Potential Supply Chains for Seaweed Produced for Food in the Northeastern United States

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Introduction

Seaweed (specifically Eucheuma and Japanese kelp) is the top aquaculture crop produced worldwide (by volume) (Fig. 1). Gracilaria seaweeds rank tenth in the world in terms of total volume of production. The vast majority of the world supply of seaweed is farmed (30.1 million metric tons farmed in 2016 as compared to 1.1 million tons harvested from the wild) (FAO 2018). The leading global suppliers of seaweed are China, Indonesia, the Philippines, and the Republic of Korea.

Globally, the major use for seaweed has been for human consumption (McHugh 2003; Cottier-Cook et al. 2016) with calls for increasing consumption of seaweed as a sustainable food source (Forster and Radulovch 2015) and for use in developing functional foods (Mendis and Kim 2011). Secondary uses of seaweed include processed, powdered forms used as hydrocolloids in industrial processes for the food and cosmetic industries and as texturing agents and stabilizers (Bixler and Porse 2011). Smaller volumes of seaweed are also sold for use in animal feeds and fertilizers. Demand for contaminant-free seaweed for use in nutraceuticals and pharmaceuticals appears to be increasing. Seaweed has also been proposed for bioremediation as a component of integrated multitrophic aquaculture (IMTA) systems (Ridler et al. 2007) and as a source of material for biofuel production, although low lipid content may restrict its use (Roesjadi et al. 2010).

While consumption of seaweed in the U.S. has been restricted traditionally to sushi dishes and products sold in health food stores, consumer demand for seaweed in the U.S. appears to be expanding. “Sea vegetables” and “sea salads” have been appearing on menus in upscale U.S. restaurants, and Costco imports seaweed from Korea to sell as bulk packages of “Kirkland’s Signature Roasted Seasoned Seaweed,” and other products.

In the Northeast U.S., seaweed has been harvested for a number of years on a relatively small scale by both commercial harvesters and farmers. Some oyster farmers in the region have begun to farm kelp as a second crop as a way to diversify their farming business. The growing season for seaweed in the Northeast U.S. is the off-season for oyster production and has potential to improve cash flow by generating off-season revenue (Redmond et al. 2014) and to provide year-round employment.

While several species of seaweed grow in the Northeast U.S., much of the recent interest has been on sugar kelp, *Laminaria saccharina*. While Rhode Island was reported to be located at the southern limit for this species, its productivity levels, while variable, were found to be similar to those of kelp in Nova Scotia and Spain (Brady-Campbell et al. 1984).

Demand for locally grown food has increased (Donahue et al. 2014), potentially creating demand for development of new products such as locally grown seaweed. Yet in spite of apparent potential and interest, the U.S. market for edible seaweed is largely un-developed (Griffin and Warner no date). Production research is underway at several universities, but the volumes of production and sales are too limited to conduct detailed quantitative market analyses.

Supply and value chain approaches have been suggested as effective approaches for market analysis and development (Jacinto and Pomeroy 2011). A farmer considering seaweed production must identify appropriate market outlets, obtain information on potential price points, understand the extent of on-farm processing required, and arrange for effective transportation for product distribution, among other supply chain questions. Such information does not exist to provide guidance for those in the Northeastern U.S. interested in raising seaweed.

Supply chain analyses examine entire sets of market channels for a product and typically include requirements at the production, processing, wholesaling, retail (supermarket), and food

service (restaurants) levels (Graef et al. 2014; see Radtke and Davis 2000 for an early description of the U.S. seafood product chain). Supply chain analyses are descriptive in nature and describe the range of activities required for a product to be cleaned, processed, and transported to appropriate market outlets. Appropriate marketing functions for each product form must be considered, and often include the need for consolidation and storage of product at a wholesale level and processing considerations related to adding value to raw products. Other important considerations include relative sizes and market power of actors along the supply chain. For example, if a large company controls one or more supply chain levels, it may exert power over prices, volumes purchased, or quality characteristics. Finally, the overall regulatory environment frequently has important implications for market development through the supply chain.

There are a number of recent examples of supply and value chain analyses in fisheries and aquaculture. The supply of fish was evaluated in Uganda (Gordon and Maurice 2015), Bangladesh (Sapkota et al. 2015), and Thailand (Singh et al. 2015). Bjorndal et al. (2015) and Dey et al. (2015) summarized dynamics of value chains relative to small-scale businesses, while Kainkainen et al. (2016) identified traits for a European whitefish breeding program that would be profitable across supply chains. Several studies (eg., Alam and Pokrant 2009) refer to the need for adequate storage facilities and distribution infrastructure and negative price effects of rapid supply expansion without parallel growth in market demand. Asche et al. (2014) studied price transmission in the salmon supply chain in France; Macfadyen et al. (2012) the performance of Egyptian aquaculture across the supply chain; and Navy et al. (2016) assessed potential climate change effects on fisheries and aquaculture production in Cambodia and Vietnam.

For supply chains to exist, all participants need to be economically successful (Jacinto and Pomeroy 2011). Thus, if oyster farmers need to hire specialized harvesting and processing

services for their kelp, the harvesting and processing companies must also be profitable for a viable kelp supply chain to emerge. In a study of the European Union seaweed market, Bord (2015) discussed competition from Asian suppliers, concluding that Irish seaweed producers should focus on edible species not currently supplied to avoid competition with existing high-volume suppliers.

Navigating seafood supply chains can be especially difficult for small-scale businesses (Jacinto and Pomeroy 2011). Bjorndal et al. (2015), in a value chain analysis, found cash flow constraints to be problematic for small-scale producers. Small-scale producers also received the lowest economic benefits, likely due to greater market power of processors and retailers. Other disadvantages of small-scale producers include lack of market information, sector fragmentation, and lack of technological expertise (Pomeroy et al. 2017). Regulatory requirements can increase costs to a greater degree for small-scale as compared to larger-scale producers (van Senten and Engle 2017; Engle and van Senten in review). Linkages within supply chains can be beneficial for small-scale producers, but skilled management is needed for organizations to successfully achieve the intended economies of scale and increased bargaining power (Engle et al. 2016).

In the Philippines, small family farms out-competed corporations due to the intensity and scheduling variability required of labor, and low capital and technological requirements (Valderrama et al. 2015). The Philippine seaweed supply chain included seed suppliers, producers who grew and dried seaweed, traders who consolidated, dried, and stored seaweed at the village level, processors in larger cities, and exporters (Pomeroy et al. 2017). Traders also provided financing to producers and shipped product to processors located in larger cities. Seaweed farming was found to be prone to substantial production risk from boom and bust cycles (Valderrama et al. 2015). Seaweed production found in a number of countries was sold

through direct contracts between producers and processors. Thus, the supply chain consisted of producers to processors, both as independent actors in the supply chain but linked through direct contracts for sales.

Roesijadi et al. (2015) described a hypothetical U.S. supply chain for macroalgae farmed and harvested for use in biofuel production that included: harvesting, pre-treatment (washing, screening out stones, sand, litter, epiphytic organisms, and de-watering), processing, and sales. De-watering to 20% to 30% water was beneficial to stabilize seaweed for transport.

An emerging literature has reported costs and economics of seaweed farming in several countries. van den Burg et al. (2016) found that seaweed production offshore in the North Sea was not economically feasible. Valderrama et al. (2015) identified differences in economic performance of seaweed farms across six countries in Asia and Latin America due primarily to the scale of operation and farm prices. Wakamatsu and Miyata (2015) assessed alternative processing standards and associated cost effectiveness for seaweed and related consumer preferences. In the U.S., costs to produce seaweed for potential biofuel use were estimated to range from $21 to $150 per metric ton of dried seaweed (Chynoweth 2002; Reith et al. 2009; and Oilgae 2010).

Focus groups, a qualitative research tool, have been used in supply and value chain analysis in aquaculture. Focus groups convene small groups of individuals to discuss pre-determined topics and issues as guided by a trained facilitator (Bernard 2006; Krueger and Casey 2014). Commercial businesses began to use focus groups in the 1940s to inform development of new products and marketing strategies, but they have been adopted and adapted by social scientists for research to elicit qualitative information on topics for which detailed data are not yet available. For example, Macfadyen et al. (2012) used focus groups to map Egyptian

aquaculture value chains, while Islam (2008) characterized shrimp commodity chains in Bangladesh with focus groups. Aarset et al. (2004) convened focus groups in five European countries to explore market potential for organic farmed salmon. Verbeke et al. (2007) explored perceptions of farmed versus wild-caught seafood through focus groups to provide marketing guidance to seafood suppliers. Claret et al. (2012) found, through focus groups, that country of origin, farmed versus wild-caught, price, and storage conditions influenced consumer preferences for seafood. Neira and Engle (2006) identified new product concepts for farm-raised fish through focus groups.

The overall goal of this study was to conduct an analysis of potential seaweed supply chains in the Northeastern U.S. (New York to Maine). Specific objectives were to:

1. Identify seaweed supply chains in the Northeastern U.S. (New York to Maine);
2. Develop a qualitative assessment of the potential supply chains identified; and
3. Produce descriptions of potential supply chains for seaweed.

