Oyster Co.) (280 m seedstring; Fig. 4)
9) Dec. 13th, 2015: Aeros Shellfish Co. (Karen Rivara, 70 m seedstring)
10) Dec. 16th, 2015: Norm Bloom & Son, LLC (Copps Island Oyster Co.) (490 m seedstring)
11) Dec. 16th, 2015: Sea Green Farms (70 m seedstring)
12) Dec. 16th, 2015: DJ King Lobsters (70 m seedstring)
13) Jan. 15th, 2016: BRASTEC (70 m seedstring)
14) Jan. 15th, 2016: Sea Green Farms (70 m seedstring; Fig. 5)
15) Jan. 15th, 2016: 10 m of *Laminaria digitata* seedstring was also outplanted at the Sea Green Farms and BRASTEC's seaweed farms

In the 2016-2017 growing season,

1) Nov. 18th, 2016: DJ King Lobsters (70 m seedstring)

2) Nov. 18th, BRASTEC (140 m seedstring)
3) Nov. 28th, David Blaney & Sons (280 m seedstring)
4) Nov. 28th, : Sea Green Farms (140 m seedstring)
5) Dec. 12th, : Cornell (560 m seedstring)
6) Dec. 21st: Norm Bloom (420 m seedstring)

Water sampling bottles and Secchi disks were delivered to each grower for monthly water sampling and measurements at their sites. HOBO temperature/light sensors were installed at each farm site too.

Figure 4. Sugar kelp outplanting by UCONN personnel at Norm Bloom & Son's (Copps Island Oyster Co.) kelp farm at Norwalk, CT (December, 2015).

Figure 5. The sugar kelp growing at Thimble Island Oyster farm on Jan. 2016.

**2.3. Determination of productivity and nitrogen (N) and carbon (C) sequestration by sugar kelp.**

- In year 1 (2015), February and March severe weather conditions created unusually cold sea temperatures that resulted in sea ice covering all kelp culture locations in southern New England.
- At BRASTEC site, all lines were moved to > 1.5 km east from the farm site by the ice. All kelp plants were scoured off the line (Fig. 6 and 7). HOBO sensors were also lost.
- At DJ King Lobsters, all lines were moved by the ice, and two lines were found 1.0 km east from the site without any kelp left on the line. Ice sheered all plants off these lines too.
- At Sea Green Farms, the ice hit the farm very hard. Some lines moved over 1.0 km away from the farm by the sea ice. Only two kelp lines remained with sparse growth of kelp. Ice sheered most of the plants off these lines.
- At Taylor Cultured Seafood and Quissett Point Oyster Co., all longlines were disturbed by ice moving the anchors or stripping the buoys of the longlines, and the temperature loggers were lost.

- At MBL, the longline and buoys were completely submerged under several inches of ice for 4 to 6 weeks. The kelp had reduced pigmentation and minimal growth. The kelp were severely damaged by the ice (by early June the blades were less than 15 cm in length).
- Additional outplantings (2 x 100 m longline) were made on Mar 17th, 2015 at DJ King Lobsters with the seedstring that UCONN maintained at its nursery, but little growth was observed into June.

Figure 6. Frozen harbor at Captains Cove, Black Rock Harbor, Bridgeport, CT (Feb. 2015).

Figure 7. The iced moved the kelp farm system at the Fairfield, CT, farm site to > 1 km near Penfield Reef (tangled buoys and longlines (Feb. 2015).

**Productivity**

During the 2014-2015 growing season, standing crop was measured only at Sea Green Farms, 3.7 kg FW per meter, which was way less than the standing crop in previous years (10-17 kg FW per meter). At MBL site, standing crop was less than 39 g FW per meter.

In May 2016, the kelp was harvested from all four seaweed farms in LIS. However, the kelp didn't grow at the other farms in RI and MA. For example, the kelp at the MBL site grew several cm by Feb. 2016 but the color of kelp became pale and then disappeared by March. Kelp didn't grow at all at Blaney, Walrus and Carpenter Oysters, Quissett Point Oyster Co. and Martha's Vineyard Shellfish Group's Oak Bluffs sites. This low growth or no growth at RI or MA may have been due ice damage and nitrogen depletion at those sites (see below).

In LIS, however, over 14 kg FW, on average, of kelp per meter of longline was harvested at the Bloom site on May 19. At the BRASTEC site, 6.6 kg FW of kelp per meter of longline was harvested on May 18. At the Sea Green Farms, the final harvest was made on May 25, and the biomass per meter was 5.7 kg FW. Finally, the DJ King Oysters farm harvested its kelp on May

26 with an average biomass of 1.9 kg FW (Table 1). According to our previous nutrient monitoring data in LIS (Kim et al. 2015), the nutrient concentration in the western LIS (e.g. the Bloom site) were higher than that in central LIS (e.g. King and Thimble Island sites). During the 2015-2016 growing season, however, the inorganic nitrogen and phosphorus concentrations were similar at the Bloom and Thimble Island sites.

The seedstring was produced from three nursery systems (UCONN, BRASTEC and Noank Aquaculture Coop.). Based on visual inspections, the quality of seedstring was highest at the UCONN facility followed by the BRASTEC and Noank Aquaculture Coop. The Bloom site received most of the seedstring from UCONN and lesser amounts from the other nurseries. The BRASTEC farm received their seedstring from their nursery. King, Blaney, Walrus and Carpenter Oysters, and MA farms received the seedstring from the Noank Aquaculture Coop. Thimble Island Oyster Co. received the seedstring from all three nurseries. The source of the seedstring appears to have significantly affected the productivity during the 2015-2016 growing season. The UCONN nursery produced the superior seedstring.

Table 1. *Saccharina latissima* standing crop in Long Island Sounds farms in 2016

| | Bloom | BRASTEC | DJ | Thimble |
|---|---|---|---|---|
| Standing crop (kg $m^{-1}$) | 14.8 (±4.0) | 6.6 (±2.0) | 1.6 (±0.7) | 5.7 (±0.5) |

**Tissue N and C**

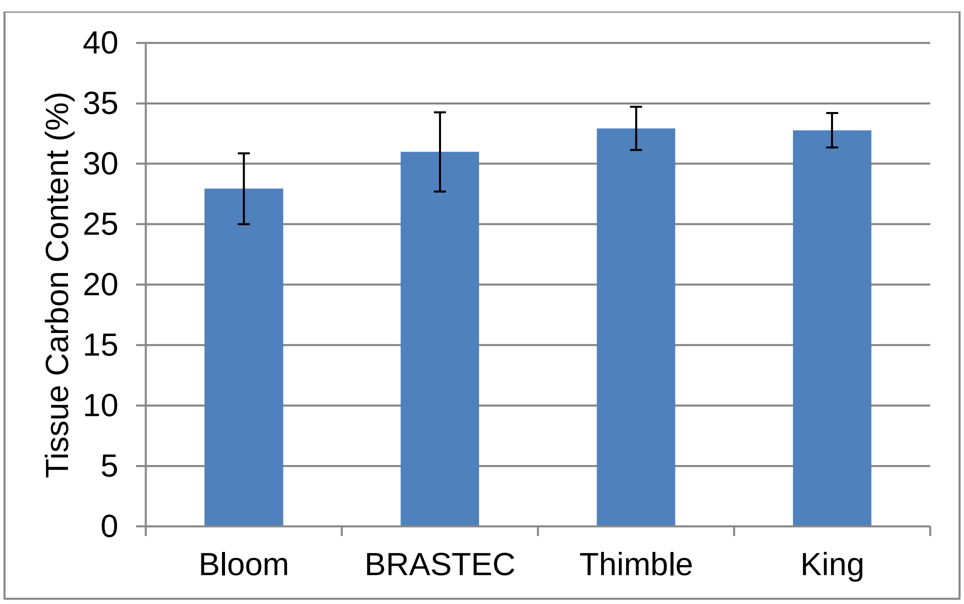
At final harvest, 30 plants were collected from each farm and delivered to the laboratory in a cooler. After washing the plants with Nanopure water, fresh weight was measured. The kelp samples were then dried in an oven at 55ºC and later ground (Model MM200 Grinder, Retsch, Haan, Germany) for CHN analysis. The tissue N and C contents were determined using a CHN analyzer (Series II, CHNS/O 2400 Analyzer, Perkin Elmer Analytical Division of E.G. & G, Wellesley, MA).

