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Aquaculture Canada and Sea Farmers 2017
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Cover picture: Drying of the sugar kelp, *Saccharina latissima*, at Magellan Aqua Farms Inc. (Steven Backman). Photo credit: Thierry Chopin (Chopin Coastal Health Solutions Inc.)

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Contributed Papers

INTRODUCTION TO THE CANADIAN SEAWEED SYMPOSIUM HELD DURING THE AQUACULTURE CANADA & SEA FARMERS 2017 CONFERENCE, ON MAY 31, 2017

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Seaweeds have been wild harvested and farmed for centuries as part of the seascape of coastal communities. Today, farmed seaweeds account for 27.3 million metric tonnes (wet weight) globally and are the largest group of maricultured organisms (second largest if considering both freshwater and marine aquaculture) on this planet.

Seaweeds are used in a variety of applications including, but not limited to: food and feed products, ingredients, supplements, biopolymers, fine and bulk chemicals, agrichemicals, biostimulants, pharmaceuticals, cosmeceuticals, nutraceuticals, functional foods, bio-oils, botanicals, pigments, etc.

They are increasingly being recognized as a food source containing essential nutrients with important health benefits. The ecosystem services provided by seaweeds are becoming more and more recognized, particularly through the development of integrated multi-trophic aquaculture (IMTA) systems. They should be valued and used as financial and regulatory incentive tools.

The Seaweed Symposium discussed global seaweed production from tropical to temperate regions, their uses in food and non-food applications, and the prospects for future growth of the industry. A panel of experts and producers was assembled to review seaweed mariculture in Canada and the Canadian contributions to the sector, present their findings, and to provide insight as to future directions for research, development and commercialization of the seaweed sector, focusing on the Canadian scene.

We acknowledge the contributions of the Aquaculture Collaborative Research and Development Program of Fisheries and Oceans Canada and the Aquaculture Association of Canada for enabling and supporting the Symposium.

SEAWEED AQUACULTURE – FROM THE GLOBAL, MOSTLY ASIAN, PICTURE TO THE OPPORTUNITIES AND CONSTRAINTS OF THE CANADIAN SCENE

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Abstract

In 2016, farmed seaweeds accounted for 27.3 million metric tonnes (wet weight), worth USD 5.6 billion and represented the largest group of maricultured organisms. Farmed seaweed production exceeded wild seaweed harvesting in 1971 and now represents 95.6% of the world's seaweed supplies. It is, however, mostly an Asian story, as 97.6% is produced in 6 Asian countries. Nine genera of seaweeds (6 groups) provide 97.9% of the production. Systematically, green, red and brown algae do not have much in common and are an unnatural (polyphyletic) grouping. They have very different life histories and, consequently, their culture techniques vary widely. It is imperative to know the biology, physiology, biochemistry, etc. of these organisms very well before attempting their cultivation, as they are definitely not the "low-hanging fruits" of aquaculture. To cultivate our endemic species appropriately, we will need to understand their biological cycles and develop appropriate annual strategies accordingly. It also means that there is a need for timely and enabling regulatory changes instead of the current hampering regulatory hurdles. We will need to develop seaweed products and markets, evolving from a linear approach to move towards the integrated sequential biorefinery (ISBR) approach. We will need the aquaculture industry to diversify beyond fish and develop appropriate regulations to allow this diversification.

Global perspective on seaweed aquaculture production

According to the latest statistics available [2014; published by the Food and Agriculture Organization (FAO) of the United Nations in 2016], farmed seaweeds accounted for 27.3 million metric tonnes (wet weight), worth USD 5.6 billion and represented the largest group of maricultured organisms (second largest if considering both freshwater and marine aquaculture) on this planet.

Farmed seaweed production now represents 95.6% of world seaweed supplies. Seaweeds were the first group of organisms to pass the 50% farmed/wild harvest threshold in 1971 (Cottier et al., 2016). Farmed production (fish + seaweeds + aquatic plants + invertebrates) surpassed capture fisheries in 2013; farmed food supply (fish + seaweeds + aquatic plants + invertebrates) surpassed capture fisheries in 2014 (FAO, 2016). The average annual production growth rate of the seaweeds and aquatic plants industry increased from 6.2% during the period 1995 - 2004 to 8.0% during the period 2005 - 2014, while during the same time that of fish decreased from 7.2% to 5.8% for the same periods.

There are approximately 10,500 known species of seaweeds and around 220 are cultivated. Nine genera (6 groups) provide 97.9% of the production (Fig. 1):

- *Kappaphycus*/*Eucheuma*: 40.3%
- *Saccharina*/*Laminaria*: 28%
- *Gracilaria*: 13.7%
- *Undaria*: 8.5%
- *Porphyra*/*Pyropia*: 6.6%, and
- *Sargassum*: 0.7%.

However, very little of this is known in the western world because 97.6% of seaweed aquaculture is concentrated in 6 Asian countries:

- China: 48.8%
- Indonesia: 36.9%
- The Philippines: 5.7%
- The Republic of Korea: 4.0%
- Japan: 1.3%, and
- Malaysia: 0.9%.

Figure 1
Six groups (nine genera) of seaweeds provide 97.9% of the world seaweed aquaculture production.