This study provides insights into potential supply chains for seaweed producers in the northeastern U.S, describes advantages and disadvantages of potential marketing pathways, and summarizes opportunities and barriers associated with the supply chains analyzed. This paper proceeds by first describing methods used to collect information, and identifies current and potential marketing channels for seaweed. Marketing functions required by various actors in supply chains are described along with implications for product volumes and possible price points. Implications related to the regulatory framework for seaweed are discussed.

Methods

Data were collected from producers, market intermediaries (processors, wholesalers/ distributors, institutional buyers/chefs), consumers, and representatives of agencies with regulatory authority through a combination of focus groups and direct personal interviews.

Various entities that provide support services (Extension specialists, Sea Grant extension specialists, researchers, and community development specialists) were included either in focus groups or with in-person interviews. Lists of potential participants and their contact information were compiled for six states (Connecticut, Maine, Massachusetts, New Hampshire, New York, and Rhode Island) through consultation with collaborators throughout the region. A brochure was designed and emailed to potential interviewees to invite participation.

A structured list of topics and prompts was developed prior to each focus group as well as pre- and post-focus group forms to record individual information that might not have been expressed during focus groups. Two note-takers were assigned to each focus group. Focus groups began with a brief explanation of the project. Participants were asked to explore and discuss alternative supply chains, product forms, and opportunities for seaweed.

Seaweed Producers

Focus groups were convened with seaweed producers in Rhode Island on April 12, 2017, and in Massachusetts on August 8, 2018. Key topics of discussion included: market channels that farmers have used for seaweed, prices received, quantities sold, and thoughts related to other potential market channels, advantages and disadvantages of various market channels. The Rhode Island producer focus group included eight producers who have raised kelp, and the Massachusetts focus group included two active kelp producers, two prospective kelp producers, four individuals who provide assistance to shellfish and kelp producers, two researchers, one shellfish producer, and one fish trader who also trades seaweed. For scheduling reasons, a local government official and three regulators also attended the Rhode Island focus group, but their responses were included in the section on the regulatory framework.

In other states in the region, scheduling difficulties and/or low numbers of seaweed producers precluded organizing focus groups, and in-person interviews were conducted. Eleven direct in-person interviews were conducted with: 1) one prospective seaweed producer in New York; 2) three seaweed producers (two with several years experience and one in their first year) and four kelp researchers in Maine; 3) two interviews in New Hampshire (one with a current seaweed researcher/producer and one Extension specialist working on seaweed); and 4) two community development specialists working with prospective kelp producers in Maine. Two of the seaweed producers in Maine had businesses based primarily on wild harvest of seaweed.

Intermediaries

A focus group of eight institutional buyers/chefs (representing Maine, Massachusetts, New Hampshire, and Rhode Island) and a buyer for a private company serving regional (New England and Mid-Atlantic state universities) universities and colleges in the mid-Atlantic region was convened. In addition, four kelp processors, one whose business focused primarily on wild harvested kelp in Maine and a chef in New York City were interviewed. Key information discussed included: 1) awareness and experience buying and selling seaweed products; 2) degree of interest in testing various types of seaweed products; and 3) suggestions for effective supply chains for seaweed products.

Consumers

Consumer intercept surveys were conducted in southern New England to gain some information related to consumer perceptions and preferences with regard to seaweed consumption. Direct, personal interviews were conducted also at three farmers markets in Rhode Island, two food festivals (one each in Massachusetts and New York, and one community-supported fisheries pickup location in New Hampshire). Information elicited included knowledge

and familiarity with edible seaweed, preferences for product forms, and purchasing habits. A total of 142 respondents completed the interviews.

Regulatory Framework and Implications for Development of Kelp Aquaculture

A focus group was conducted of representatives of regulatory agencies from four states (two from Connecticut, one from Massachusetts, one from Rhode Island, and one from Maine) on April 17, 2018. The regulatory focus group concentrated on identifying regulations relevant to seaweed production and sales, permitting and compliance requirements, concerns related to seaweed farming and marketing, and governance factors that need to be considered. Additional individual interviews were conducted with six seaweed regulators in Maine.

The regulatory focus group was conducted by conference call due to travel restrictions of the various agencies. For scheduling reasons, a local government official, and three regulators attended the Rhode Island focus group.

Supply Chain Analysis

The supply chain analysis was developed by synthesizing the information obtained. The first phase was to describe the actors in seaweed supply chains in the Northeastern U.S., and the second phase analyzed relative advantages and disadvantages of seaweed supply chains.

Results

Description of Principal Actors in Seaweed Supply Chains in the Northeast U.S.

Table 1 summarizes the different types of principal actors who could participate in potential seaweed supply chains in the Northeast U.S. and the marketing functions to be performed. These include producers (nursery and growout) and intermediaries (processors, wholesalers/distributors, restaurants, university food service, and retailers.

Seaweed Producers

There are two main types of production levels for seaweed production. The first is the hatchery or nursery phase in which spools of seed are produced and supplied to farmers for growout. The second production level is the growout of seaweed to a marketable size.

Nursery seed spool production. Seaweed production begins with seed production in a nursery facility. Seed production is viewed as a difficult process that requires a laboratory operated under mostly sterile conditions to avoid contamination with other species. Seaweed producers other than those involved in wild harvesting depend upon nurseries to obtain seed for planting, and the availability and quality of seed spools can be a constraint for producers. There are two main seaweed nurseries in the Northeast U.S. (one in Maine and one in Connecticut) that supplied the majority of seed spools for seaweed producers. In addition, there were a number of producers and at least one local community who were working to establish their own nurseries. Focus group participants commented on delays in obtaining seed spools that may have prevented them from planting at the most appropriate times.

Seaweed nurseries use sterile laboratory facilities with water filtered through 5 micron-bag filters to avoid contaminated seed that results in poor production at the growout level. In addition to having adequate laboratory space and conditions, key inputs include nutrients necessary for production of seaweed seed spools, and skilled labor. Nursery seed production is expensive due to the cost of water filtration, the cost of required nutrients for seaweed, and the need for adequate amounts of skilled labor. The longer the seed must remain in the nursery, the more expensive it will be. Reducing the time that seed strings remained in the nursery was mentioned as a cost-reduction strategy, but others reported that quality may be sacrificed by selling seed spools with less "fur" that do not grow as well after planting. Hatchery and nursery businesses must also invest in long-term inputs such as boats, motors, moorings, and floats.

The major products of seaweed nurseries are the spools of seed that are either sold to producers or provided by a vertically integrated company with the commitment to sell final product to the same company at harvest. In cases where seed spools were provided at no cost, the price paid to growers for harvested product was adjusted to cover the cost of the seed.

The key marketing function provided by seaweed nurseries is to supply the seed inputs. In some cases, seed was transported by the nursery, but in other cases, the producer had to pick seed up from the nursery.

A few nurseries, particularly those established by a vertically integrated company, provide some technical support and information to producers in an effort to stimulate increased supply of product for later processing and sales. Some nurseries were developed by university researchers and continue to be supported with grant-funded university research programs.

Producers who participated in the focus groups commented on the variability of quality of seed spools. Those who reported spotty seed strings also reported poor production.

Seaweed Growout. The seaweed growout phase is the primary production level of the farmed seaweed supply chain. There are, however, only a few established seaweed producers in the Northeast U.S., several of whom built businesses and supply chains in Maine from wild-harvested seaweed. There were comments from focus group participants that the quality of wild seaweed harvested in states other than Maine is not suitable for processing in Maine. There are growing numbers of producers experimenting with seaweed in the region, but the greatest concentration is in Maine. In 2014, 54,000 lb of sea vegetables were reported sold by Maine seaweed producers, not wild harvesters (Cole et al. 2016).

Many of those experimenting with seaweed production are shellfish growers (oysters, scallops, quahogs) who are seeking to diversify their businesses with a secondary crop, but there

are also several vertically integrated seaweed businesses in the region. The vertically integrated businesses vary in their relationships with independent producers, with at least one actively encouraging shellfish producers to experiment with seaweed, providing spools of seed at no cost (but with reduced price paid at time of harvest), while the other sells seed and actively purchases seaweed from independent growers. Both vertically integrated businesses have their own production farming locations.

A number of seaweed producers reported trials with a number of species of seaweed. Gracilaria, porphyra, and sugar kelp were mentioned by producers in this study. Some producers expressed interest in raising nori, sea lettuce, dulse, and fucoid seaweed to develop sources of year-round product supply. Laver was reported to not grow well in the region. Aleria, laver, rockweed/ bladderwrack, rigosa, and kelp have been wild harvested and sold for many years in Maine. Of these seaweed species, sugar kelp has become the predominant species farmed in the region. It is viewed as the easiest to raise, with fewer biofouling problems than those reported with gracilaria. Thus, most comments from producer focus groups were related to sugar kelp.

Given its experimental nature in the Northeastern U.S., there was a great deal of discussion on kelp production in the producer focus groups. One of the attractions reported for farming kelp was that it can be done in a small area, with production potential of 5 to 10 lb of seaweed biomass per foot of kelp line, but reported production varied from 1.5 lb/foot to 4 lb/ft., with better production in Maine. Shellfish growers can use existing farm structures for seaweed.