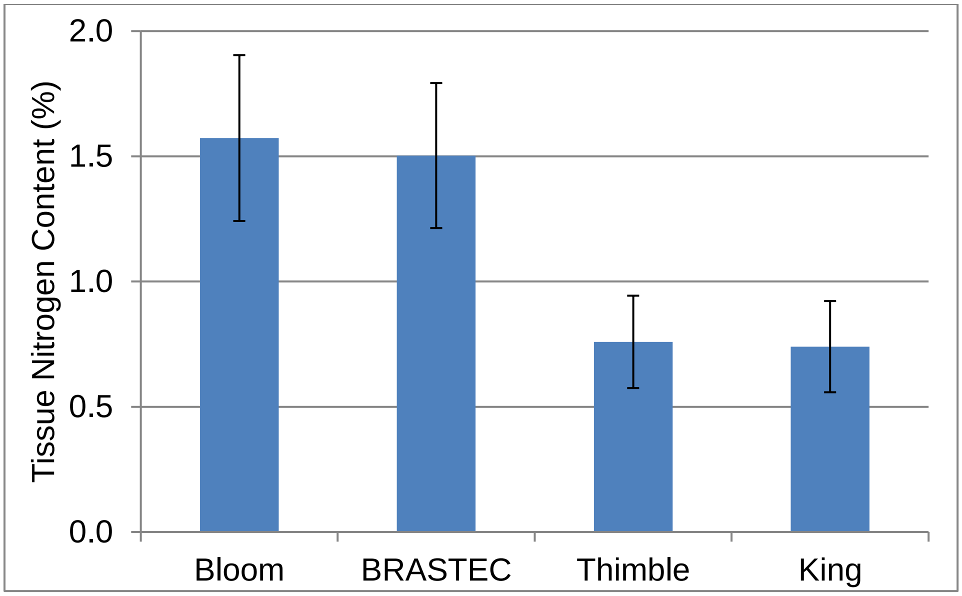
During year 1, the tissue carbon and nitrogen contents were analyzed from the kelp grown at The Thimble Island Oyster Farm and MBL. The average tissue C and N contents were 35.4% and

1.55%, respectively at Sea Green Farms. The tissue C and N contents at MBL were 16.6% and 1.27%, respectively.

In May 2016, the sugar kelp was harvested from all four seaweed farms from western LIS (Bloom and BRASTEC) to central LIS (Sea Green Farms and DJ King Lobsters). The tissue carbon contents at Bloom and BRASTEC sites were 27.93% (±2.93%) and 30.98% (±3.28%), respectively. Those from the central LIS sites were 32.93% (±1.79%; Sea Green Farms) and 32.78% (±1.42%; King), respectively (Fig. 8). While the tissue carbon contents were similar at all four sites in LIS, the tissue nitrogen contents were significantly different. The kelp harvested at the Bloom (1.57±0.33%) and BRASTEC site (1.50±0.29%) had twice as much nitrogen in tissue as the kelp from Sea Green Farms (0.76±0.18%) and DJ King (0.74±0.18%) sites. The C:N ratio at Sea Green Farms (46.16) and DJ King (54.52) indicated that nitrogen was limiting during the harvest period, May, 2016.

Interestingly, the tissue N content at Sea Green Farms was much higher in 2015 than the tissue N content in 2016. The low tissue N content in 2016 was probably because of a prolong phytoplankton bloom in LIS. The extremely mild winter conditions might help phytoplankton to rapidly grow in the spring 2016. In other words, the severe weather during the 2014-2015 growing season inhibited the spring bloom of phytoplankton in LIS, therefore more inorganic nutrients available for the kelp.





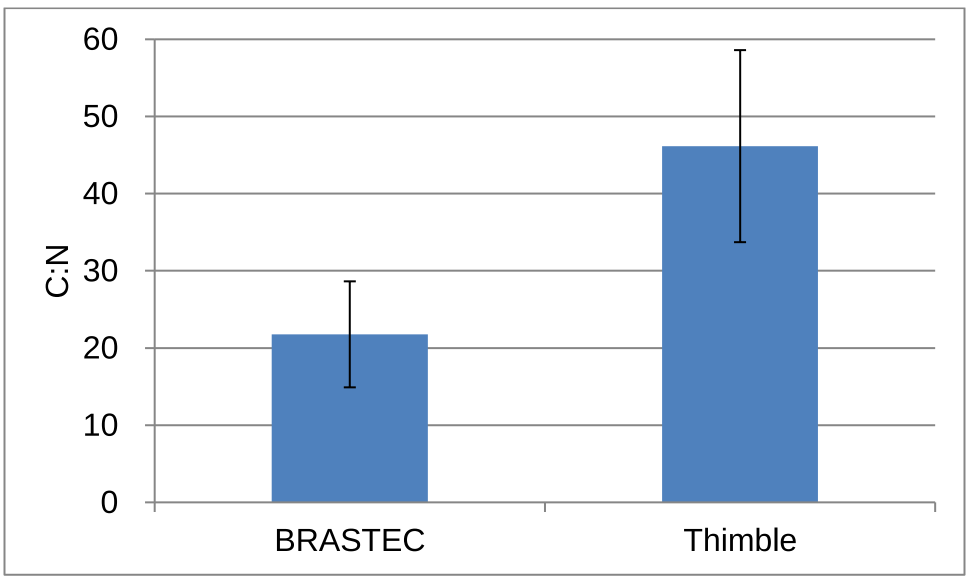




Figure 8. Tissue carbon and nitrogen contents, and C:N ratio in the kelp harvested in LIS in 2016

**$CO_2$ and N removal and its potential economic value**

The amount of N and C removed (mass per time; g per meter per growing season) by the kelp was assessed to assign a value to their nutrient bioextraction. The N and C removal rate multiplied by the kelp biomass per meter of culture line yielded the total amount of N and C sequestered by this kelp species.

Assuming the sugar kelp was cultivated at a hypothetical 1 ha seaweed farm with the spacing of 1.5 m or 6 m between longlines, the production values were calculated based upon mean production values from the farm sites. At the BRASTEC site, the production could be > 4,400 kg while the Thimble Island farm could produce > 3,800 kg. The estimated $CO_2$ removal at each farm was > 5 MT at BRASTEC and > 4.5 MT at The Thimble Island site. Nitrogen removal was over 66 and 29 kg, respectively (Table 2).

Table 2. Estimated $CO_2$ and N removal at a 1 ha hypothetical kelp farm in LIS

| | Production (kg DW $ha^{-1}$) | | Tissue C (%) | Tissue N (%) | $CO_2$ removal (kg $ha^{-1}$) | | N removal (kg $ha^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | 1.5 m spacing | 6 m spacing | | | 1.5 m spacing | 6 m spacing | 1.5 m spacing | 6 m spacing |
| BRASTEC | 4422 | 1122 | 30.98 | 1.5 | 5023.6 | 1274.6 | 66.3 | 16.8 |
| Thimble | 3819 | 969 | 32.23 | 0.76 | 4513.6 | 1145.2 | 29.0 | 7.4 |

We also estimated the potential economic values of N and C removal via sugar kelp aquaculture in LIS, using the most recent market values for these 2 elements in the US ($11.04 $kg^{-1}$ N, $6.00–$60.00 $mt^{-1}$ C [as CO2]; Stephenson & Shabman 2011, CDP 2013, CT DEEP 2013, Tedesco et al. 2014) and for N and C removal. The potential monetary values of N and $CO_2$ sequestration by the sugar kelp at the 2 sites are up to $1000 (BRASTEC) and nearly $600 (Thimbles) $ha^{-1}$ (Table 3).

Table 3. Estimated potential economic values of $CO_2$ and N removal at a 1 ha hypothetical kelp farm in LIS

| | $CO_2$ removal (US $) | | N removal (US $) | |
|---|---|---|---|---|
| | 1.5 m spacing | 6 m spacing | 1.5 m spacing | 6 m spacing |
| BRASTEC | 301 | 76 | 732 | 186 |
| Thimble | 271 | 69 | 320 | 81 |

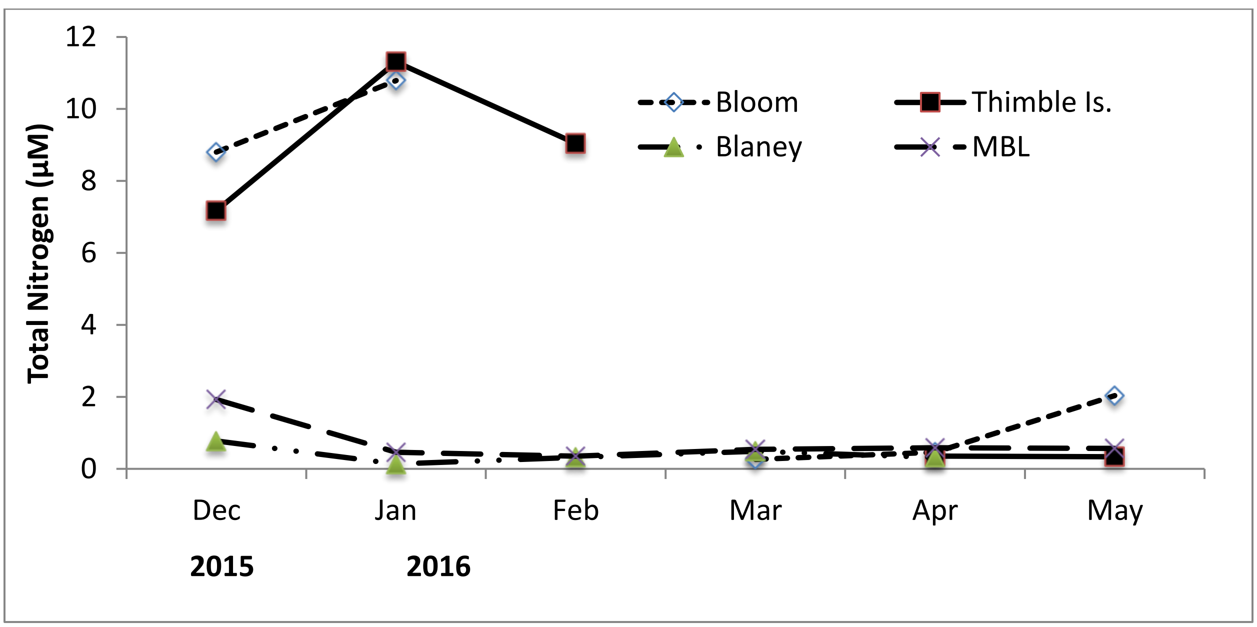
**Inorganic nutrients**

For the inorganic nitrogen and phosphorus analysis in 2015-2016 growing season, water sampling bottles were distributed to all seaweed farmers at outplanting after UCONN personnel provided training for proper sampling method. However, only four farmers collected and provided the water samples to UCONN for analysis. Water samples could not be collected in 2014-2015 growing season due to the severe weather conditions.