Should we be surprised that we know how to cultivate only a few genera/species of seaweeds?

Let's see what kind of animals we eat/grow most:

- 4 marine fish: salmon, sea bass, cod and tuna (Greenberg, 2010),
- 5 terrestrial animals: chicken, pig, turkey, sheep and cow.

So, 6 groups of seaweeds are not that surprising. Why is that and what does that mean for growing a viable seaweed aquaculture sector in the Canadian context?

One could pretty much argue that "a fish is a fish is a fish" and that is the reason why there are not many differences in culture techniques. However, this is not the case with algae. We have to go back to the Greeks and the Romans. When they did not know in which group of organisms to classify a new species, they described them as "incertae sedis" (of uncertain placement). Over time, a lot of algae/seaweeds became "incertae sedis"… The end result of several centuries of neglect is that systematically, green, red and brown algae do not have much in common and are an unnatural grouping (polyphyletic group; i.e. with different ancestors and different evolutionary histories). They have very different life histories and, consequently, their culture techniques vary widely. One could say that farming green, red and brown seaweeds is as different as farming chicken, kangaroos and alligators; therefore, it is imperative to know the biology, physiology, biochemistry, etc. of these organisms very well before attempting their cultivation, as they are definitely not the "low-hanging fruits" of aquaculture.

So, why do we hear these two conflicting messages in Canada: on one hand "grow that species and do a good job at it", and, on the other hand "you should put more (like 10) species on your site amendment list, while you are at it"? I guess it is, unfortunately, more a reflection of a general lack of understanding of what seaweeds are, how to cultivate them, what we can do with them and the interesting ecosystem services they can provide.

A fish farmer or a shellfish farmer is not asked to do that; why would we expect that from a seaweed farmer? Instead, what we should do is a good job with a few species in each group (seaweeds, fish and invertebrates). The diversification comes through integration within integrated multi-trophic aquaculture (IMTA) systems, using an integrated coastal area management (ICAM) strategy.

What do we need to cultivate endemic seaweed species in Atlantic Canada?

To cultivate appropriately endemic seaweed species in Atlantic Canada, we will need to understand their biological cycles and develop appropriate annual strategies accordingly. It also means that regulatory amendments, and authorization to grow at particular sites, must be in place early enough to allow appropriate planning for the season.

Typically, the annual cycle for kelp cultivation in Atlantic Canada is as follows (Chopin et al., 2004):

- During the spring, it is important to get the equipment ready to be on time for the rest of the process. It is the time to decide on the number of ropes, the number of sites, and the infrastructure to put in place. Twines need to be cut, washed and spooled.
- During the second part of August, the spools are inoculated.
- From August to October, the microscopic stages of the kelp life history are cultivated in a "spore-gametory". There are no eggs to hatch in seaweeds, so we should not talk about a hatchery! Instead spores germinate into male and female gametophytes and male gametes fertilize female gametes, which develop into microscopic sporophytes, which will become the big kelps most people know.
- Second part of October – early November is the time to transfer the microscopic kelps to the sites, where twines are unspooled around bigger ropes. It is very important to not be late for this phase; it is not good for seaweeds or humans, as temperatures are decreasing rapidly.
- From November to May, this is the grow-out period at sea, when occasional monitoring is needed but, fortunately, seaweeds do not need to be fed.
- From May to July, this is a busy period with seaweed harvesting and processing to be done.

Once seaweeds have been harvested, the question remains "what to do with all this biomass?"

We will have to change our attitudes and business models to develop seaweed products and commercialize them, evolving from the linear approach (one species – one process – one product), used too often with fishery and aquaculture products, to move towards the integrated sequential biorefinery (ISBR; Fig. 2) approach (one species – several processes – several products) (Chopin et al.,

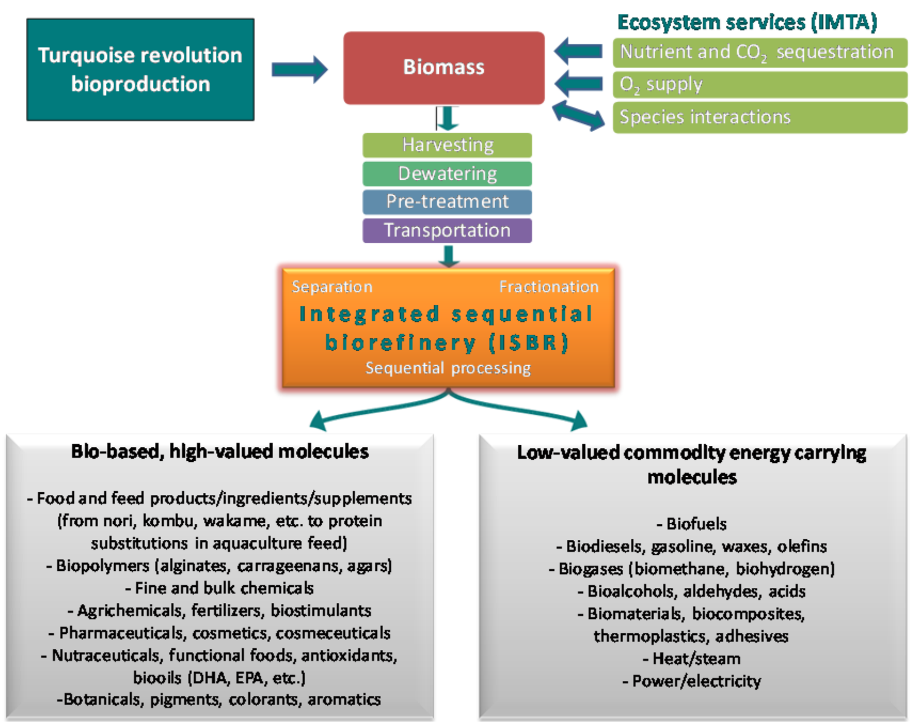

Figure 2
The integrated sequential biorefinery (ISBR) concept.