Focus group producers spent time discussing several production problems, related to variable production from the same site or difficulties finding good sites for seaweed. For example, one producer reported that initial plantings went well, but by February March, the kelp was “starving” changing from a dark brown color judged to represent healthy kelp, to a

translucent pale color. This producer planned to move seaweed production to a site where oysters were known to grow well. Another producer, after 3 years of trial had not successfully raised a crop. Others mentioned raising kelp successfully for several years, but then experiencing poor production years. Generally, there seemed to be consensus among many producers that successful kelp production was more site-specific than previously thought. Some mentioned that "dirty" water, likely water with more nutrients, was more conducive to adequate kelp growth, but other participants reported variable production in nutrient-rich water as well as greater problems with toxic blooms. Thus, finding good sites was generally considered to be a constraint to expanding kelp production in the Northeast.

A variety of other production-related problems and uncertainties were discussed at length by producers in focus groups. One concern was the availability of seed and the variable quality of seed spools. Spools with "bigger fur" were reported to produce greater yields but not all spools performed equally well. One oyster grower reported sugar kelp dying off on the lines. In some cases, the seed string broke and came un-raveled. Others reported patchy lines with short, skinny blades that grew only 4 to 14 inches, resulting in a harvest of 5 lb. There was speculation as to whether the type of rope, newer or older, affected the growth of kelp.

The optimal planting time was a point of discussion, with some producers planting in December while others stated that it needed to be planted earlier, in October or November. One who planted in December said that he had been unable to obtain seed earlier, and that his kelp seed did not take. Another producer tried planting at various depths in October, November, December, and January, and none grew well. No strings snapped, but growth was not good (only 3 inches). Some mentioned a need for setting out larger seed, but the cost would be higher due to

the longer time in the nursery. Thus, seed availability, in terms of quantity, quality (size of "fur", uniformness of the strings, etc.) and the availability to plant at optimal times, is a constraint.

There appears to be a lack of agreement on the best color of sugar kelp. One producer reported that kelp turned darker in April and May from lighter colors earlier on, but another producer reported the opposite. In some cases, producers were disappointed when kelp blades became light and translucent and did not maintain a dark brown color, whereas other producers preferred to see lighter colors of blades. There was some thought that the lighter colors resulted from insufficient nutrients, with darker colors produced in more productive waters. Market acceptance for differing colors of kelp is unknown.

Biofouling was a frequently mentioned production/marketing problem. One producer mentioned trials with ropes treated in vegetable oil to attempt to prevent fouling. Another producer mentioned that growth of seaweed appeared to be cleaner if the lines were seeded. In addition, one producer who was able to obtain a permit to grow seaweed in the channel (versus in more sheltered areas) experienced less biofouling, although it took a long time to obtain the permit. Even in the channel, however, the producer began to see some biofouling circles of bryozoans. One strategy used by a producer to reduce problems with biofouling was to harvest in colder months when biofouling was less of a problem.

Harmful algae blooms pose a risk to seaweed production that was mentioned by several focus group participants. Seaweed-growing areas, like shellfish growing areas, will be closed to harvest when harmful algae blooms occur, as occurred to one producer where a norovirus outbreak occurred. Public health concerns typically increase with warmer water temperatures.

Inputs used by seaweed producers include the lines, floats, boats, motors, and moorings in addition to seed spools. Other inputs required include: leases, permits, fuel, and marketing

costs associated with transportation of product. Harvesting equipment required was reported to be a knife to cut the seaweed off the line and a piece of pipe to push it along. As seaweed businesses grow, additional inputs required will include insurance, disease diagnostics services, freight and shipping, and administrative inputs (Cole et al. 2016). Seaweed costs reported by Cole et al. (2016) were reported to be: 10.5% for seed, 31.8% for gear and equipment, 4.7% for leases and permits, 7% for boat expenses, 6.5% for freight and shipping, 6.5% for fuel, 6% for insurance, 1.3% for disease diagnostics, 25.6% for administrative costs, and 2.1% for other costs. Average investment was reported to be $42,000, with a median investment of $5,000. Processing costs were a major cost for those producers who also process seaweed.

Prices paid by vertically integrated companies with processing facilities were reported to be $1 to $1.50 per pound of wet weight, with $1 per pound the price paid if seed spools had been provided by the company. There was a report that one company also provided rope for producers in addition to seed. Producers reported that both companies would take all that producers can grow, with one requesting 600,000 lb a year. One producer said that $1/lb may be too cheap, especially since one of the processors was reported to be selling frozen packages of kelp noodles for $12/lb. Another producer reported a sale of a small quantity to a wholesaler for $6/lb, who then sold it to a chef for $7/lb.

Marketing functions performed by seaweed producers ranged widely, depending upon the types of markets pursued. However, at a minimum, all seaweed farmers harvested their product and transported it to facilities on shore. Given issues with biofouling, there clearly is a need to wash and clean seaweed, removing portions with biofouling. Several farmers reported washing with seawater while others reported use of freshwater for cleaning. Many shellfish producers have facilities for washing shellfish. One producer reported selling fresh, washed seaweed at a

farmers market, packaged in 4-ounce plastic clamshells, with sales of five units a week, mostly to Asian customers. Some producers packaged seaweed on ice. Blanching was used by some producers as a way to ensure product safety and to remove epiphytes. However, blanching of kelp was also reported to negatively affect its flavor, removing the "ocean" taste. To extend seaweed sales over a longer portion of the year, some producers were drying or freezing seaweed. One producer reported selling greenhouse-dried kelp at $4/lb and sales to restaurants at $25/lb. To prepare seaweed for drying, producers would cut it off the lines and into pieces by hand.

Since some oyster farmers are licensed shellfish dealers who transport oysters to markets in larger cities, their infrastructure could also be used to also transport seaweed to major markets. Larger, integrated companies provide additional marketing functions. In addition to hatcheries, these companies typically process, vacuum pack, and freeze product either as cubes or shredded into a noodle form prior to freezing.

Several universities have active research programs on seaweed production. While much of the work has focused on seed production, there is research related to production methods. The discussions among producers in the focus groups clearly identified a series of questions that would benefit from research to provide support for increased seaweed production. Production research questions identified in the focus groups include: 1) What are the specific combinations of variables (water temperature, nutrients/productivity, water depth, water current) necessary to reliably produce a good crop of sugar kelp? 2) Does the type of rope or rope treatment affect growth of seaweed? 3) What causes kelp to be lighter or darker in color and does it make a difference to consumers? 4) Is it more effective to wash kelp with freshwater or seawater? and 5) What are the most effective ways to avoid biofouling?

Products and Product Forms

The primary product produced by seaweed producers is that of whole blades of kelp sold mostly as a fresh, raw product (Table 2). The sizes of blades produced were reported to vary substantially. Some producers harvested small blades for sale as "Baby Kelp," "Micro-Kelp," or "Micro-Greens" to reduce risk of biofouling and the subsequent extent of processing. While producers reported color of kelp blades to vary from dark brown to a translucent yellow, no attempt had been made to sell varying colors as differentiated products. Seaweed production can be certified as organic. One established seaweed producer reported raising and selling 12,000 pounds of organically certified seaweed.

One of the main seaweed products sold in food markets is that of seaweed salad. One producer mentioned success with a slaw type of salad recipe that included cabbage and kelp, but the kelp composed less than 25% of the recipe. Another producer mentioned giving their harvest away in the form of a seaweed salad, but that the salad prepared likely would have been tastier if a chef had been involved in its preparation. One disadvantage mentioned of fresh seaweed salads was the short shelf life that made it difficult to compete with the dried and frozen seaweed salad imported from Korea and China.

Other potential products would require additional processing, such as drying. In the Philippines, seaweed is dried outdoors on platforms, but indoor drying would reduce the potential for contamination from outside sources. Wild seaweed harvesters typically sell a dried product, even when sold to a wholesaler/distributor. Whole-leaf products developed from dried seaweed are sold to restaurants and supermarkets where it is sold in shakers for consumers to use as a seasoning or nutritional enhancer. There were comments from producers that the market for dried products from seaweed is limited to that of a low-volume, specialty condiment.

Some of the larger, integrated companies have developed frozen products from seafood. One sells a frozen kelp noodle product that is prepared by rinsing, removal of epiphytes, blanching, chilling, and shredding into noodles. The kelp noodles are then packed into 4- and 8-ounce packs and frozen. Focus group participants reported that this product was being sold for $12/lb. Another company has marketed a frozen seaweed cube that was displayed in supermarkets near the seafood section. This same company is developing a shelf-stable purée product that would not be associated with seafood and might have greater appeal to vegetarians. The purée product is expected to have a lower price point than fresh or frozen seaweed and was reported to generate interest at the 2017 Natural Foods Show.

Table 2 presents a list of products, forms, and descriptions of items either mentioned by focus group participants or found through literature and internet searches for seaweed products. These range from products that are fresh, dried, frozen, pickled, and fermented (kelp sauerkraut), as well as many recipes. There have been efforts to develop and test novelty products. For example, while seaweed products have been used for a number of years in the brewery industry as a clarifier, one brewery in New Hampshire has begun to promote a seasonal beer as Kelp Beer. Such use of seaweed likely would be a low-volume, novelty type of product. Some producers suggested that products such as kelp chips (to serve in microbreweries or that could be paired with oysters and wines in oyster bars), kelp crunch, kelp salsa, kelp as an ingredient in crab wontons, and kelp jerky would be potential products that use seaweed in products already familiar and desired by consumers. One participant is opening a retail store to sell seaweed tea, among other items made from seaweed. Others mentioned use of seaweed in capsules as a dietary supplement. Table 3 presents advantages and disadvantages of various types of seaweed product forms.