Three bottles of water samples were collected monthly by growers from seaweed farms in southern New England. The collected samples were kelp frozen at -20 ºC until analysis. After filtered (0.45 µm), the water samples were analyzed (µmol per liter) at UCONN Avery Point using a SmartChem Discrete Analyzer (Westco Scientific Instruments, Inc.).

At the LIS seaweed farms, the inorganic nitrogen concentrations showed a clear seasonal pattern. The total inorganic nitrogen concentration was highest during the winter months and then decreased as water temperatures increased. However, the total inorganic nitrogen concentration at RI (0.1-0.8 µmol per liter) and MA (0.4-1.9 µmol per liter) farms were low throughout the growing season (Fig. 9). These sites were nutrient limited.

During the winter months (Dec through Feb), the total nitrogen concentrations in the LIS farms (Bloom and Thimble Island Oyster; 7-13 µmol per liter) were higher than the RI (Blaney; 0.1-0.8 µmol per liter) and MA (MBL; 0.4-1.9 µmol per liter) farms. Phosphorus concentrations were also low the MBL site throughout the growing season (0.3 -0.6 µmol per liter) while other three locations showed a similar seasonal pattern like that of the total inorganic nitrogen concentration.



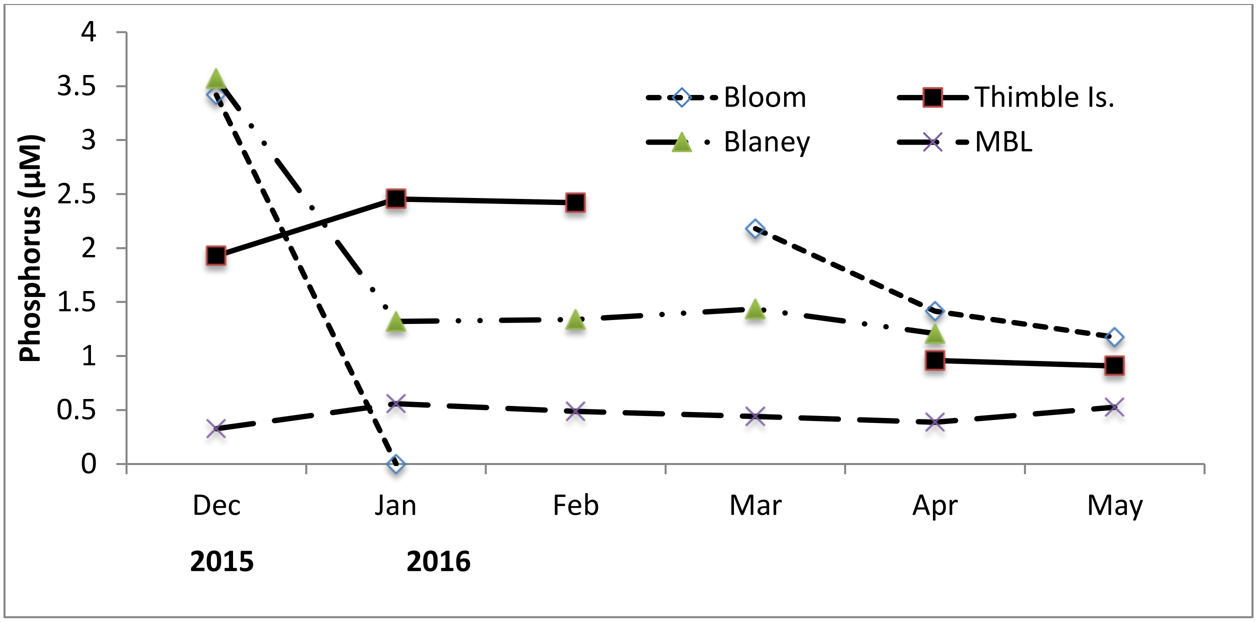



Figure 9. Total nitrogen and phosphorus concentrations at seaweed farms in southern New England

**Temperature**

- The retrieved HOBO temperature data loggers (Sea Green Farms-Thimble Island., DJ King Lobsters and MBL sites) indicated that during Jan 30 – Mar 10, 2015 (Sea Green Farms-Thimble Island., DJ King Lobsters sites) and Feb 1 – Mar 15, 2015 (MBL site), the water temperatures were below 0 °C. The lowest water temperature was < -1.7°C at all sites (Fig. 11). Due to this severe weather conditions, ice was formed rapidly, which precluded the growers the opportunity to go out and do any maintenance of the longlines.
- During 2015-2016 growing season, although HOBO temperature sensors were installed at all seaweed farms, we obtained data from only some of the kelp farms due to maintenance issues by the grower. The water temperatures in LIS farm sites, Bloom (Norwalk), BRASTEC (Fairfield) and King (Branford) were not significantly different from each other. The temperature was high even during the winter months. Temperatures below 3 °C were only observed less than 15 days in January and February at all three sites (Fig. 10).
- The temperature in 2016 was higher than that in 2015 throughout the growing season.
- Especially, the average temperatures in January and February in 2015 were 1.95 and -0.89 °C, respectively, while the temperatures in 2016 were 4.97 and 3.03 °C, respectively (Table 4).

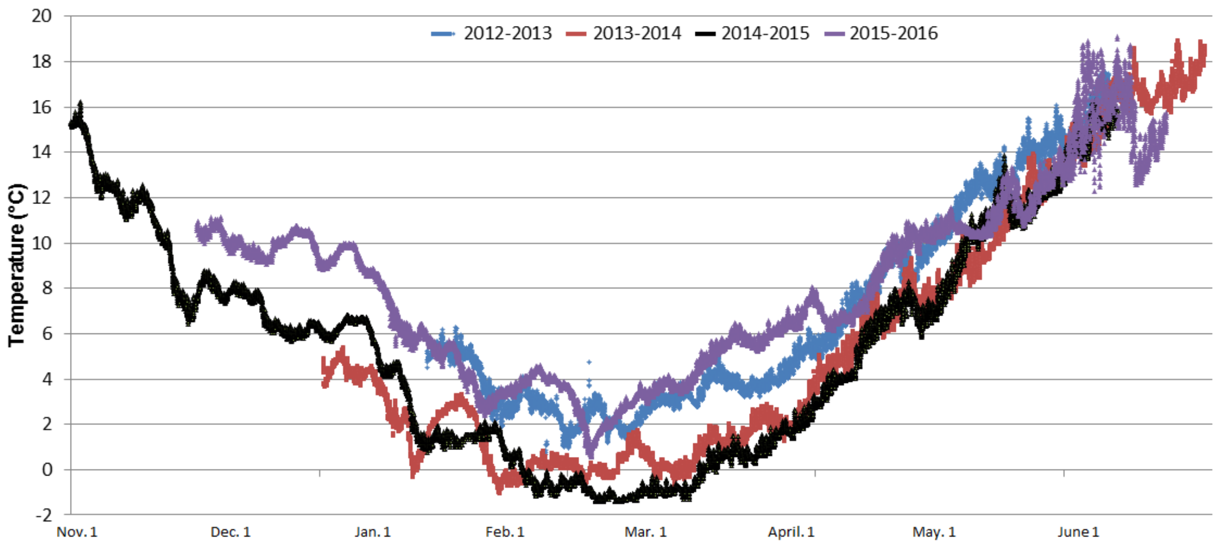



Fig. 10. Temperature profile at the farms sites (2012-2016)

Table 4: Average temperatures in January and February from 2013 to 2016 (unit °C).

| | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|
| January | 4.22±1.10 | 1.52±1.34 | 1.95±1.32 | 4.97±1.51 |
| February | 2.38±0.58 | 0.32±0.43 | -0.89±0.34 | 3.03±0.96 |

**Objective 3. Develop a mobile seaweed processing facility for fresh and frozen products**

- During the project period, we designed and developed a kelp processing system and successfully transferred this technology to educational, private and public sectors throughout New England. Currently, at least three new kelp processing facilities are operating with the PIs assistance in New England.
- In year 1, UCONN personnel worked with Gaya Skinner (Busan, Korea) to modify a mobile squid and seaweed cutting machine. A mobile kelp-cutting machine was purchased from Gaya Skinner (Fig. 11) and installed at a HACCP certified facility (BRASTEC, Bridgeport, CT). The processing machine has a fast feeding capability (> 500 kg FW per hour) and is easy to assemble and disassemble for transport. The machine is capable of cutting kelp blades and stipes at a range of widths by simply changing the blade cutting head assembly. We purchased four

different sizes of blade assemblies: 0.38, 0.68, 1.0 and 2.0 cm, to produce different products for salads and kelp noodles. The machine has been successfully operating for processing fresh and dried species of kelp.