2011). Within a circular economy framework, there are no longer by-products in an ISBR system, but co-products, which can also be marketed.

We have already adopted this ISBR diversification approach with our IMTA products: seaweeds for human consumption, for cosmetics, for partial fishmeal substitution, organically-certified IMTA kelps, and kelps for biochar production as a substrate for freshwater IMTA (or aquaponics).

The aquaculture industry will have to diversify beyond fish and develop appropriate regulations

To allow diversification of the aquaculture industry, there is a need for timely and enabling regulatory changes instead of the current hampering regulatory hurdles.

The ecosystem services provided by seaweeds, and other extractive species (invertebrates), will have to be valued and used as financial and regulatory incentive tools.

We cannot continue to read in magazines "Seaweeds are the next superfood" and do nothing in our own "sea backyard". Consequently, the Safe Food for Canadians Regulations, which are presently completely silent on seaweeds, need to be amended.

Conclusion

Hopefully, as people in the western world begin to recognize the benefits seaweeds offer them and the environment, we will see this aquaculture sector emerge, particularly in Canada, instead of remaining a missed opportunity.

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SEAWEEDS AS HUMAN FOOD AND AQUACULTURE FEEDS

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Abstract

Seaweeds have been used by humans as an important food source in some countries for at least 1500 years. In addition to an impressive nutritional portfolio, seaweeds also contain numerous useful bioactive secondary metabolites, many of which exhibit robust antioxidant capacities. One of the more common uses of seaweed extracts is as thickening or gelling agents, where they add texture and structural stability to industrial formulations of foods and personal care items. However, dietary seaweeds can provide all the essential nutrients necessary to meet the requirements for the definition of food, with the exception of adequate calories. Seaweeds in general do not contain significant amounts of fat, but those lipids they do contain are mostly in the form of omega-3 and omega-6 fatty acids, in a ratio of approximately 1:1, just as it is in our brains. As primary producers, seaweeds can also supply nutritional elements to fish, which in turn can be consumed by humans, providing important health and wellness benefits, and a more concentrated form of polyunsaturated fatty acids. Characteristics of aquacultured fish positively impacted by the inclusion of seaweeds in the diet include protein content, colouration of flesh, lipid content, nutrient utilization, feed efficiency, and growth performance.

Introduction

Commercial and economic utilization of seaweeds for their antioxidant properties with respect to benefits to human health and nutrition is still in its infancy. However, seaweeds are a robust and reliable source of a broad range of antioxidants and their application in whole foods, as food ingredients and in nutritional supplements is on the rise (Cornish & Garbary, 2010; Kadam &

Prabhasankar, 2010). Industrial usages over the last century typically capitalized on the gelling and texturizing properties associated with various seaweeds as a function of their wide diversity of sulfated polysaccharides, the agars, carrageenans and alginates. However, as a group, seaweeds also contain all the essential nutrients to sustain growth, repair, and vital processes, and to furnish energy, but with one minor exception. Seaweeds are very low in fat, but the fat they do contain is in the form of those important polyunsaturated fatty acids, particularly the nutritionally beneficial omega-6 and omega-3 lipids, typically in a ratio approximating 1:1 (Mouritsen, 2013). These nutritional characteristics apply to both human food and to animal and fish food.

Human health benefits

The functional aspects of macroalgae allude to their purported health-promoting functions beyond basic nutrition. For example, seaweeds not only provide significant dietary fibre, but they also can contribute an associated boost in antioxidant capacity of the bloodstream. Research suggests that in obese, or health-compromised individuals, reactive oxygen species (ROS) production is chronically increased, and that a corresponding increase in antioxidant capacity is required to cope (Huang et al., 2005). Research by a number of scientists has shown that dietary seaweeds can ameliorate or improve the status of some of the most prevalent risk factors for cardiovascular diseases (CVD). Examples of some of these specific pathologies or biomarkers include obesity, inflammation, erectile dysfunction, and nutritional imbalances (Cornish et al., 2015).

The human brain is an organ of profound complexity and sophistication, and its proper health and development underlies all the characteristics that define the human race, both individually, and collectively. A number of brain essential nutrients have been identified, such as taurine, zinc, magnesium, vitamin B12, iodine, decosahexaenoic acid (DHA), alpha-linolenic acid (ALA), and eicosapentaenoic acid (EPA), for example. All are found in seaweeds (Cornish et al., 2017). Today, neurodegenerative diseases are on the rise (Hibbeln, 2007; Olesen et al., 2012) and poor nutritional regimes are leading to serious health pathologies triggered by widespread and chronic risk factors clearly related to poor diets. Gut microbes also play a significant role, and research highlighting the mental and physical health impacts of the gut/microbe/brain axis are coming to light, and again, dietary seaweeds have been demonstrated to positively influence populations of beneficial gut microorganisms (Jutur et al., 2016).