The focus group discussions generated many suggestions for potential new products that could be produced from kelp for which in-depth market testing would be useful. For example, one producer reported that Maine kelp was "chewier" than kelp produced in other Northeastern states. Thus, whether differing textures of kelp harvested in different states can result in products differentiated by water body where harvested would be an interesting research question. Oysters often are marketed with a focus on the name of the water body, with differing saltiness and flavors used as key promotion points. Similarly, market testing to determine whether there are groups of consumers who might prefer the lighter, translucent kelp to the dark brown or vice versa would be very useful guidance for kelp farmers and those working on market development.

Focus group participants also reported development of a variety of non-food products with some innovative ideas of tapping into high-value markets. For example, participants mentioned using seaweed with fouling to make liquid fertilizer (price was reported to be $3/quart) for gardens, to sell to marijuana producers, or for use on golf courses. Others reported selling seaweed products for livestock feed (price reported to be $2 to $3/lb), and as a nutritional supplement for racehorses. Other participants reported efforts to make a bath and body product with seaweed.

Intermediaries

Wholesalers/distributors. Wholesalers/distributors historically have played an important role in food supply chains around the world. Key marketing functions provided by wholesalers and distributors include assembling sufficient quantities of product to supply larger markets on a consistent basis, processing, packaging, licensing, market development, and transportation and distribution to buyers. The consolidation and concentration of the retail sector into a smaller number of very large retailers such as Walmart has resulted in similar consolidation at the

wholesaler/distributor level in the U.S. and in the EU. In spite of this general transformation of the retail food sector in recent decades, wholesalers and distributors continue to play important roles particular with smaller and potentially emerging food sectors. With respect to seaweed, for example, Cole et al. (2016) found that 25% of the farmed seaweed sold in Maine and 50% of the farmed seaweed sold outside of Maine in 2014 was sold to wholesalers or distributors.

Much of the wild harvested seaweed in the Northeastern U.S. is sold to wholesalers/distributors who have the processing, storage, and marketing expertise and infrastructure required. A small company in Maine provides wholesaler/distributor marketing functions to wild seaweed harvesters in the form of collecting, storing, further processing, distribution, and marketing seaweed. As inputs, they provide infrastructure facilities, labor, and business expertise to the supply of wild harvested seaweed. The company sells into high-value natural foods markets, including Whole Foods and other large natural food retailers, where they can compete with organically certified whole leaf products from laver, kelp, and aleria. The company has found that they cannot compete on price with Asian nori sushi sheets. The core product of the company is as a nutritional product and flavor enhancer, not as a center-of-the-plate product. In spite of some reports by producers of successful sales to wholesalers/ distributors there are other reports of producers having to buy back unsold product.

Prices reported to be paid by wholesalers/distributors varied substantially, but it is important to note that these were based on very small quantities that were sold on a trial basis. One grower reported selling 1 lb of kelp to a wholesaler for $6/lb, while another reported selling 5 to 15 lb a week of gracilaria for 4 to 6 weeks to a wholesaler in New York City for $12 to $14/lb who then sold it to restaurants to be used as a garnish on salads.

Restaurants. Focus group participants discussed restaurants as a promising intermediary for introducing seaweed to their patrons. Many consumers are more willing to try a new type of seafood in a restaurant than in a supermarket (Engle et al. 2016). One producer reported that "every chef wants it, from Maine to Florida," but they would prefer to source it locally rather than purchase from Maine. This same producer reported that he could easily sell 1,000 lb a year. Some focus group participants, who also farmed oysters, reported some trial sales of seaweed to restaurants that purchase their oysters. In such cases, there is an established relationship between the farmer and the restaurant buyer that can be beneficial when experimenting with new products. Most reported sales to restaurants, however, were one-time sales (due to lack of product supply) of small quantities used primarily for seasoning.

Chefs mentioned various potential products for consideration. These included: 1) small cubes for use in smoothies; 2) powdered seaweed to make broth; 3) kelp vinaigrette; and 4) frying dried seaweed as seaweed bacon or seaweed pasta.

Other participants pointed out that restaurant owners were interested in offering kelp, but that chefs were not sufficiently familiar with it or its preparation to be comfortable adding it to menus. Chefs have little time to develop kelp dishes and that innovative recipes are needed that use greater volumes of seaweed. One of the difficulties for chefs is the difficulty to judge quantities to be sourced because kelp is not currently a main feature in dishes. Information on shelf life is also important for kelp; some reported that it will last for a couple of weeks if kept cool and moist, but if sold as microgreens, it has a much shorter shelf life. There is a need for more research on packaging alternatives to meet the needs of restaurants and the associated shelf life of fresh seaweed products. The seasonality of fresh kelp can be problematic for restaurants unless their concept is based on locally raised foods and patrons are accustomed to seasonal

variation in menu offerings. Overall, chefs preferred fresh product to frozen to dried. Restaurant owners and chefs viewed the current lack of supply of kelp as the first barrier to be resolved.

Inputs provided by actors at the restaurant level include the culinary skill of the chef and time and effort of waitstaff. Marketing functions provided at the restaurant level include development of menu items that transform seaweed into attractive products, offering product information, and providing opportunities and encouragement for trial of new menu items.

University food service. Institutional markets, such as university dining halls and schools were also discussed as intermediary market outlets with potential for seaweed sales. One researcher provided 200 lb of seaweed to a university dining hall that was consumed in a few days. Inputs and marketing functions provided by institutional dining services are similar to those described for the broader restaurant category.

Retailers. The retailer level of food supply chains includes supermarkets, grocery stores, and hypermarkets that offer opportunities for consumers to purchase food items, including the growing ready-to-eat products offered. Within this category, producer group participants reported that there is greater variety of seaweed products sold in upscale retailers like Whole Foods, Wegmans, and Trader Joes, than in stores such as Walmart and Aldi. Costco sells seaweed products, but most are imported from Korea or China. Supermarkets that cater to Asian customers offer the widest variety of seaweed products, often dried, and frequently imported.

Key inputs used by retailers include the store's location, refrigerated and frozen display cases, staff who organize and maintain displays that include complementary food items attractive to consumers. Marketing functions include aggregating multiple products in a single convenient location, point-of-display information on products, and advertising services. Some large retailers provide distribution services from large distribution centers to various individual stores.

There appear to be few support services available to those who have potential to become intermediaries in a seaweed supply chain. Most of the product and food manufacturing process development for seaweed appear to have been done by the few integrated companies that have engaged in seaweed production and marketing. One attempt to develop marketing services is that of the Seaweed Exchange in Maine. This online service was created to serve as a broker/dealer for seaweed buyers and sellers. Its objectives include the intent to provide other marketing functions such as to coordinate processing and packaging and to work in product development.

Overall, other than those buying and selling wild harvested seaweed, there currently are few intermediaries engaged actively in buying and selling farmed seaweed products. The choice of specific supply chain partners will be important for development of effective supply chains and markets for locally grown seaweed products. It may be necessary for seaweed farmers to develop strong relationships with a wholesaler/distributor to develop and handle the necessary post-harvest processing and product development issues that appear to be a current bottleneck to greater industry development.

Consumers

The early adopters of seaweed were people with preferences for health food and vegan diets. Some sort of breakthrough, whether from an easier seaweed dish with familiar (not fishy or ocean) tastes will likely be needed for seaweed products to become mainstream consumer products. Those consumers who have traditional preferences for seaweed products currently purchase imported dried product for a price at which U.S. farmed supply likely cannot compete.

Respondents from the surveys conducted in farmers markets and seafood festivals were mostly female (55%), higher income (33% had incomes of $100,000 or more; 30% $50,000 to $99,999), and above 25 years of age (38% were 25 to 34 years old; 32% were more than 54 years old; and 25% were from 35 to 54 years of age). Nearly two-thirds ate seafood weekly or more

often, and 82% reported eating a variety of foods. Preferences for seafood consumed in restaurants were for salmon (24%) and shellfish (24%), followed by shrimp (17%). At home, salmon was preferred more often (31% of respondents) and was followed by shrimp (23%). A high percentage of respondents had eaten seaweed in a variety of forms that included sushi wrapped in nori, miso soup with seaweed, seaweed snacks/chips, or as a seaweed salad. Respondents indicated fairly strong interest in trying new seaweed products generally (Fig. 2). More respondents said that they would be more willing to try a new seaweed product in restaurants (41%), followed by farmers markets (32%), and supermarkets (21%). There was relatively greater degree of being very interested in trying seaweed salad, followed by seaweed chips, noodles, granules, and smoothies (Fig. 3). Attributes that were very important in terms of food choices, taste was mentioned most often, followed by nutrition, sustainability of product, locally sourced, and affordability (Fig. 4). Overall, for frequent, high-income seafood consumers in the Northeastern U.S., offering seaweed salad products in restaurants appeared to be the option with the most appeal. As is typical of most consumers generally, the most important attribute in choosing foods was the taste. Thus, developing seaweed products with flavor profiles desired by the targeted market demographic segments will be key to successful development of seaweed markets.