Figure 11. Kelp cutting device purchased from **Gaya Skinner, Busan,** Korea

- In year 1, due to insufficient biomass produced from southern New England farms, several kelp species (*Saccharina latissima* a broad sugar kelp, *Saccharina angustissima* a narrow or skinny sugar kelp, *Laminaria digitata*, *Alaria esculenta*) were donated to the project by Sarah Redmond (ME Sea Grant, Franklin, ME), and Seth Barker, Peter Arnold and Peter Fischer (the principals of Maine Fresh Sea Farms LLC, Bristol, ME). Our machine worked very well to process all four species of kelp. Over 50 kg of kelp products were successfully produced by the mobile kelp cutter in 2015 at the BRASTEC facility (Fig. 12, 13).

Figure 12. Kelp processing machine cutting the blades and the blanching process.

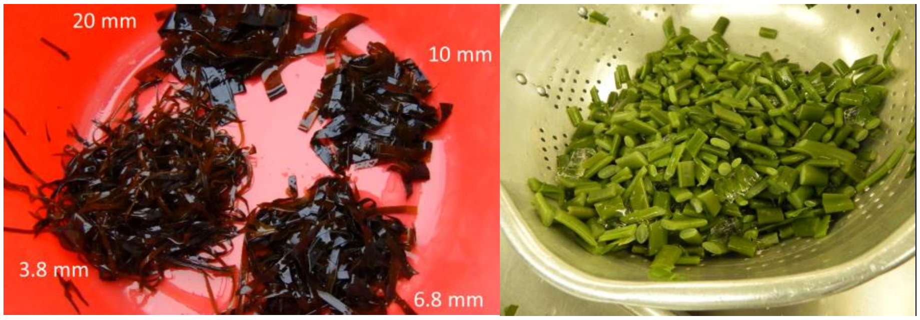



Figure 13. Different sizes of kelp noodles and salad (left), and processed kelp stipes from the

- With the PIs' guidance, Chef Jeffrey Trombetta (Professor of Culinary Arts, Norwalk Community College-NCC) and Justin Davis (NCC teaching coordinator for Culinary Arts Program) completed a HACCP training program offered by the Connecticut-RI Sea Grant Programs and obtained HACCP certification for kelp processing at Norwalk Community College.
- With the PIs' assistance, NCC Professors, Dr. J. Thomas Failla and Chef Jeff Trombetta, developed a HACCP plan for kelp processing and received certification from the State Department of Consumer Protection for the NCC facility.
- During 2015 summer, Chef Trombetta, with our assistance, offered a course at NCC solely dealing with kelp aquaculture products. Through this course and now another course developed by the Culinary Arts Program at NCC has developed recipes using several kelp species being cultivated in the Northeastern US and processed by the UCONN mobile kelp-cutting machine. Chef Trombetta, with the support of NCC, expects to publish a kelp recipe book by late December 2017.
- During year 2, the PIs has assisted GreenWave and Maine Fresh Sea Farms (Bristol, ME) to purchase the UCONN kelp-processing machines, from Gaya Skinner (Busan, Korea). GreenWave has now set up a seafood hub in Fair Haven, CT, where kelp is being processed. GreenWave has obtained HACCP certification and received certifications and approvals from CT State agencies, including the Department of Public Health and The Department of Consumer Protection. Their HACCP plan for kelp processing was modeled after the BRASTEC and NCC HACCP plans. In 2016 and 2017, over 1.7 MT and 4 MT, respectively, of sugar kelp was processed and packaged at GreenWave's seafood hub (Fig. 14).


Figure 24. Kelp noodles produced by GreenWave

**Objective 4. Market analysis, financial model, and business plan template for sugar kelp.**

### 4.1 Production Costs of Kelp Farming in New England

We have developed a model to estimate the production costs of a vertically integrated commercial-scale kelp farm off the coast of New England. The model assumes a vertically integrated operation that includes seed string production (nursery), the open water grow-out operation (farm), a processing facility, and marketing and distribution activities. The farming operation is scaled to fully employ one farm crew of three employees on the water during an eight-month grow-out and harvest cycle (November to June). We estimate that one such crew can manage about 250 longlines of 100m length. At a yield of 10kg/m, this implies an annual production volume from the farm of 250 tons wet weight.

### 4.2 Model Assumptions

Table 5 below summarizes the main assumptions behind the economic analysis. The assumptions are based on conversations with Bren Smith and other growers. The model reflects their experience with prototype kelp farms and information from shellfish and finfish aquaculture operation models (Jin et al. 12007; Kite-Powell et al. 2003).

Because of limited experience with farm-scale kelp farm production in New England, considerable uncertainty still remains about some of the parameters in the model. We used sensitivity analysis to determine the effect of three key parameters (the cost of producing kelp seed string, the cost of longlines, which varies with location characteristics and the yield per meter of longline, which depends on environmental factors) on the total farm gate production cost.

### 4.3 Farm and Seed String Nursery

The cost of seed string production is estimated to lie between \$2.00 and \$4.00 per meter of seed string. We use \$3.00/m as our baseline estimate, and the range of \$2.00 to \$4.00/m for our sensitivity analysis. The baseline installed cost of grow-out longlines is estimated at \$2,000 per 100m line, including materials and labor. The installed cost depends in part on the specific conditions and location of the farm site. Estimates range from less than \$1,000 per 100m to about \$3,000 per 100m, and we use a range of \$500 to \$3,000/100m for our sensitivity analysis. We assume that the longlines have a working life of five years before they must be replaced. Additional expendable costs are estimated at \$100 per 100m longline per year. We assume that the farm requires two workboats with a capital cost of \$30,000 each, and working life of five years (an alternate configuration with similar cost structure is one larger boat at \$40-50,000 and two skiffs at \$5-10,000 each). We assume that operating expenses for these boats are \$4,000/boat/year. The farm work team consists of three full-time workers who are employed for eight months/year at a wage rate of \$25/hour.

Table 5. Assumptions for economic model

| | | | |
|---|---|---|---|
| **Seed string nursery** | | $/meter seed string | 3.00 |
| **Farm** | longlines (LL) | total m of longlines | 25,000 |
| | | $ per 100m LL (deployed) | 2,000 |
| | | working life (years) | 5 |
| | boats | number of boats | 2 |
| | | $ capital cost, farm boat | 30,000 |
| | | working life (years) | 5 |
| | | $ OpEx and fuel/boat-year | 4,000 |
| | operations | months/year | 8 |
| | | FTEs | 3 |
| | | $/hour | 25.00 |
| | | $/LL/year expendables | 100 |
| | | kg/m yield | 10 |
| **Processing** | trucks | number of trucks | 2 |
| | | $ capital cost per truck | 30,000 |
| | | working life (years) | 5 |
| | | $ OpEx and fuel/truck-year | 5,000 |
| | facility | $/year lease | 30,000 |
| | | $/year utilities | 50,000 |
| | | $ capital cost, machines | 75,000 |
| | | working life (years) | 10 |
| | operations | months/year | 3 |
| | | FTEs | 25 |
| | | $/hour | 20 |
| | | $/mt expendables, etc. | 500 |
| | | $/kg frozen storage | 2.00 |
| **Management & Administration** | | $/year | 100,000 |
| **Marketing & Distribution** | | $/year | 200,000 |

### 4.4 Onshore Processing Operations

Onshore processing operations are assumed to take place over three months (May, June, July) centered on the harvest season. The operation employs a total of 25 workers for these three months at a wage rate of $20/hour. This is based on processing labor requirements of four to five employees for 1,000 lbs. of product per day, as reported by Bren Smith (GreenWave). We assume an annual lease payment of $30,000 for the processing facility and an up-front investment of $75,000 for processing equipment and related modifications to the facility. The working life of the processing equipment is assumed to be 10 years. Annual maintenance and utilities costs are estimated at $50,000/year; much of the utilities cost is due to the high energy requirement of blanching the kelp. Post-processing freezing and storage is estimated to cost $2.00/kg of product, assuming that product is kept in storage for an average of 2-3 months before being brought to market. Transportation of product between farm and processing and frozen storage facilities, and from these facilities to customers, is provided by two trucks with a capital cost of $30,000 each, a working life of five years, and $5,000/year/truck in operating costs. We estimate the cost of expendables and packaging used in the processing facility at $500/ton of harvested product. Product loss in the course of processing is estimated at 30% of wet harvest weight, so that 1 kg of wet harvest weight translates into 0.7 kg of product brought to market.

### 4.5 Management, Marketing, and Distribution

Management and administrative costs for the integrated operation are estimated at $100,000/year (one employee plus office expenses), and marketing and distribution costs at $200,000/year (a second employee working out of the same office space, with a marketing budget).

### 4.6 Results

Our analysis suggests that, at the 250 ton/year farm scale, the production cost for kelp to the farm gate, using baseline assumptions as described above, is about $1.16/kg wet weight. (Note: all results described here are quantified in terms of cost per kg of wet harvest weight, unless otherwise noted.) This finding is consistent with recent work on the economics of seaweed farming in Europe (van Dijk and van der Schoot 2015). Sensitivity analysis using the ranges described above on the cost of seed string production ($2-4/m seed string), cost of deployed longlines ($500-3,000/100 m), and farm harvest yield (5-15 kg/m longline) suggests that while a farm gate production cost of just over $1/kg is the most likely outcome, there is also a significant probability that lower than baseline yield in particular can quickly push farm gate production costs closer to $2/kg (Fig. 15). The lowest feasible cost under low seed string and longline expenses and high yield is in the vicinity of $0.50/kg, while farm gate costs in the $2-5/kg range are possible under high cost/low yield conditions. This is consistent with reports from New England growers that a dockside price of about $1/lb ($2.20/kg) is needed for growing operations to be profitable.