As primary producers, seaweeds and other algae provide a plethora of nutrients to fish and other animals that eat them, and as the tertiary, or top consumers of marine fauna, humans again benefit from the bioaccumulation of important nutrients such as DHA, ALA, and EPA. With over 10,000 species of seaweeds in the oceans of the earth, opportunities for their sustainable exploitation abound. Aside from their well-established textural and stability applications, the utilization of such nutrient dense, macroalgal resources will eventually lead to healthier foods and food ingredients, and these will provide functionality in addition to basic nutrition… naturally.

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THE CULTIVATION OF SEAWEEDS FOR HIGH VALUE PRODUCTS: PROSPECTS AND CHALLENGES

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Abstract

The domestication of seaweed cultivars (in the 1940s) ended the reliance on natural cycles and raw material availability for some species, driven by consumer demands that far exceeded the available supplies. Currently, global seaweed cultivation is unrivaled in mariculture with 96% of annual seaweed biomass derived from cultivated sources.

In the last decades, research has confirmed seaweeds as rich sources of potentially valuable compounds. Most existing seaweed cultivars and current cultivation techniques may not necessarily be optimized to produce valuable bioactive compounds. The future of the seaweed industry will include the development of high-value markets for functional foods, cosmeceuticals, nutraceuticals, and pharmaceuticals.

Entry into these markets will require a level of standardization, efficacy, and traceability that has not previously been demanded of seaweed products. Composition of bioactive compounds can fluctuate seasonally, geographically, bathymetrically and genetically even within individual species, especially where life-history stages can be important.

Successful expansion of seaweed products into new markets requires the cultivation of domesticated cultivars. Demands of an evolving new industry, based upon efficacy and standardization, will require the domestication of new species, the selection of improved cultivars, and a refinement of existing cultivation techniques to improve quality control and traceability of products.

THE RENEWED INTEREST IN THE CULTIVATION OF SEAWEEDS, AS THE INORGANIC EXTRACTIVE COMPONENT OF INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA) SYSTEMS, AND FOR THE ECOSYSTEM SERVICES THEY PROVIDE

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Abstract

A renewed interest in the mariculture of seaweeds in the western world has been triggered by their cultivation in integrated multi-trophic aquaculture (IMTA) systems, the ecosystem services they provide (e.g. nutrient biomitigation, irrigation-less and deforestation-less food production, oxygen provision, habitat restoration, carbon sequestration, coastal acidification reduction, etc.), and the development of novel uses/applications. The value of the ecosystem services needs to be recognized, accounted for and used as financial and regulatory incentive tools. Extractive aquaculture now represents 54.4%, but is unevenly distributed worldwide and needs to increase.

A renewed interest

Seaweed cultivation is well established in Asia and needs little explanation or justification. In the western world, a renewed interest in seaweed mariculture has been triggered by their cultivation in integrated multi-trophic aquaculture (IMTA) systems, the emerging understanding of the ecosystem services they provide, and the development of novel uses and applications.

Extractive species need to be valued for more than their food trading values

To bestow full value to seaweeds and IMTA, extractive species need to be valued for not only their biomass and food trading values, but also for the ecosystem services and the increase in consumer trust and societal/political licence to operate they provide within a circular economy framework. The value of these ecosystem services needs to be recognized, accounted for and used as financial and regulatory incentive tools (e.g. nutrient trading credits).

Seaweeds are excellent nutrient scrubbers

An often-forgotten function of seaweeds is that they are excellent nutrient scrubbers (especially of dissolved nitrogen, phosphorus and carbon). We should take advantage of the benefits of nutrients, which, in moderation (i.e. within the assimilative capacity of the ecosystem) are not waste but food. It is all about recycling, which we have no problem with on land (in your house, office, hotel room, garden, farm, etc.), but for which we experience a mental blockage when translated to the aquatic and marine environments. We should allocate a value to recapturing feed and energy, otherwise lost, and their conversion into other commercial crops.

Much has been said about carbon sequestration and the development of carbon trading taxes. In coastal environments, mechanisms for the recovery of nitrogen and phosphorus should also be highlighted and accounted for in the form of nutrient trading credits (NTCs, a much more positive approach than taxing).

If the composition of seaweeds can be averaged at around 0.35% nitrogen (N), 0.04% phosphorus (P) and 3% carbon (C), and the NTCs valued at USD 10-30/kg, USD 4/kg and USD 30/tonne for N, P and C, respectively, the ecosystem services for nutrient biomitigation provided by the worldwide seaweed aquaculture industry (27.3 million tonnes) can be valued at between USD 1.024 billion and USD 2.935 billion, i.e. as much as 52.4% of their present commercial value (USD 5.6 billion). The value of this important service to the environment and, consequently, society is, however, never accounted for in any budget sheets or business plans of seaweed farms and companies, as seaweeds are being valued only for their biomass and food trading values.