Advantages and Disadvantages of Potential Supply Chains for Seaweed in Northeast U.S.

Four generalized types of potential supply chains were identified for seaweed produced in the Northeastern region of the U.S. (Figs. 5-8): 1) direct sales of fresh seaweed by producers; 2) direct sales of processed seaweed by producers; 3) sales by producers to processor/wholesaler/ distributor; and 4) vertical integration of various supply chain levels in a single company. Each of these supply chains will be described in terms of their respective actors, marketing functions, potential volumes traded, potential price points, and constraints. This will be followed by

discussion of associated effects on: bargaining power of suppliers and of buyers, threats of substitute products/services and of new entrants and the potential intensity of competition. Critical factors that affect the performance of each supply chain identified will be analyzed.

Potential Supply Chains for Independent Seaweed Producers

Six potential supply chains were identified for independent seaweed producers. Three involved direct sales of fresh seaweed to farmers markets, restaurants, and university food service, a fourth was suggested for direct sales of seaweed processed on the farm. Two additional potential supply chains for independent seaweed producers would be either sales to a wholesaler/distributor or to a processor.

Sales of fresh seaweed by independent producers to farmers markets. Some fresh seaweed has been sold by a few producers in the northeastern U.S. (5 to 10 lb per market event) in local farmers markets. The farmer must wash and clean the seaweed, package it in small quantities for sale, transport it, and attend to sales during the hours the farmers market is open.

Advantages of sales by independent producers in a farmers market include opportunities to: 1) engage directly with potential customers to discuss nutritional and health benefits of seaweed, opportunity for trial taste testing by potential customers; 2) higher prices; 3) capture full margins of direct sales to end buyers (minus marketing costs of packaging, transportation, and time; and 4) increase awareness of products and availability. Disadvantages include the investment needed for delivery vehicles and food-grade containers, and time spent selling in the markets. Constraints to selling through farmers markets include the following: 1) price points and demand volumes not well understood; and 2) seasonal sales.

Sales of fresh seaweed by independent producers to restaurants. A few seaweed producers have sold very small quantities of fresh seaweed directly to restaurants, often on a one-

time basis due to lack of supply. To sell seaweed to a restaurant, the farmer must wash and clean the seaweed, prepare it for sale, and deliver it to each restaurant customer on the days that the restaurant needs it in the volumes and forms required.

Advantages of selling directly to restaurants include opportunities to: 1) engage directly with chefs who understand preferences of their patrons related to the attributes of seaweed products, and provide samples for taste testing and experimentation; 2) capture a portion of marketing margins (those related to wholesaling and distribution); 3) develop more formal linkages/partnerships with chefs for successful product development.

Disadvantages of sales to restaurants include the investment in vehicles and food-grade containers for product delivery to each restaurant. If the seaweed purchased is used only as a garnish, the volumes sold will be small, the delivery costs relatively high, and marketing margins captured relatively low (food ingredients are a relatively small portion of menu prices).

Constraints to selling to restaurants include the following: 1) no established recipe that uses substantial volumes of seaweed; 2) chefs not familiar with product with little time to develop popular dishes from new ingredients; 3) price points and demand volumes unknown; 4) quality standards unknown; 5) lower margins to producer than in direct sales to consumers; 5) seasonal sales of fresh product; and 5) requirement for wholesaler/dealer license in some states.

Sales of fresh seaweed by independent producers to university food service. A few seaweed producers who were affiliated with seaweed research projects have sold some fresh seaweed (as much as 200 lb) to university food service for use in dining halls. Such reports were one-time sales due to lack of supply. The farmer must wash and clean the seaweed, package, and deliver it to each university in the volumes and at the time and dates required by the food service manager. Producers reported interest in the product.

Advantages of selling to university food service include opportunities to: 1) access Asian populations with preferences for seaweed; 2) sell to university student populations who tend to be more willing to experiment with new foods; 3) capture a portion of marketing margins (those related to wholesaling and distributing); and 4) develop more formal linkages/partnerships with university chefs for product development and trial.

Disadvantages include the investment cost for vehicles and food-grade containers for delivery to each university food service location. If the seaweed purchased is used only as a garnish, volumes sold will be small, delivery costs relatively high, and marketing margins captured relatively low.

Constraints to selling to university food service include: 1) no established recipe that uses substantial volumes of seaweed; 2) chefs unfamiliar with product with little time to develop popular dishes from new ingredients; 3) chefs may prefer dried product; 4) price points and demand volumes unknown; 5) quality standards unknown; 6) lower margins to producer than with direct sales to; 7) seasonal sales of fresh product; 8) bidding and procurement procedures of universities may be difficult; and 9) state requirements for wholesaler/dealer license.

Sales of processed seaweed by independent producers. Further processing of seaweed by independent producers into dried or frozen products was mentioned by several participants in focus groups as a potential supply chain. Other than drying seaweed by wild harvesters for sale to a wholesaler/distributor, however, there were no reports of independent seaweed producers doing any further processing.

The principal advantage of further processing by independent producers would include opportunities to: 1) capture marketing margins associated with adding value to the product; 2) year round sales; 3) meet demand for dried or frozen product; 4) reduce delivery costs due to

much lower product weight; and 4) possibly receive greater prices (one focus group participant reported that dried product could be sold for $4/lb as compared to $1/lb for fresh product).

Disadvantages of further processing by independent producers include: 1) costs of the value-added process; 2) price and volume competition with imported product; and 3) the need to transform business into a vertically integrated company with processing and marketing expertise.

Constraints to sales of dried or frozen seaweed by independent producers include: 1) low price points due to import competition; 2) investment cost of facilities for processing, value addition, and cold/frozen storage; 3) development of appropriate packaging; and 4) advertising costs to gain foothold in already established markets.

Sales by independent producers to wholesalers/distributors. Wild seaweed harvesters have sold dried seaweed product to wholesalers/distributors in Maine for a number of years, and some focus group participants mentioned some small-volume trial sales through distributors to restaurants in major cities. Overall, there has been little involvement of wholesalers/distributors in supply chains for seaweed in the Northeastern U.S., unlike those in other countries (Griffin and Warner no date; Valderrama et al. 2015). Sales to a wholesaler/distributor require that the farmer wash, clean, and deliver it, or possibly dry it on farm prior to delivery.

An important advantage of selling to a wholesaler/distributor is that the independent producer can take advantage of existing marketing relationships between the wholesaler/ distributor with restaurants or supermarkets. Such relationships provide opportunities for market development. In many cases, producers already sell shellfish through a licensed wholesaler/distributor. Other advantages include: 1) access to the storage and transportation infrastructure and sales and marketing expertise of a wholesaler/distributor; 2) participation in an organic product supply chain that can lead to higher prices (company that is certified must

control the product throughout the supply chain); and 3) access to larger markets developed from the greater supply as wholesalers purchase from multiple producers.

Disadvantages of sales by independent producers to wholesalers/distributors include: 1) lower price points to producer with the wholesaler/distributor capturing the marketing margins; 2) reliance on the degree of interest of the wholesaler/distributor in market development; 3) reduced ability to differentiate or brand the producer's seaweed because wholesalers also purchase from other producers; and 4) reduced control over the quality of the end product during the wholesaling and distribution phases.

The primary constraint associated with sales to a wholesaler/distributor would be the degree of interest in engaging with seaweed sales. Given the general lack of a supply chain for seaweed raised in the region, a strong partnership relationship would need to be developed between producer and wholesaler/distributor.

Sales by independent producers to processors. There are few vertically integrated seaweed processors in the Northeastern region who purchase seaweed from independent producers. To sell to a processor, the farmer must wash, clean, and deliver the seaweed. Volumes sold to date have been low given supply constraints, but the processors have reportedly stated that they can purchase up to 600,000 lb. Producers have been encouraged to enter production with promises of the processor purchasing all that can be produced at a price of $1/lb (if seed spools provided) up to $1.50/lb (without provision of seed spools).

Advantages to selling to a processor include the convenience of the producer not having to engage in marketing activities. The processor handles all marketing functions, from processing, market development, advertising and promotion, quality control, and distribution.

Thus, a producer with little marketing experience can sell large volumes of seaweed without incurring the time and expense associated with market development.

Disadvantages to sales to processors include: 1) lowest prices as processor captures all marketing margins; 2) monopolistic control by processor (given the small number of processors, the power to set price, delivery times and volumes, or to not purchase at all lie entirely with the processor); and 3) high degree of risk to producer if the processing company exits the industry.

There are few constraints at this time to sales to a processing company. A few companies are actively seeking to source product from producers.

Vertically Integrated Supply Chains for Seaweed

A vertically integrated supply chain is one in which a single entity handles several levels of the supply chain. With seaweed production, there are examples of a few different types of vertical integration. For example, there is a restaurant owner who also produces shellfish and seaweed that is sold in the company's restaurant. With growth in "farm-to-table" restaurants, additional similar opportunities may develop. In addition to "farm-to-table" types of vertical integration, there are a few seaweed processors whose companies are integrated from production through processing, value addition, marketing, and distribution. An integrated producer-processor may also sell to established wholesale seafood dealers rather than handle all marketing functions required of the supply chain.