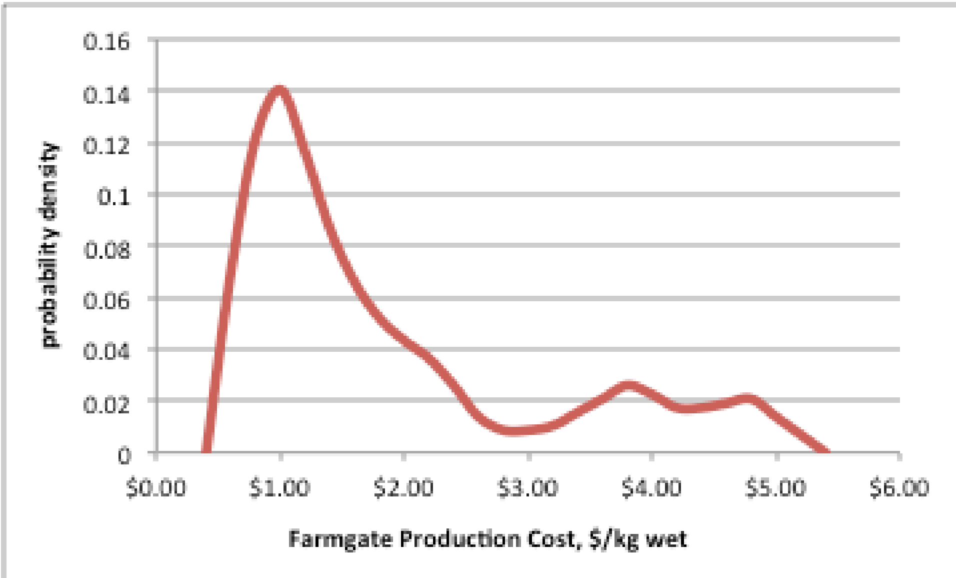



Figure 16: Farm gate production cost probability density

The estimated baseline delivered cost of consumer product, including processing, packaging, marketing, and distribution, is about $5.80/kg ($2.64/lb.) of wet harvest weight, or $8.29/kg ($3.77/lb) of delivered consumer product weight. Incorporating the range of farm gate production cost associated with the main probability peak from the sensitivity analysis (Fig. 16) produces a range of delivered product cost from $5.39 to $6.51/kg of wet harvest weight, or $7.70 to $9.30/kg ($3.50 to $4.20/lb.) of delivered consumer product. This suggests that kelp farmed for high-end food markets with prices on the order of $15/kg ($7/lb.) can be produced profitably with an integrated farm and processing operation at the 250 ton/year scale.

Table 6 shows the breakdown of costs across components in the farm and processing/distribution system. Longlines and labor are the largest cost components in the farm; and labor and packaging/expendables are the largest cost elements in the processing and distribution system.

Table 6. Unit cost components, $/kg wet harvest weight

| | | | ***$/kg wet harvest*** |
|---|---|---|---|
| **seed string** | | | **0.30** |
| **Farm** | | | |
| | long lines | 0.30 | |
| | boats | 0.08 | |
| | labor | 0.38 | |
| | other | 0.10 | **0.86** |
| **Processing** | | | |
| | facility | 0.35 | |
| | trucks | 0.09 | |
| | labor | 0.96 | |
| | expendables | 0.50 | |
| | frozen storage | 1.54 | **3.44** |
| **management/administration** | | | **0.40** |
| **marketing/distribution** | | | **0.80** |
| **Total** | | | **5.80** |

Figure 16 illustrates the relative contribution of major production system components to unit cost. The seed string nursery process accounts for about 5% of the overall delivered product cost, while the longline farm operation accounts for about 15%. Processing accounts for nearly 60% and other onshore functions (management, marketing, distribution) account for the remainder.

There are likely opportunities for economies of scale to reduce unit production costs, especially at the processing and management/administration/marketing components. At the farm component, so long as the approach involves longlines services by small boats in coastal waters, there is likely to be limited room for scale economies once the farm reaches a scale where a boat crew is fully occupied. On the management and marketing components, on the other hand, it is likely that a staff of two could handle the work for several 250 ton/year farms.

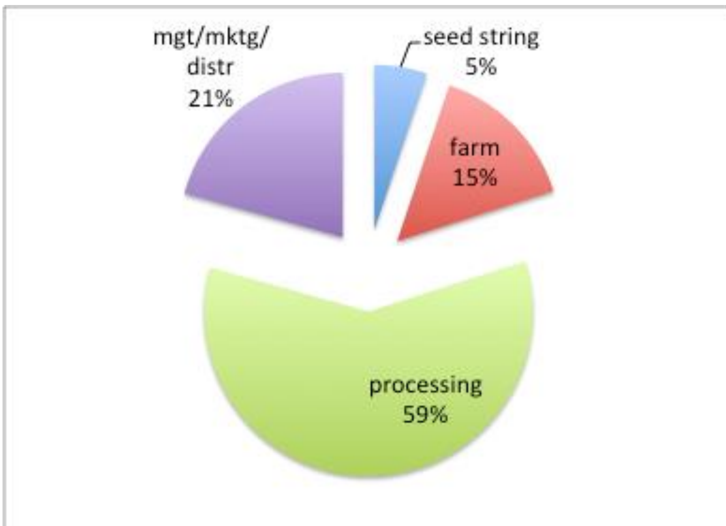



Figure 16. Unit cost components

**Objective 5. Outreach and Education: workshops and best management practices for sugar kelp growers in Southern New England.**

**5.1. Workshops**

The PIs Yarish and Kim organized and chaired two workshops at Northeast Aquaculture Conference & Exposition and the Milford Aquaculture Seminar, entitled "Seaweed Farming" (Jan. 14-16, 2015, Portland, ME; http://www.northeastaquaculture.org/wp-content/uploads/2015/01/NACE-Program.pdf), and at Milford Aquaculture Seminar, entitled "An update of the status of sugar kelp aquaculture in southern New England: from seed to market" (Jan. 11-13, 2016, Shelton, CT; http://www.nefsc.noaa.gov/nefsc/publications/crd/crd1606/crd1606.pdf).

The presentation titles and presenters are as follows:

Northeast Aquaculture Conference & Exposition and the Milford Aquaculture Seminar (Jan. 14-16, 2015, Portland, ME; Fig. 17):

- Introduction to the kelp nursery technologies: wild-sourced seeding and hybridization (Jang K. Kim)
- Introduction to the kelp farming technologies: Open water farming (Sarah Redmond)
- Development of a cultivation program for a morphologically distinct strain of the sugar kelp, *Saccharina latissima* forma *angustissima* from Southern Maine (Simona Augyte)
- Kelp farm design for Long Island Sound (Cliff Goudey)
- Experience with the culinary industry-Developing new seaweed products (Paul Dobbins)
- Training guidance to new kelp growers (Brendan Coffey)
- Development of laver, dulse, and *Alaria* in the University of Maine's Sea Vegetable Nursery Facility (Susan Brawley)

The Milford Aquaculture Seminar (Jan. 11-14, 2016, Shelton, CT; Fig. 17):

- Advances in kelp farm design (Cliff Goudey)
- The development of sea vegetable aquaculture in Maine (Sarah Redmond)
- Insights into the cultivation of morphologically distinct strain of the sugar kelp, *Saccharina latissima* forma Angustissima from Southern Maine (Simona Augyte)
- Development of a mobile kelp processing facility in New England (Jang K. Kim)
- Economics of seaweed farming in New England (Hauke Kite-Powell)
- GreenWave farmer training program (Bren Smith)
- “Kelping Today”, culinary attributes and practical application of kelp (Jeff Trombetta; Fig. 18)

Figure 3. Kelp Aquaculture workshop at Portland, ME (left) and Shelton, CT

Figure 18. Kelp recipe developed by Chef Trombetta of NCC.

## 5.2. Education and technology transfer

- At BRASTEC, over 200 high school students were trained by the PIs, and BRASTEC teachers and staff for the kelp cultivation techniques, from nursery to open water cultivation to harvest, and processing technologies.
- NCC students and staff were also trained for kelp processing and are in the process of developing a recipe book.
- During the project period, new nursery systems were set up at Noank Aquaculture Cooperative, NOANK, CT, which has been relocated to Aeros Cultured Oysters, Southold, NY (Peconic Bays). Currently, the PIs are continuing to assist GreenWave in expanding their large-scale industrial kelp nursery systems at Fair Haven, CT. In cooperation with GreenWave,

another nursery operation has been setup at the Milford Labs, NMFS, NOAA. PIs have trained the personnel at all these organizations and continuously assist- them with the expansion of kelp nursery technologies.

- The PIs have been working with GreenWave (Executive Director, Bren Smith; http://greenwave.org/) to assist new kelp farmers in the US (primarily in the Northeast) to start new businesses and share UCONN kelp farming and processing technologies for a farmer growing program..
- The PIs has also extended their assistance to ME seaweed growers. Seth Barker, Peter Arnold and Peter Fischer (the principals of Maine Fresh Sea Farms LLC) and Maine Sea Grant Extension agent, Sarah Redmond, were introduced to the UCONN mobile kelp-cutting machine.