The above calculations are based on costs of recovering nitrogen and phosphorus in wastewater treatment facilities and values often cited for carbon tax schemes. It is interesting to note that the value for carbon is per tonne, whereas those for nitrogen and phosphorus are per kg, i.e. there is a factor of 1,000… Nobody seems to have picked up on that when looking at the sequestration of elements other than C. Moreover, having organisms able to accumulate P is becoming increasingly attractive when considering that, in the not too distant future, the next P peak will not be that of petroleum, but that of phosphorus.

The recognition and implementation of NTCs would give a fair price to extractive aquaculture species. They could be used as financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable aquanomic option to their current practices.

Nutrient biomitigation is not the only ecosystem service provided by seaweeds

Seaweeds can be cultivated without the addition of fertilizers and agrochemicals, especially in an IMTA setting, where the fed aquaculture component provides the nutrients. Seaweed cultivation does not require more arable soil and transformation of land for agricultural activities (and loss of some ecosystem services); if appropriately designed, it can be seen as engineering new habitats, harbouring thriving communities, and can be used for habitat restoration. Moreover, it does not need irrigation, on a planet where access to water of appropriate quality is becoming more and more an issue.

Whereas all other components (fed and organic extractive) are oxygen consumers, seaweeds are photosynthetic organisms, and are the only aquaculture component with a net production of oxygen, hence they help to avoid coastal hypoxia.

While performing photosynthesis, seaweeds also absorb carbon dioxide and, hence, participate in carbon sequestration (Chung et al. 2011), even if in a transitory manner. Consequently, they could be a significant player in the evolution of climate change, slowing down global warming, especially if their cultivation is increased and spread more throughout the world.

By sequestering carbon dioxide dissolved in seawater, seaweeds could also play a significant role in reducing coastal acidification (Clements & Chopin 2017). The key chemical reaction at work is:

$$CO_2 + H_2O + CO_3^{2-} \rightarrow 2\ HCO_3^-$$

carbonate bicarbonate

The problem is that the increase of dissolved carbon dioxide in seawater shifts the reaction towards the right; unfortunately, shellfish (and other calcifying organisms such as corals), which use carbonates for the calcification of their shell, cannot use bicarbonates and that is why ocean acidification has been associated with mortalities in some shellfish hatcheries and lack of recruitment in some natural populations. It would be interesting to combine seaweed and shellfish aquaculture operations where seawater would go through seaweed tanks first to reduce acidity, before being piped into the mussel tanks where it would help larvae calcify properly.

The IMTA multi-crop diversification approach (fish, seaweeds and invertebrates) could be an economic risk mitigation and management option to address pending climate change and coastal acidification impacts.

IMTA systems could also be associated with offshore wind farms. These farms are often exclusion zones where no other activities are permitted. Using the pillars of wind turbines as infrastructures for IMTA systems would allow for the combination of these two activities, and, consequently, reduce their cumulative footprint through sharing, which should increase their respective societal acceptability.

Diversification is imperative

It is well known that monoculture in agriculture is risky, much like investing in only one stock on the stock exchange. The same applies to aquaculture: putting all your eggs in the same basket is also risky. The future growth of the aquaculture sector hinges on diversification.

Extractive aquaculture of seaweeds/aquatic plants/molluscs/crustaceans/non-fed finfish now represents 54.4% of the world aquaculture production (Table 1), but is unevenly distributed worldwide (97.6% of seaweed aquaculture is taking place in 6 Asian countries; Chopin 2017) and needs to increase. Consequently, if aquaculture is to make a major contribution to the efficient and responsible food production systems of the future, geographical diversification is also needed, particularly in the western world.

In Atlantic Canada, overwhelmingly dominated by finfish aquaculture (Chopin 2015), diversification into seaweeds and invertebrates such as mussels, oysters, sea scallops and clams, and cultivation of sea cucumbers, sea urchins, sea worms, lobsters, and beneficial bacteria should be contemplated, as finfish production has been decreasing in recent years. If we still want to talk about "aquaculture development", the "development" will need to involve other species. IMTA can diversify and broaden the salmon aquaculture industry away from a monoculture model, advancing business cases, increasing resilience and improving the societal acceptability of this industry.

Table 1: Distribution of the different types of aquaculture operations between extractive and fed aquaculture.

Extractive aquaculture		
Seaweeds + aquatic plants	25.4%	
Molluscs	15.0%	54.4%
Crustaceans	6.4%	
Non-fed finfish	7.6%	
Fed aquaculture		
Fed finfish	38.8%	45.6%
Other animals	6.8%	

Conclusion

Humans will soon not be able to continue thinking of mostly land-based agronomic solutions and fed finfish aquaculture operations for securing their food, or for providing many other derived products. They will have to turn, increasingly, to responsible aquanomy, as we enter a new era of ecosystem responsible aquaculture.

It is time to make the Blue Revolution and the Blue Economy greener and apply agronomic principles to the management of aquatic environments and "aquatic fields", i.e. it is time to mature into the Turquoise Revolution, the Turquoise Economy, and aquanomy.