The primary advantage of vertical integration is greater control over the product and its quality throughout the supply chain. Coordination of production, processing, distribution, and overall marketing is facilitated as is quality control management. As a larger volume supplier, there is a greater likelihood of reduced production and marketing costs due to economies of scale that may exist.

Disadvantages to vertical integration of seaweed production, processing, and marketing is the investment in required facilities for processing, value addition, transportation, marketing, and distribution. An integrated company will also need skilled professionals to handle the various processing and marketing functions it undertakes.

Constraints to vertical integration of a production-processing-marketing company would include primarily the degree of capital required and the risk associated with a new startup company of the scale required to cover all investment and salary expenditures. In addition, if profitable, competitors will inevitably emerge to free ride on the products developed by the early entrants.

Regulatory Influences on Supply Chains

Regulators who participated in focus groups indicated that there were increasing numbers of applications for permits to raise seaweed in their respective states. The earlier applicants reported that the regulatory process took a long time and later applicants reported regulatory concerns over user conflicts in certain areas, particularly with boat traffic (summer boating begins in about May), and in some locations, with prohibitions from the U.S. Army Corps of Engineers due to whale migrations.

Nevertheless, in several states, there does appear to be an existing regulatory framework for seaweed. In these states, shellfish producers are allowed to raise seaweed on existing shellfish leases, using tags similar to those used for oysters and other shellfish. Producers are required to keep records and inform the relevant state department prior to harvesting to ensure that there are no water quality or safety issues at harvest time.

There appears to be a grey area, however, with regard to sales of fresh seaweed by someone who does not have a shellfish lease. There does not appear to be consensus as to

whether fresh seaweed should be regulated as a fresh agricultural product by the state Department of Agriculture or as a shellfish. If a producer applies for a lease to only raise seaweed, reports were that this would take quite a while to process due to the lack of a clear regulatory framework for fresh seaweed. Similarly, there is no well-established regulatory system for export permits, for example, to Canada.

Some focus group producers expressed a desire to sell only fresh product because they were leery of regulations related to processing. Regulators mentioned that there is not an established process for processing seaweed. The processor would need to obtain approval for a specific label from FDA, including ingredients and nutritional information, but the process was reported to not allow for including some of the most positive attributes of seaweed products. From a regulatory perspective, processed seaweed does not quite fit with either fish or vegetables. One example is the recently enacted FSMA set of regulations. Seaweed does not fit into the FSMA matrix, and seaweed processors are not able to provide the paperwork needed for certification. The only clear standard by FDA is for a dried seaweed product and requires that it contain 0.85% or less water, to prevent bacterial contamination.

There are few support services for seaweed producers in terms of engaging in the regulatory process. One attempt to provide some support for good regulations for seaweed was the formation of a Seaweed Council in Maine. Membership in the Council is voluntary, but both harvesters and farmers are eligible.

Discussion and Recommendations for Additional Research

Seaweed production and marketing in the Northeastern U.S. is in its infancy with a few producers experimenting with production and marketing with some indications of opportunities. At the time of this study, neither the supply nor the market was well developed. Thus, quantitative analyses of the economic feasibility were not possible due to the lack of data. The

supply chain approach used in this study provides a structure to assess the types of marketing functions that are currently under-developed and to provide some guidance as to the major advantages, disadvantages, constraints, and opportunities to develop adequate supply chains for growth of a seaweed industry.

If the market for U.S. seaweed is to expand and develop, a more stable supply will be needed. The focus group discussions with producers indicated clearly that there are critical technical barriers to seaweed production related to siting production areas. There was little consensus in terms of the specific types of physical and biological requirements for consistently productive seaweed production sites, particularly in states other than Maine. There is a strong need for a comprehensive study across the Northeastern region with the goal of developing a range of parameter values with which seaweed can be grown with acceptable rates of productivity and quality. Useful parameter ranges for seaweed production that need to be developed include: water temperature, current, water depth, and nutrients for various seaweed species, but especially sugar kelp. Research is further needed to understand the parameter ranges that result in differing colors (dark brown to light yellow) and translucency (opaque to translucent) in sugar kelp, and what those variations mean in terms of taste, nutritional quality, and consumer acceptance. There may be potential to develop different products from sugar kelp depending on these variations, but only if taste and nutritional profiles meet consumer preferences.

Seaweed market development will also require a more complete supply chain with adequate market infrastructure. The volumes of seaweed sold at the time of this study were low with wild harvested seaweed sold in small quantities by small-scale wholesalers/distributors of a dried product as flavor or nutritional enhancers or by a few processors working to develop

mostly retail markets for frozen kelp noodles or cubes for use in soups and other preparations. Consumers indicated that they would be most likely to try new seaweed products in restaurants, but in spite of indications that restaurant owners were interested in offering locally raised kelp products, there appear to be substantial barriers to increasing sales to restaurants. These barriers consist primarily of the lack of recipes that use kelp as a primary ingredient (and would result in demand for greater volumes of product than for seaweed used as a garnish or seasoning) and that meet the taste profiles of restaurant patrons. This barrier exists in spite of large numbers of seaweed recipes available on the internet and mentioned by focus group participants.

Development of seaweed supply chains for independent seaweed producers likely will require establishment of strong partnerships with wholesalers/distributors (who are licensed to sell shellfish and seaweed and have marketing expertise), and restaurant chefs. The individuals involved at each supply chain level will need to be committed to spending time to select specific types of products, develop them, and offer them as hors d'oeuvres, catch-of-the day, or other special promotions. Vertically integrated producer-processors-wholesalers would similarly benefit from development of some strong partnerships with specific restaurant or retail outlets.

Throughout the effort to develop effective supply chains and markets for seaweed grown in the Northeastern U.S., it is critical to not lose sight of the need to position U.S.-raised product in a way that does not compete directly on price with lower-priced imported product from China, Indonesia, and Korea. While Mumford (1990) suggested that there was potential for a few farms in North America to provide a direct substitute for imported Japanese and Korean nori by developing a premium local label, focus group respondents indicated that it was difficult to penetrate markets established by international nori suppliers.

The need for higher-valued seaweed products (that avoid direct price competition with less expensive imported product) will require extensive Research and Development (R & D) work that includes research on food manufacturing practices as well as market development. For example, while there are many products and recipes that have been developed for seaweed, these all require development of cost-effective processing methods. Drying, freezing, washing to remove biofouling and epiphytic organisms, pickling, processing as noodle chips, or other products all have potential but each require detailed planning and market development. Most R & D work in the U.S. food sector is done by large, vertically integrated companies with dedicated marketing and product development teams. Substantial capital is required to manage the innovation process from the initial conception of a potential new product through to its market launch. Sankaran and Mouly (2006) suggested a process model for such value-chain innovation for a high-quality aquaculture product and discussed the need to balance relative expenditures on production and product development research for aquaculture companies.

Development of the market for seaweed produced in the Northeastern U.S. will require constant attention to product quality. Biofouling was reported as a problem by many focus group participants. Much of the biofouling consisted of epiphytic organisms that would reduce market appeal and acceptance by consumers. Kim et al. (2017) investigated epiphytic organisms present on various types of kelp and identified six different types. Of these, 12% were hydroids, 6% bryozoans, 3% polychaetes, 3% algae, 3% caprellid, and 1% oysters, but the composition varied from farm to farm. Epiphytes occurred more frequently during higher water temperatures. In 1984, Brady-Campbell et al. found seven species of epiphytes on *L. saccharina* in the Northeastern U.S. Epiphytes were most abundant in August and September, when the kelp was not growing as quickly and temperatures exceeded the ideal range of 13 ^{o}C. Focus group

participants commented that invasive species on seaweed and bryozoan growth problems are getting worse. Kelp snails can also mar the blades. Thus, development of efficient and safe cleaning and washing protocols are critical. The variety of methods currently in use by producers may indicate a need for research to identify protocols that are most cost effective, practical, and safe to clean and wash seaweed prior to sale.

Attention to product safety is also required. Some regulators expressed concern over the possibility of heavy metals, pathogens, and cyanobacteria. Especial concern was expressed with regard to production of gracilaria than for other seaweed species, and at least one state does not approve applications to farm gracilaria in open waters for this reason.

Conclusions

This study is the first to trace supply chains that are beginning to develop in the infant seaweed industry in the northeastern U.S. Eight different potential supply chains (six for independent seaweed producers and two for vertically integrated producer-processor-wholesaler companies) were described. Advantages, disadvantages, and constraints for development of each were discussed and compared along with regulatory implications for seaweed production and marketing development.

Independent seaweed producers likely would benefit the most from developing strong partnerships with a wholesaler/distributor who has strong relationships with restaurants and chefs interested in developing new, seaweed-based dishes. The interaction of the following factors points to this supply chain as likely to be the most effective: 1) most current state regulations typically require that seaweed be sold through a licensed dealer; 2) consumers typically prefer to try new products in restaurants, but most chefs currently view seaweed as a low-volume garnish or seasoning; 3) most independent producers do not have the storage and processing facilities or

the marketing expertise for the long-term product and market development required to create sufficient demand to support greater volumes of production; and 4) there are well-established high-volume seaweed products available in the market from low-cost international suppliers.