**5.3. Best Management Practices**

The seaweed, especially kelp aquaculture is a new industry in the United States. The first commercial kelp farming started in 2010 in Maine by Ocean Approved LLC with the assistance of Yarish and Kim team of the University of Connecticut. Currently, more than five kelp nurseries and nearly 20 open water kelp farms are operating in the Northeast America. Additionally, the States of Washington and Alaska have also begun to cultivate the same species in their waters. The demand by the US market for kelp has increased rapidly due to growing consumer demand for new protein sources, healthy food supplements and the food industry's interest in sustainable textural additives. Nearly all locally grown kelp products went to the US food industry. Therefore, it is extremely important to have a Best Management Practice (BMP) appropriate for the New England sugar kelp aquaculture.

**5.3.1. Species**

The kelp species mostly cultivated in New England is *Saccharina latissima*, known as sugar kelp. *Saccharina latissima* is a cold temperate brown algal species. The sugar kelp is the sister species of *Saccharina japonica* which is the major farmed species in Asian countries.
Besides the sugar kelp, two additional native kelp species have received attention in the Northeast: the horsetail kelp, *Laminaria digitata* and the winged kelp, *Alaria esculenta*. *Saccharina latissima* has the widest geographical distribution of the three species in the Northeast, and can be found growing from Maine to eastern Long Island Sound, its southernmost

limit of distribution. *Laminaria digitata* extends down to Eastern Connecticut, while *Alaria esculenta* can be found only as far south as Rhode Island (Block Island Sound; Egan and Yarish 1988, 1990). Recently, a new species, *Saccharina angustissima* (Collins) Augyte, Yarish & Neefus *comb. nov. et stat. nov*. (Formerly designated *Saccharina latissima* forma *angustissima* (Collins) Mathieson) has been suggested as a potential cultivar in the Northeast with yields up to 24 kg per m (Augyte et al. 2017). This species has only been found in southern Maine, highly wave-impacted intertidal sites. The blade morphology of this alga is unique with very narrow, thick and long blade, as much as 10-20 times narrower than *S. latissima* (Augyte et al. 2017in press). However, this BMP focuses only on *S. latissima*. Since the cultivation techniques (both nursery and open water) for all of these kelp species are very similar, this BMP may also apply to other New England kelp species (Redmond et al. 2013).

**5.3.2. Permit**

To operate aquaculture facilities in the U.S., a federal permit (Section 10; Rivers and Harbors Act) from the U.S. Army Corps of Engineers (ACOE) is required. ACEO regulates the installation of aquaculture gear that may cause a barrier to navigable waters. The legal regime governing U.S. coastal waters gives jurisdiction to individual states. Therefore, aquaculture regulations vary from state to state, and sometimes from town to town within a state, which sometimes causes inconsistent results (Duff et al., 2003). At least 120 federal laws were identified that affect aquaculture either directly (50 laws) or indirectly (70 laws) and more than 1,200 state statutes regulate aquaculture in 32 states (Aspen Research and Information Center, 1981). Regulatory complexity is further increased when towns or counties are given jurisdiction over local waters. To site and operate, aquaculture businesses may need more than 30 permits under the purview of a state. In general, therefore, this permitting process can take up to two years because of numerous federal, state and local agencies involved in these processes. Public comment periods and hearings are also required to address local community's concerns (Langan et al., 2006; Flavin et al. 2013).

### 5.3.3. Site Selection: minimal environmental conditions required for the sugar kelp farming in New England

Appropriate site selection for the sugar kelp farming is critical to minimize potential environmental impacts, to optimize the seaweed productivity and to ensure human health. Site selection is dependent on many criteria, including environmental conditions for the kelp growth, regulations, accessibility, etc. Flavin et al (2013) described proper characteristics for the kelp farm site selection. In short:

Physical conditions

1) Good water exchange and adequate current velocity (e.g. one to two knots during peak ebb and flood);
2) Good holding ground for moorings (e.g. mud or sandy bottom);
3) Sufficient depth to avoid the kelp touching the bottom at mean low tide (e.g. 10 m or deeper); and
4) Water temperature preferably above 0 °C during the winter months. The optimal temperature is 5-10 °C for the growth of sugar kelp (Kraemer et al. 2013; Kim et al. 2015).

Chemical Conditions

1) Sufficient nutrients (e.g. preferably 10 μM of total nitrogen concentration or higher during the winter months) (Kim et al. 2015); and
2) Ambient salinity (around 30 psu) is preferable.

Biological conditions

1) Avoid essential habitats of endangered species, ecologically important species (e.g. eelgrass), avoid entanglements of migrating mammals (whales) and turtles;
2) Avoid moving around genetic strains from different bays and biogeographic zones (Britton et al. 2017; Augyte et al. 2017, in press);
3) Be cognizant of any invasive species that could be spread by moorings and farm lines (need to adequately dry and clean lines out at the end of every growing season); and
4) Minimize impact on donor populations.

Other requirements

1) Avoid conflicts with navigation, recreational and commercial fishing, lobstering ferry routes, etc.; and
2) Sufficient distance from wastewater treatment plants, piers, bathing beaches, etc.

Based on the findings in this project, shellfish aquaculture lease sites are, in most cases, suitable for the sugar kelp farming in New England. In addition, considering the productivity of the sugar kelp, nutrient and temperature seem to be the primary environmental factors that govern the productivity of the kelp. In most potential locations for kelp farming in Southern New England, temperature conditions are similar. Therefore, nutrient may be the key factor for the success of the kelp aquaculture in southern New England.

**5.3.4. Nursery**

Kelp nursery consists of three steps: reproductive sorus tissue collection, inoculation and laboratory cultivation. By maintaining the nursery, it is important to note that we can minimize the impact on the donor populations by wild harvest. Nurseries should encourage local cultivar development, without using populations from other geographic regions or even the non-indigenous species (Britton et al., 2017; Augyte et al. 2017). Please see Redmond et al. (2014) for more details about the process

- In New England, the sorus tissue, dark banded area on the blade, can be collected wild via SCUBA throughout the year, but the peaks occur in the spring and fall.
- Sorus tissues are very sensitive to exposure, and therefore, need to be protected from exposure during collection and transport.
- It is important to note that once sorus tissue is collected, it must be kept in a cooler with ice (but there should be no direct contact between ice and the plants) and transferred to the laboratory immediately.
- The collected sorus tissues must be processed as soon as possible to enhance meiospore discharge.
- A rigorous and thorough physical cleaning of sorus tissue without the use of chemicals is best, however, if needed, soak sorus tissue in an iodine bath for 30 seconds (using a

Betadine® solution at 5 mL $L^{-1}$ sterilized seawater at 10°C). This iodine treatment should disinfect ciliates that are often associated with the sorus tissue

- The sorus tissue must then be rinsed in clean seawater a few times for 5-10 minutes, followed by wiping it with a clean paper towel.
- After cleaning, the sorus tissue is placed between clean paper towels and refrigerated overnight, allowing the sorus tissue to undergo gentle desiccation to stimulate meiospore release when re-submerged in seawater.

There are two different methods for inoculation.

1) Direct seeds using wild-collected meiospores (from sorus tissues) onto seedstring.
   Pros: ensures a high density and consistent seeding on the seedstring;
   Cons: no genetic control, obtaining sorus tissues is seasonal dependent
2) Seed using lab grown fragmented gametophytes onto the seedstring
   Pros: allows genetic control and crossing of plants with desirable characteristics, ensures a reliable source of seed throughout the year and less environmental impact;
   Cons: requires additional laboratory space and maintenance of the cultures year round, therefore higher nursery costs

Tank cultivation conditions of seedspools

- Spools should be cultured in clean sterilized seawater with half strength PES and germanium dioxide (=$GeO_2$). Germanium dioxide helps inhibit the growth of diatoms (Lewin 1966).
- Light should be initially 20-30 µmol $m^{-2}$ $s^{-1}$, and gradually increase 20-30 µmol $m^{-2}$ $s^{-1}$ every week up to 100 µmol $m^{-2}$ $s^{-1}$
- Temperature maintained at 10 °C during the entire nursery period.
- Seedspools are ready to outplant when the plant size reaches 1mm in length
- The medium should be changed and fresh half strength PES should be added weekly.

### 5.3.5. Outplanting

Extra care and caution are required to handle and transport seedstring from nursery to an open-water farm

- Outplanted when plants on seedstring are 1-2 mm in length.
- Transport the seedspools in small, sealed containers in seawater and the containers in a cooler to maintain the temperature low (≤ 10 °C)
- While transporting, handle the seedspools with extra care to minimize potential loss of small blades
- Avoid days with too low air temperature (<5 C)
- A cloudy day is preferable for outplanting.