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SUSTAINABLE AND NATURAL POTENTIALS OF SEA VEGETABLES

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Abstract

Sea vegetables provide healthy food and feed options for humans, animals, and plants. Cultivated sea vegetables can be seen as a secure food and specialty ingredient source for the world's increasing population. Sea vegetables do not require feed or fertilizers to grow and can offset certain pollutants in the oceans naturally. Although market demand exists and is growing, certain challenges are faced such as the public perception of seaweeds as a food, and the challenge of securing consistent biomass in a sustainable way to create products through wild harvesting alone. Not only are sea vegetables nutrient dense as a food, they offer sustainable and natural alternatives to many existing chemical ingredients throughout various industries. Through cultivation and regulation, sustainability can be achieved in both our environment and local economy.

Overview

After introducing Mermaid Fare Inc., we discuss the healthy highlights of sea vegetables; trending terms used in association with sea vegetables and their rising popularity in the western market, observing the changes in marketing and packaging of existing products from Japan, China, and other Asian countries to reach a new audience; local boundaries and challenges faced in meeting demands through wild species alone; and a positive outlook for the future with cultivated sea vegetables in the Canadian aquaculture industry context.

Introducing Mermaid Fare Inc.

Mermaid Fare Inc. brings cultivated and sustainably managed wild sea vegetables and sea-vegetable-based products to market. Taylor Widrig created Mermaid Fare Inc. in July 2013 with a background in culinary arts, recipe development, and health and wellness. She envisioned a product line that assists in the health of humans and the environment. Mermaid Fare Inc. has become a trusted brand and has formed strategic partnerships internationally to deliver high-value sea-vegetable products into the retail, food service and specialty ingredient sectors, specializing in brown seaweeds originating from the shores of Nova Scotia, New Brunswick, and North Eastern USA.

It is proud to call social enterprise Dartmouth Adult Services Centre (DASC) Industries its home facility, based in Dartmouth, Nova Scotia (Fig. 1), for packaging of its products. Mermaid Fare Inc. is also a member of the Aquaculture Association of Nova Scotia. Social impact and being active within the community and industry is an important factor for the company.

Figure 1
Linda from the Dartmouth Adult Services Centre (DASC) Industries, where Mermaid Fare's retail and food service products are processed and shipped (photo credit: Alexandra Wilson).

Local partners include Acadian Seaplants Limited and, more recently, Magellan Aqua Farms Inc., located in St. Stephen, New Brunswick, producing cultivated brown seaweeds using the integrated multi-trophic aquaculture (IMTA) concept with Thierry Chopin, professor of marine biology at the University of New Brunswick in Saint John and owner of Chopin Coastal Health Solutions Inc. (Figs. 2 - 3). International partners include the French company Algaia, with facilities in Brittany, Normandy, and headquarters in Paris.

Figure 2
Taking a look at the 2017 kelp bounty at Magellan Aqua Farms Inc. in Bocabec Bay, New Brunswick, Canada (photo credit: Thierry Chopin).

Healthy highlights

There are many healthy highlights of sea vegetables but below are just a few key points in what edible sea vegetables and extracts of seaweeds have to offer.

Seaweeds are becoming well known for so many deserved healthy reasons. Constant research is being developed on their cancer fighting properties, assistance in weight loss, hair regrowth, skin health, prebiotics, depression, and are often recommended by naturopaths for thyroid support. Sea vegetables are an excellent

Figure 3
Poster of the partnership Chopin Coastal Health Solutions Inc./Magellan Aqua Farms Inc./Mermaid Fare Inc. for the 2017 Aquaculture Canada and Sea Farmers Conference (photo credit: Taylor Widrig).

natural source of iron and iodine, and are very popular with vegans and vegetarians because of their range of B vitamins, which are difficult to find in a plant-based diet without supplementing. Sea vegetables also offer culinary diversity in vegan and vegetarian diets, adding new flavors and ingredients to incorporate into every day routine. Seaweed-based extracts, in addition to food products, are being developed for the nutraceutical industry as well as agricultural biostimulants.

Trending terms

As popularity rises in the western world for seaweeds, so do catch phrases and terms directly associated with them. Here we look at four terms often used when discussing sea vegetables.

Umami – The savory and meaty flavour often found in edible sea vegetables, and more so when they are cooked, is due to naturally occurring glutamate. The discovery of the 5th flavor, umami, the taste that describes 'comfort' or 'savory' led to the manufacturing of the flavor-enhancing food ingredient monosodium glutamate (MSG).

Sea vegetable – This term is used to describe edible seaweeds. The term "seaweeds" can have a negative connotation in association with "weeds", which most people try to remove from their gardens or are seen as unfavorable.

Sustainability – Cultivating sea vegetables is generally well perceived. Sea vegetables do not require feed or fertilizer to grow making them a sustainable, secure food and manufacturing ingredient source for the world's growing population. Consumers want to know from where and how their food has been produced, and ultimately its environmental impact to grow it.

Carrageenans – Many vegan, dairy-alternative companies have removed these ingredients after public backlash over a debate that has been going on for decades. Little has been proven to show that these allegations are valid, and the debate continues.

The rise in western popularity

While incorporating edible sea vegetables into everyday diet is still a new concept in western countries, there has been a rise in the popularity and positive public perception of edible sea vegetables throughout the western world.

The rise in this popularity can be seen both statistically and in the difference in marketing and packaging of the same food products that have always been sold in North America as well as their location within grocery stores.