Vertically integrated seaweed producers-processors-wholesalers will need to invest heavily in the long-term R&D necessary to develop, test, promote, and market new seaweed-based products. Such companies will need to expend capital and time on brand development that articulates the company's core values and ensures that each product entering the market consistently supports the brand's expressed values. Brand development will be essential for long-term success because, if successful with specific products, competitors will be attracted as free riders on the investment incurred in development of those specific products. Brand development and on-going product development will allow individual companies to continue to grow as competitors enter the industry.

This study has identified a series of critical research needs to support the growing interest in developing a seaweed industry. These include:

1. Comprehensive study across the Northeastern U.S. to develop a better understanding of the range of acceptable values of key parameters that result in consistent and adequate levels of seaweed productivity and quality for various seaweed species, but especially sugar kelp. These likely include: water temperature, current, water depth, and nutrients.
2. Study that identifies environmental conditions that cause color and translucency variations in sugar kelp (from dark brown to light yellow). Research needs to include taste and nutritional profiles of the various color/translucency forms of kelp as well as consumer acceptance.

3. Economic feasibility study of kelp production and marketing, including potential profitability, cash flow implications, and returns on investment to aquaculture producers.

The growing interest in seaweed production and consumption has resulted in increased experimentation with various types and forms of seaweed. This emerging aquaculture sector poses opportunities for entrepreneurs at several levels of the supply chain but such opportunities inevitably are accompanied by production and marketing risks. This study provides insights into these opportunities and risks, and contributes to understanding various steps towards further development of seaweed aquaculture businesses in the Northeastern U.S.

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Table 1. Principal actors in potential seaweed supply chains, concentration, and marketing functions.

Actors in seaweed supply chain	Relative numbers	Barriers to entry	Degree of concentration	Marketing functions
Producers				
Nurseries	Relatively few	a) Technical skill b) Capital for sterile conditions	High, for those who provide regular supply	Supply seed for growout
Growout	Growing numbers	-Few, but many reports of failure; -Good sites may be barrier to entry for viable production	Low, at this time	a) Grow raw product b) Harvest raw product c) Wash, remove fouling d) Transport product
Intermediaries				
Processors	Very few	a) Capital for processing facilities b) Capital for storage facilities	High	a) Processing b) Value addition
Wholesalers/ distributors	Very few	Knowledge of product	High	
Restaurants	Multiple	a) Unfamiliar with product b) No seaweed-based recipes that fit patrons' palates	Low	a) Product transformation into dishes b) Encourage trial by waitstaff
Univ. food service	Several	a) Unfamiliar with product b) No seaweed-based recipes that fit patrons' palates	Low	a) Product transformation into dishes b) Encourage trial by waitstaff
Retailers	Multiple	a) Volume requirements b) Regional purchasing by large retailer	Medium	a) Aggregate multiple product types at a single location

	c) Consumers less willing to try new products in supermarkets	b) Point-of-display information c) Distribution d) Advertising

Table 2. Seaweed Products and Recipes.

Name	Description	Supply chain level targeted
Fresh Seaweed		
Raw seaweed	Washed, fouling removed	Farmers markets
		Restaurant
		Processor
		Wholesaler/distributor
Fresh whole	In UK, as a salad, side, or component of another dish	Food service to restaurants
Fresh Puree	In UK, as a flavoring, coloring agent, garnish	Food service to restaurants
Dried Seaweed		
Whole leaf		Retail supermarket
		Specialty retail stores
Seaweed salad		Restaurants
Seaweed garnish		Restaurants
Seaweed, herb in soups		Retail supermarket
Powdered seaweed seasoning	Shaker	Specialty retail stores
Dry whole	In UK, as an infusion, flavoring element	Food service to restaurants
Dried powder	In UK, as a flour in crackers, crisps, dough+	Food service to restaurants
Milled seaweed	In 40-50 lb bags	
Seaweed capsules		Dietary supplement

Frozen Value Added		
Kelp noodles	Shredded	Supermarkets, restaurants
Kelp cubes	Soup broth	Supermarkets, restaurants
Other Value Added		
Kelp chips		Supermarkets, restaurants
Kelp crunch		Supermarkets, restaurants
Kelp jerky		Supermarkets, restaurants
Kelp pickles		Supermarkets, restaurants
Kelp sauerkraut		Supermarkets, restaurants
Smoked kelp		
Other Products Developed Experimentally		
Sea Vegetable Power Bar	Dry dulse flakes are used to flavor a nutrient dense power bar that remains shelf stable after cooking. Laver and alaria can also be used in combination with or as a substitute to the dulse in the formula.	

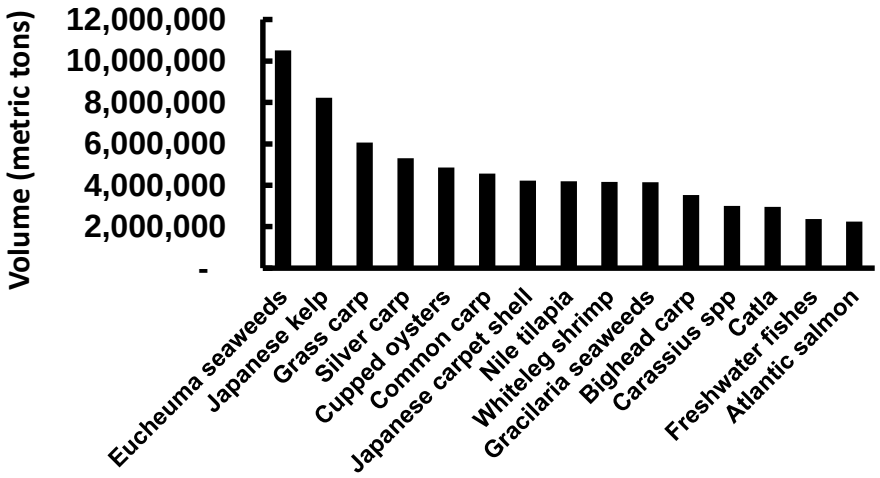
Dulse Cucumber Salad	This vegan, ready-to-consume fresh salad highlights Asian flavors and features rehydrated wild dulse, though rehydrated sea lettuce works well in the formula.
Sugar Kelp Flat Bread	This yeast raised bread with powdered kelp as an inclusion is intended to serve as a foundation for other preparations such as pizza or as an hors d'oeuvre base. The dry sugar kelp powder provides a nutritional boost and color agent.
Sea Vegetable Lasagna	Rehydrated dry sugar kelp is used in place of pasta when making this lasagna. The formula features a filling made with haddock trim and wild white shrimp though nearly any seafood can be substituted. Once cooked and cooled the item can be proportioned for packaged sale at retail or à la carte sale in foodservice.
Maple Dulse Cranberry Scone	Dry dulse flakes are used to flavor a traditional scone base, though dry alaria or laver can be used as a substitution.
Sea Vegetable Chick Pea Salad	This vegan item features fresh frozen sugar kelp and rehydrated alaria and is intended for production and sale as a fresh, nutritious, ready to consume salad.
Sea Vegetable Beans and Sausage	Fresh frozen random cut sugar kelp is featured in this product adding umami intensity. Enzymes in the kelp help tenderize and flavor the beans in the dish. This item is intended to serve as a base for grilled, seared, or roasted proteins such as pork belly or chicken legs.
Sugar Kelp Shrimp Tempura	The tempura batter features dry sugar kelp powder and can be made with Dulse powder and powdered Alaria. This product is suitable for packing as a dry, ready to finish mix, and it works well on all types of seafood and poultry.

Savory Sea Vegetable and Onion Broth	This product features an umami rich onion -based broth infused with sugar kelp, dulse flakes, and tamari, and is suitable for sale as a packaged item at retail or a menu item component in foodservice.	
Dulse Ice Cream	Dry powdered wild dulse is used to flavor and color traditional French vanilla ice cream base.	
Non-food products		
Liquid fertilizer	Any seaweed with fouling on it used to make liquid fertilizer	Sold to marijuana growers, golf courses
Animal feed	Nutritional supplements for racehorses	
Bath and body products		

Table 3. Advantages and disadvantages of various seaweed product forms.

Product Form	Advantages	Disadvantages
Fresh	Little processing	Short shelf life
	Less cost	Wet product is heavy to ship
	Takes less time	Short period of time to get it sold.
Dried	Little processing infrastructure needed	Lower price for buyer
	Light for shiping	Competition with imports
	Long shelf life	
	Re-hydrating allows for use like fresh	
Frozen (noodles, cubes)	Long shelf life- potential for many uses	Infrastructure
		Labor needed for processing
Fermented		
Kelp sauerkraut	Long shelf life	

Figure 1. Global Aquaculture Production of Top 15 Species.



SOURCE: FAO (2018)

Figure 2. Degree of Interest in Trying New Seaweed Products Generally (by Respondents Who Have Eaten Seaweed Previously).