### 5.3.6. Farm maintenance

- Plan on visiting the farm site on a regular basis (e.g. every two weeks) for observation
- Check the growth of the kelp, address buoyant: add additional weights to lines when needed
- Check if the lines are tangled: leaving the lines tangled causes damage to the kelp even loss of the biomass on the lines
- Visit the farm after storm or strong wind events to check damage
- Perform other maintenance as required
- Monitor the water conditions including temperature, salinity, light penetration (Secchi disk), nutrients if possible (Table 7)

Table 7. A list of environmental factors to monitor at the kelp farm during the growing season and a preferable range for each factor

| Factor | Range of preferable value(s) |
|---|---|
| Temperature | <15°C and > 0°C |
| Nitrogen | > 10 µM during winter months |
| Salinity | 28-34 psu |
| pH | 7.8 – 8.2 |
| Secchi depth | >1.5m |

### 5.3.7. Harvest

- The sugar kelp in Southern New England may be harvested April through May but may even extend into June depending on temperature and nutrients.
- If fouling or degradation of the plants is observed, the sugar kelp should be harvested as soon as possible
- It is suggested to harvest before the water temperature reaches 18°C but growth could be sustained at higher temperatures if nutrients are not limiting
- Follow HACCP procedures for harvest if the kelp biomass will be used for human consumption (see Appendix for example)
- To maintain the quality of the kelp, date selection of harvest is important: calm wind and waves, cloudy, slack tide
- If the kelp is used for human consumption, heavy metals and harmful organic matters in the tissue should be analyzed (Kim et al. in review)

### 5.3.8. Processing

- Vary depending on the use of biomass

For human consumption, follow HACCP procedure. This HACCP was based on the kelp processing system developed in this study and was developed for the HACCP certified facilities (BRASTEC, Bridgeport and Norwalk Community College, Norwalk, CT) (see above Objective 3. Develop a mobile seaweed processing facility for fresh and frozen products, for details about the kelp processing system and see Appendix for details about the HACCP)

### 5.3.9. Fouling and disease management

Diseases are not very common in the New England kelp farming. Most diseases are caused by environmental stress; therefore, the BMPs for these issues are basically maintaining preferable environmental conditions for growth (Table 8; Getchis 2014).

Table 8. Disease and fouling organisms potentially occurring in the kelp in New England (Getchis, 2014)

| Disease/fouling | Symptom | Reason to occur | BMPs |
|---|---|---|---|
| Bryozoans (*Membranipora membranacea* and *Electra pilosa*) | Bryozoans grow on the blades | High water temperature (e.g. 15 °C) | Harvest the kelp before bryozoans settle on the blades |
| Snails (*Littorina littorea, Testudinalistestudinalis, Astyris lunata*, etc.) | Usually co-occur with bryozoans; perforations in the blades | High water temperature (e.g. 15 °C) | Harvest the kelp before bryozoans and kelp snails settle on the blades |
| Green sea urchin (*Strongylocentrotus droebachiensis*) | Climb up and consume the kelp | | Keep lines from touching the sea floor |
| White rot disease | Unhealthy discoloring and eventual decay of tissue | High light levels | Increase depth of culture lines |
| Green rot disease | | Insufficient light | Raise kelp lines to increase illumination |
| Black rot disease | | High temperatures | Harvest before excessive summer temperatures, or lower lines to colder depths for black rot. |
| Twisted blade disease | Blades to twist and wrinkle | Exposure to excessive light or currents | Increase depth of culture lines to reduce light intensity |
| Twisted frond disease | Swollen stipes, twisted, roughened fronds, and thickened holdfasts | Low current flow (less than 10cm/sec) with insufficient nutrient levels, and a mycoplasma-like organism | Remove all infected individuals |
| Dark spot disease | Deformations and dark spots on the thallus and spiraling and warts on the stipes of kelps | Endophytes | Remove and discard any affected individuals |
| Blister disease | Blisters on blades | Sharp changes in salinity | Place culture lines at a sufficient depth to avoid freshwater run-off |
| Stipe blotch disease | Marine fungi penetrate algal tissue. overall reduced health, legions, necrotic tissue, blotchiness, blackened patches and contortions | Marine fungi | Remove and discard all infected tissue |

**5.4. Media Appearance**

Current project has been highlighted in national and local media including The New Yorker, Washington Post, CNN, NBC News, Hartford Courant, Inkct.com, Wild Food Girl, Gastropod.com, Futurefood2050.com, thinkprogress.org, gizmodo.com, www.pressherald.com, www.ticotimes.net, www.boston.com, nationswell.com, Stamford Advocate, TheHour.com, ecopreneurist.com, Wrack Line, etc. (see below for details)

- CNN, 'I'm on the front lines of this crisis' Sept. 22, 2014 (http://www.cnn.com/2014/09/20/opinion/sutter-climate-change-oysters/)
- Future Food 2050, Seaweed farming reaps trendy new ocean-borne ‘vegetables’, Oct. 23, 2014 (http://futurefood2050.com/seaweed-farming-reaps-trendy-new-ocean-borne-vegetables-audio/)
- Gastropod, Kale of the Sea, Oct. 2014 (http://gastropod.com/kale-sea/)
- Wild Food Girl, Northeast Seaweed Farming and Foraging, November 7, 2014 (http://wildfoodgirl.com/2014/northeast-seaweed-farming-foraging-charles-yarish/)
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## 5.5. Publications

Kim J.K., G.P. Kraemer and C. Yarish. (in review) Phytoremediation of *Gracilaria tikvahiae* and *Saccharina latissima* Aquaculture in Long Island Sound and New York Estuary. Marine Pollution Bulletin

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## 5.6. Presentations:

Yarish C. and J.K. Kim. 2017. Cultivation of Economically important seaweeds in New England for nutrient bioextraction and IMTA systems. National Institute of Fisheries Science. International Symposium of IMTA

Kraemer G.P., L. Gorman, J.K. Kim and C. Yarish. 2017. Seaweed Nutrient Bioremediation: Field Test of Concept in Long Island Sound. Ecological Society of America

Augyte S., C. Yarish C., J.K. Kim and S. Redmond. 2017 Cultivation of a unique form of sugar kelp, *Saccharina latissima* forma *angustissima* from Northwestern USA with a focus on nutrient uptake and production. 6th Congress of the International Society for Applied Phycology

Park M.S., B.H. Min, Y.D. Kim, C. Yarish and J.K. Kim. 2016. Seaweed aquaculture in Korea: Status and future directions. Aquaculture 2016.

Yarish C. and J.K. Kim. 2016. Seaweed aquaculture for nutrient bioextraction in New England. Harbor Branch, Florida Atlantic University. Feb 20

Yarish C. and J.K. Kim 2016. Nutrient bioextraction and other ecosystem services by seaweed aquaculture in urbanized estuaries in northeast America. Mote Marine Laboratory & Aquarium. Feb. 19

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Kim J.K. and C. Yarish. 2016. Macroalgae cultivation in Korea/Asia with emphasis on emerging technology trends. Advanced Research Projects Agency - Energy - U.S. Department of Energy. Feb. 11-12.

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Kim J.K. and C. Yarish. 2016. Development of a mobile kelp processing facility in New England. Milford Aquaculture Seminar.

Turner H., K. Shadle, K. Tober, E. Kranyik, J.K. Kim and C. Yarish 2016. Development of a Secondary School Curriculum for *Saccharina latissima* (Sugar Kelp) Production. Milford Aquaculture Seminar.

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Kim J.K. and C. Yarish. 2016. Integrated multi-trophic aquaculture (IMTA) or nutrient bioextraction? Annual Meeting of the Korean Society of Phycology. Sept. 28-30.

Kim J.K. and C. Yarish. 2016. Evaluation of Ecosystem Services of Seaweed Aquaculture. In Session entitled "Strategic Approaches to $CO_2$ Sequestration Using Harvestable Algae and Kelp Forest." Jeju Forum. Theme: Asia's New Order and Cooperative Leadership. May 25-27

Kim J.K. and C. Yarish. 2015. Nutrient Bioextraction for Ecosystem Services. Jeju National University. July. 21.

Kim J.K. and C. Yarish. 2015. Seaweed Aquaculture Industry Development in Northeast America. Gangneung Wonju National University. July. 13.

Kim J.K. and C. Yarish, 2015. Seaweed Aquaculture for Nutrient Bioextraction in Long Island Sound and other Urbanized Estuaries in North America. Long Island Sound Assembly. New Haven, CT, April 27, 2015.

Kim J.K. and C. Yarish, 2015. Cultivation of native seaweeds including kelp and the red alga, *Gracilaria*, in Northeast America for Food, Feeds and Fertilizer. Cornell Cooperative Extension of Suffolk County. Riverhead, NY. April 8, 2015.

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Yarish, C. Introduction to the marine life of Long Island Sound. Brooklyn New School (PS 146), Meet the Scientists, Brooklyn, NY, April 16, 2015 (Invited).

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Kraemer G.P., T. Hidu, J.K. Kim and C. Yarish, 2015. Seaweed for food, feed and fertilizer – now and in the future. CT NOFA 33rd Annual Winter Conference, Danbury, CT. March 7, 2015 (http://www.ctnofa.org/winterconference/index.html ).

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Augyte, C. Yarish and S. Redmond, 2015. Development of a Cultivation Program for a Morphologically Distinct Strain of the Sugar Kelp, *Saccharina latissima* forma *angustissima* from Southern Maine. Northeast Aquaculture Conference and Exposition & the 35th Milford Aquaculture Seminar, Jan. 14-16, 2015, Portland, Maine, Book of Abstracts (http://www.northeastaquaculture.org/wp-content/uploads/2015/01/NACE-Program.pdf ).