Until recent years, packaging of roasted nori sheets, for example, included only their manufacturing country language, traditional images, and were found only in the international aisle. Now these same companies, same products, same over-seas facilities have changed their packaging to reach the western world's audience. Packaging now shows sustainable and emotional slogans like "Seaweed Love", "Gimme Organic", "Sea Snax", "Sea's Gift" and use pictures of cute sea creatures to attract children, parents, and millennials. Sea vegetable snacks and food products can now be found near the check-out line, to-go counters, health food sections (Fig. 4) and in online monthly box subscriptions (Fig. 5).

Figure 4
Mermaid Fare's retail dehydrated Hana Tsunomata (photo credit: Taylor Widrig).

Figure 5
Mermaid Fare's dried edible sugar kelp flakes were featured recently in an online monthly box subscription (photo credit: The Taste Box).

Local challenges

While the Canadian Atlantic Provinces are at a geographical advantage for being a source of high-value seaweed products, certain boundaries and challenges are still being faced.

Throughout the history of the industry, wild species with valuable attributes have generally resulted in cultivation to meet market demands if wild stocks fall short or prove to be inconsistent for the products harvested. To introduce sea-vegetable products from the Atlantic Provinces into the western market, while the demands of large retailers increase, means that cultivation is necessary to maintain sustainability.

It is extremely difficult and could be seen as unsustainable to supply large retail chains with wild species that are only available in limited supply. Moreover, it is difficult to develop consistent, high-value products using only harvested wild species, the biomass of which is presently not managed and regulated in most cases.

A positive future

As scientists and researchers continue to work on acquiring new data and uncover the natural potentials of seaweeds for humans, animals, and plants, alongside a shift within consumers and companies to desire more plant-based, sustainable and secure ingredient sources, the demand and positive public perception of sea vegetables will continue to grow in the western market.

Cultivating sea vegetables will also invite and include vegans and vegetarians into the Canadian aquaculture product line up. These new clients, who make up a significant proportion of the Canadian population, might not know a lot about the benefits of aquaculture, having been excluded from it because they do not eat finfish or shellfish. However, cultivated sea vegetables could offer a unique and new outlook specifically to this demographic.

Increased demand in sea vegetables should add value to the aquaculture industry as a whole, put another product on the map of Atlantic Canada and increase exports.

COLLABORATIVE PROJECT FOR SEAWEED CULTIVATION IN NOVA SCOTIA

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Abstract

The Nova Scotia mussel industry has been hit very hard by invasive tunicates over the past decade. This has resulted in several industry members no longer seeding their mussel lines. At many sites, lines have been left in the water and, in some cases, naturally settling seaweeds have colonized the lines. Mussel growers are looking for options for their leases and seaweed aquaculture offers promise. Seaweeds on lines can grow in less than a year and could provide annual incomes to growers, with limited site modifications. Seaweed aquaculture is a USD 5.6 billion global industry and several, potential, high-value-added products can be derived from seaweeds, ranging from food items, extracts for nutraceuticals and cosmeceuticals, ingredients for natural health supplements, as well as agricultural inputs. The Aquaculture Association of Nova Scotia and its partners have created an initiative to develop seaweed cultivation in Nova Scotia.

Introduction

The invasive vase tunicate (*Ciona intestinalis*) appeared in Nova Scotia in the early 1990's and large populations have been observed around the province since the mid 1990's. Vase tunicates settle on structures in the water including aquaculture equipment and mussel lines (Fig. 1), competing for food and increasing maintenance costs of aquaculture operations. The establishment of vase tunicates in Nova Scotia has resulted in the closure of many mussel farms along the coast, leaving numerous leases underutilized. Some sea farmers expressed an interest in diversifying their crops after seeing how local seaweeds naturally coated their lines already present on their unused leases (Fig. 2). In winter 2015, a survey was done on the Eastern Shores of Nova Scotia to assess seaweed species with potential for aquaculture in that area (Ross & Chopin, 2015). The study identified two local kelp species (*Saccharina latissima* and *Alaria esculenta*) with potential for aquaculture and for which the techniques to grow from laboratory to grow-out sites are well established (Chopin et al., 2004). One additional local species has also been identified with potential for aquaculture, dulse (*Palmaria palmata*), but some work is still needed to refine the grow techniques from laboratory to grow-out site (Chopin, 2017). Following that report, the Aquaculture Association of Nova Scotia (AANS) decided to move forward with some of its members to develop seaweed cultivation in Nova Scotia.

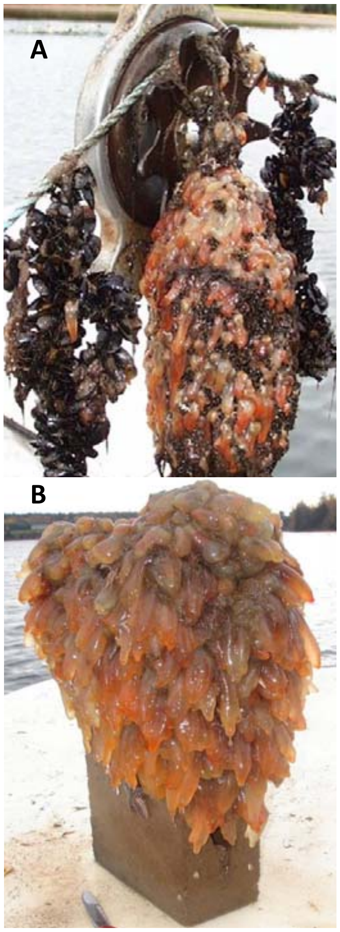

Figure 1
Vase tunicates (*Ciona intestinalis*) on mussel lines (a) and cement block (b). Photo credit: Jeff Davidson.