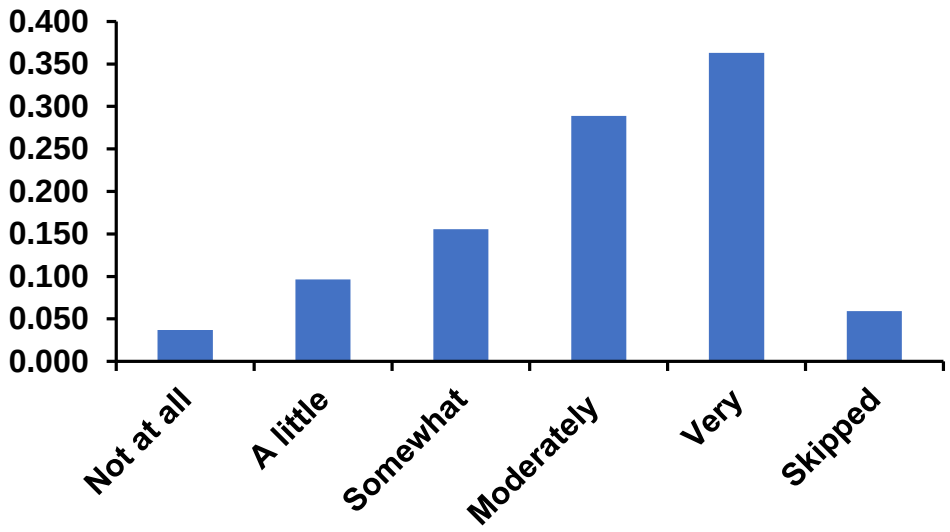


Figure 3. Relative Interest in Trying Various Seaweed Products.

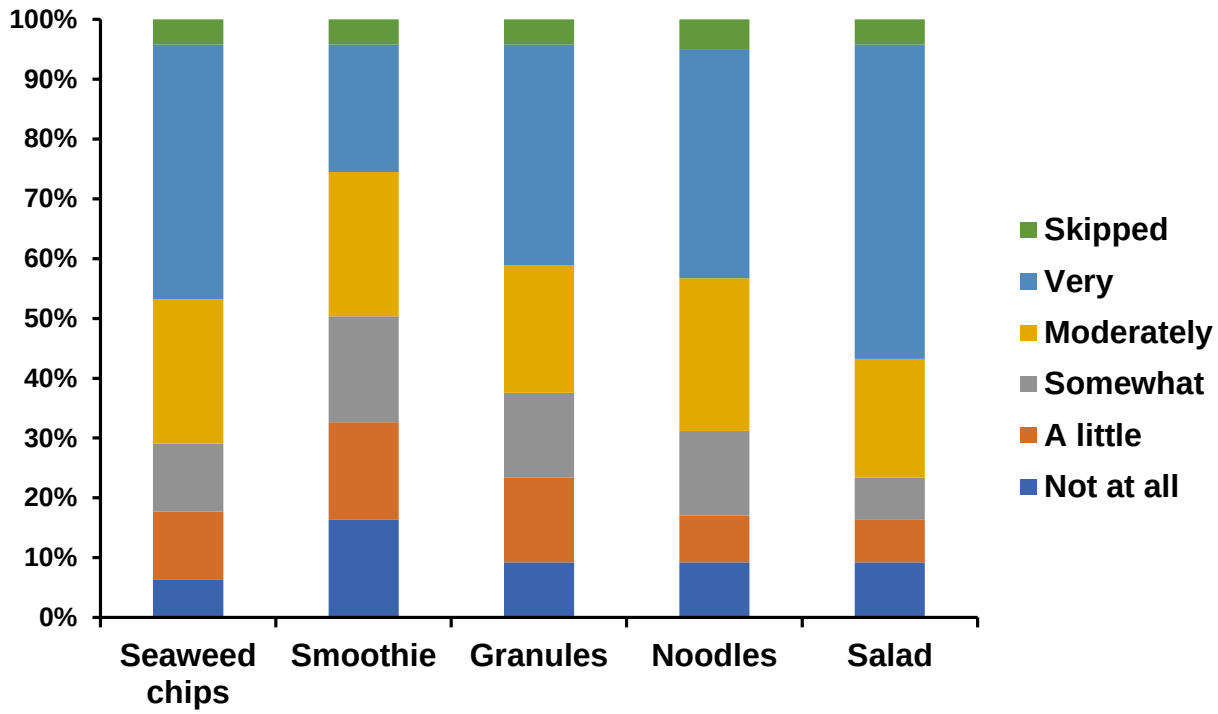


Figure 4. Relative Importance of Various Attributes of Products in Terms of Purchase Choices.

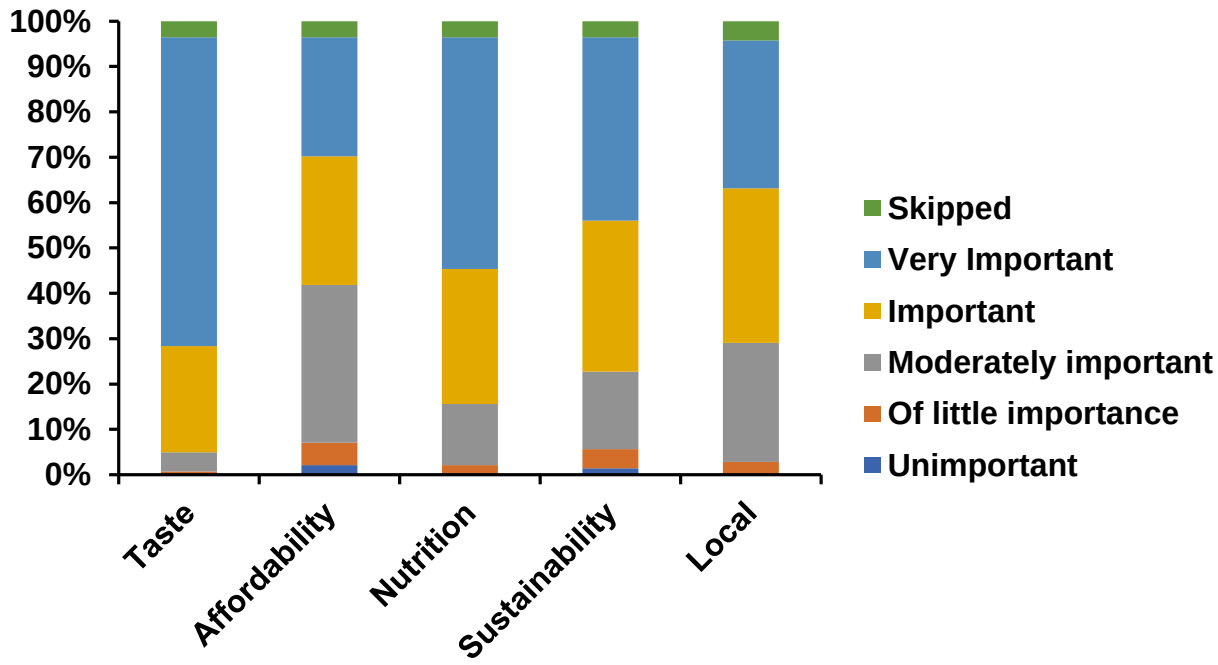


Figure 5. Direct Sales of Fresh Seaweed

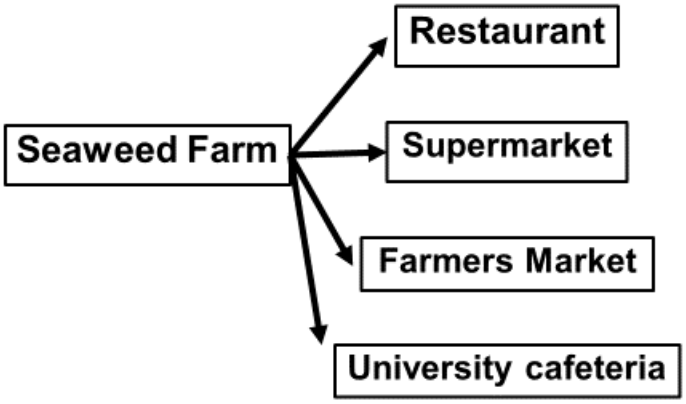


Figure 6. Direct Sales of Processed Seaweed

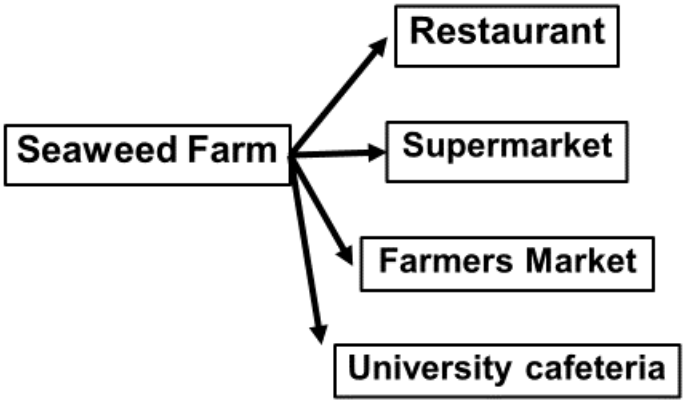


Figure 7. Sales to Processor, Wholesaler, Distributor

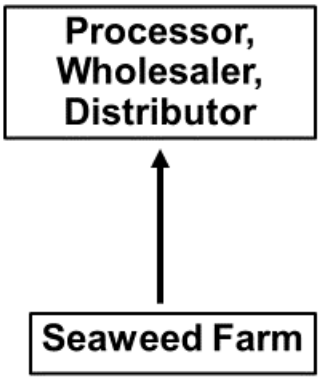


Figure 8. Vertically-Integrated Supply Chain