Kim J.K., C. Yarish and S. Redmond. 2015. Introduction to the Kelp Nursery Technologies: Wild-sourced Seeding and Hybridization. Northeast Aquaculture Conference and Exposition.

Goudey C.A., J.K. Kim, C. Yarish. 2015. Kelp farm design for Long Island Sound. Northeast Aquaculture Conference and Exposition.

Redmond S., J.K. Kim and C. Yarish. 2015. Introduction to the Kelp Farming Technologies: Open Water Farming. Northeast Aquaculture Conference and Exposition.

Kim J.K. T. Han and C. Yarish, Theme: Asia's New Order and Cooperative Leadership. 2016. Evaluation of Ecosystem Services of Seaweed Aquaculture. In Session entitled "Strategic Approaches to $CO_2$ Sequestration Using Harvestable Algae and Kelp Forest." Jeju Forum. May 25-27

Kim J.K. and C. Yarish. 2015. Korea-USA Symposium: Marine Ecosystem Based Integrated Multi-Trophic Aquaculture (IMTA). Gangwon Sea Grant, Gangneung-Wonju National University and East Sea Fisheries Research Institute. Dec. 1

Kim J.K. and C. Yarish. 2015. School of Life Sciences, Incheon National University. Nov. 27

Kim J.K. and C. Yarish. 2015. The 7th International Symposium on Natural Sciences. Institute of Basic Science, Incheon National University. Nov. 26

Kim J.K. and C. Yarish. 2015. Nutrient bioextraction by seaweed aquaculture in urbanized estuaries in Northeast America. Scripps Institution of Oceanography, UCSD.Nov. 3

Kim J.K. and C. Yarish. 2015. 8th International Conference on Environmental Health Science: Advanced Technology in Marine Ecosystem, Environmental Diseases, and Health. Korean Society of Environmental Risk Assessment and Health Science. Oct. 27-29.

Kim J.K. and C. Yarish. 2015. Algae: organisms of ultimate possibilities. Korean Society of Phycology. Oct. 22-23.

Kim J.K. and C. Yarish. 2015. 1st International Seaweed Ranching and Bioremediation Conference & 2nd International Symposium of Advanced Research on Green Tides. Shanghai Ocean University. Oct. 8-12

# APPENDIX (see attachment)

# HACCP Plan Form rev 4-14-15 rev 5-15-15

| | |
|---|---|
| *Institution Name:*<br>Norwalk Community College, Hospitality Management and Culinary Arts Program<br>*Institution Address:* 188 Richards Avenue, W123, Norwalk, CT 06883<br>*Contacts:* Chef Prof. Jeffrey Trombetta, 203-857-3393. jtrombetta@ncc.commnet.edu<br>Culinary Asst. Justin Davis 203-857-7158, jdavis@ncc.commnet.edu<br>Director Dr. Thomas Failla 203-857-7303, tfailla@ncc.commnet.edu | *Product Description:* Kelp - processed<br><br>*Method of Storage and Distribution:* Fresh and Frozen<br><br>*Intended Use and Consumer:* Fresh and Frozen |
| Signature of Institution Official: | Date: |

| *(1)*<br>*Critical Control Point* | *(2)*<br>*Significant Hazards* | *(3)*<br>*Critical Limits for each Preventive Measure* | *Monitoring* | | | | *(8)*<br>*Corrective Actions* | *(9)*<br>*Verification* | *(10)*<br>*Records* |
|---|---|---|---|---|---|---|---|---|---|
| | | | *(4)*<br>*What* | *(5)*<br>*How* | *(6)*<br>*Frequency* | *(7)*<br>*Who* | | | |
| Receiving | Micro biological growth | Time/date of Harvest and arrival time/date at processing facility <41ºF. HAACP in place at harvest, packing and shipping | Shipping Cooler temperature; ocean/boat debris; misc. physical contaminants | Thermometer. Visual inspection | On arrival. | NCC HSP staff and students | If cooler temp. is > 41ºF for >2 hrs, then product rejected.<br><br>If physical contamination found then remove. | HACCP licensee crosschecks shipping cooler temp. log and signs<br><br>Digital thermometers used and if not working replace. | Cooler temperature and temperature log; contamination notes on log. |
| Store Immediately; or sorted for processing and temporary storage | Micro biological: Pathogen growth. | Cooler Refrigerator temperature <41ºF. | Cooler Refrigerator temperature. | Thermometer and cooler refrigerator temperature device | Twice daily. | NCC HSP staff and students. | If cooler temp. is >41ºF for < 2 hrs, then product quick chilled to <41ºF | HACCP licensee crosschecks cooler temp. log and signs weekly.<br><br>Digital thermometers used and if not working replace. | Cooler temperature and temperature log; contamination notes on log. |
| Processing | Pathogenic bacterial growth. | <2 hours exposure to ambient temperature. | Time of removal from cooler. Time of processing completion. | Begin/end log. Each batch takes less than 2 hours | Each batch. | NCC HSP staff and students. | If exposed >2 hrs., then divert to non-food use or consider destruction. | HACCP licensee reviews logs within 1 week of processing. Sign logs. | Time/temperature Log. |

# HACCP Plan Form (continued)

| *(1) Critical Control Point* | *(2) Significant Hazards* | *(3) Critical Limits for each Preventive Measure* | *Monitoring* | | | | *(8) Corrective Actions* | *(9) Verification* | *(10) Records* |
|---|---|---|---|---|---|---|---|---|---|
| | | | *(4) What* | *(5) How* | *(6) Frequency* | *(7) Who* | | | |
| Inspecting and Trimming | Pathogenic bacterial growth | Remove scales foreign materials and damaged or discolored kelp<br>Cut stipes and store at <41ºF. for separate blanching;<br>Trim kelp for blanching | Time of removal from cooler. Time of inspecting and trimming. | Begin/end log. | Each batch. | NCC HSP staff and students. | If exposed >2 hrs., then divert to non-food use or consider destruction. | HACCP licensee reviews logs within 1 week of processing. Sign logs. | Log. |
| Cutting | Pathogenic bacterial growth | Feed kelp through cutting machine and temporarily store in cooler at <41ºF for packaging and labeling | Time. | Visual.<br><br>Clock/watch.<br><br>Visual. | Each batch. | NCC HSP staff and students | Check to be sure cutting machine and blades are in good working order and there is no physical contamination of kelp | HACCP licensee reviews logs within 1 week of processing. Sign logs. | Log. |
| Blanching | Pathogenic bacterial growth | Blanch in boiling potable water for 30 seconds. | Boiling water.<br><br>Time.<br><br>Product under water. | Visual.<br><br>Clock/watch.<br><br>Visual. | Each pot, each batch<br><br>. | NCC HSP staff and students. | If not boiling for 30 seconds, reblanch in boiling water immediately for a full 30 seconds. | HACCP licensee reviews logs within 1 week of processing. Sign logs. | Log. |
| Cooling | Pathogenic bacterial growth | Immerse in ice water to stop cooking/cool. | Ice Bath | Visual | Each pot, each batch | NCC HSP staff and students | Add water/ice to cover. | HACCP licensee reviews logs within 1 week of processing. Sign logs. | Log. |
| Packaging and Labeling | Micro biological Pathogens Chemical Natural toxins Chemical: Contaminants | Tag each package and container – include date, site, lot number, time exposed to air, time onto ice/into refrigeration. | Tag each container. | Visual. | End of work day. | NCC HSP staff and students | Retag if missing tag. | HACCP licensee crosschecks records and signs weekly. | Log book – enter and initial. |

# HACCP Plan Form (continued)

| *(1) Critical Control Point* | *(2) Significant Hazards* | *(3) Critical Limits for each Preventive Measure* | *Monitoring* | | | | *(8) Corrective Actions* | *(9) Verification* | *(10) Records* |
|---|---|---|---|---|---|---|---|---|---|
| | | | *(4) What* | *(5) How* | *(6) Frequency* | *(7) Who* | | | |
| Post Processing Storing | Pathogenic Bacteria Growth | Produce containers of fresh packaged material continuously surrounded by ice for shipping and stored in refrigerator at <38ºF<br><br>Freeze packaged material intended for frozen shipment and storage at <0ºF | Adequate ice surrounding product containers and refrigerated<br><br>Freeze and store frozen packages | Visual check of ice and refrigeration temperature<br><br>Visual check of freezer temperature | Sufficient frequency to assure critical limit is met<br><br>Sufficient frequency to assure critical limit is met | NCC HSP staff and students<br><br>NCC HSP staff and students | If product temperature 41ºF >2 hrs then chill and hold product until evaluation of total time and temperature exposure is completed Add ice to the product Modify the process to reduce time and temperature exposure | Record of visual checks of temperature Periodically measure internal temperature of fish to ensure that the ice is sufficient to maintain product temperatures at <41ºF Calibrate thermometer once per semester Check accuracy of thermometer daily at beginning of tasks Review monitoring, corrective action, verification records within 1 week of processing | Readings from temperature devices Number of totes Sufficiency of ice in each |
| Transfer to purchaser. | Traceability. | All produce sold recorded for traceability. | Information of which lot of product is sold to which purchaser. | Record each lot and purchaser. | Each lot sold. | NCC HSP staff and students | If product not identified, then divert to on-site use. | Review, monitor, corrective action, verification records within 1 week of processing | Record of date, lot, and customer. |