Project description

The overall objective of this project is to assess the potential for and develop a seaweed cultivation industry in Nova Scotia. We are using a collaborative (industry, government, universities, colleges and the AANS) and multi-sector (R&D for seaweed cultivation, product development, development of processing technologies and market research and development) approach aiming to develop a sustainable seaweed industry in Nova Scotia. At this point, we are at the first stage in the development of this project. We are preparing for small scale kelp (*Saccharina latissima*) growth trials on several shellfish farms (fall 2017): we are assessing potential sites for seaweed cultivation, we are recruiting shellfish farmers interested in doing kelp growth trials on their farms and we are helping those farmers with regulatory requirements (lease amendment) to allow seaweed growth trials on their farms. Simultaneously, we are assessing the interest, capabilities and capacities of various stakeholders in regards to seaweed processing and product development in Nova Scotia. The aim of this component is to identify the role that the various players would like to have in the seaweed industry development, identify the structures and capacities already present in the province and what the gaps are

Figure 2
Naturally settling seaweeds colonizing abandoned mussel lines. Photo credit: Neil Ross.

that would need to be filled. The next step for our project would be to conduct larger-scale multi-year seaweed growth trials with sea farmer partners, optimize seaweed growth on the different sites, and develop products and associated markets.

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MAXIMIZING RAW MATERIAL UTILITY AND RETURN ON INVESTMENT – PRODUCT CHANNEL AND SPECIES DIVERSIFICATION

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Abstract

When looking at any new venture, it is all about the business case: the potential economic return on the investment of your time and resources, given all the options you have for those inputs. Cultivated seaweeds can be a new and sustainable economic crop for sea farmers, and provide additional financial returns to their operations. However, beyond the complexity of growing a new biomass, successful commercialization will also depend on creating efficient logistics to move and process that biomass, fully utilizing it as a resource, and choosing the right channels to enter and products to develop.

Introduction

One approach would be to build a value chain of products, one that can be scaled up over time in terms of production complexity, investment and gross margin returns on end products (Table 1). Initial execution should access local resources to process and package any end product, and only when a greater return can be demonstrated though in-house production, should investment in bricks and mortar infrastructure occur.

Table 1: Potential market values of "end use" value-added products derived from seaweeds.

Product	Format	Industry	Price (Canadian $)	
Rockweed	Liquid extract	Agriculture	$10.00	/ liter
Rockweed	Ground/powder	Natural health products	$25.00	/ kg
Kelp	Ground/powder	Natural health products	$62.00	/ kg

Irish moss	Cut and sift	Natural health products, brewery	$63.00	/ kg
Irish moss	Powder	Natural health products, brewery	$68.00	/ kg
Dulse	Cut and sift	Natural health products	$80.00	/ kg
Dulse	Granules	Natural health products	$98.00	/ kg
Dulse	Powder	Natural health products	$103.00	/ kg
Fucoidan	Powder 95%+	Natural health products, pharmaceuticals	$197.00	/ 500 mg
Fucoxanthin	Powder 95%+	Natural health products, pharmaceuticals	$618.00	/ 50 mg

Method for incremental commercialization growth

The first step might be products destined for food applications, such as dried kelp strips and kelp flakes. These have the least amount of upfront cost to produce and can provide early positive cash flow. These would likely be retail products, which can require significant investment to bring to market and support, so other products and channels need to be developed soon after to help generate those higher long-term investments.

A key challenge in entering the food channel will be the ability to create the critical mass (volume and sales revenue) to support the marketing and promotion efforts needed to build the awareness, trial and repeat purchases with consumers. To achieve this, and to attract distribution partners and create any in-store presence, a breadth of seaweed food products will be needed, not just one or two items. If properly done, a seaweed destination in-store can be created, providing consumers a one-stop-shopping location and reducing the potential for competition in such a niche category. In practice, retailers do not carry multiple brands for small volume lines, so the principle of “first in wins” could apply here. Moreover, since North America does not have a seaweed culture yet, it is not likely that all the biomass that could be grown will be absorbed as a food.

Given similar processing methods, the next product line might be the processing of cultivated seaweeds as an ingredient. Here, additional dried biomass, and even waste material from the production of any food products (i.e. blades whose shape, size and condition do not meet a grade suitable for food use), could be milled into powders and granules and sold into the food ingredients, natural health supplement and companion pet food channels. Additional certification and higher levels of analysis will be needed to show biological composition (actives, heavy metals, etc.), acceptable microbial levels, particle size distribution and perhaps even functional properties, etc., but the gross margin return per wet and dry kg of biomass should be higher.

The next step in the value chain would likely be base extracts, liquids and powders. These products would provide concentrations of beneficial actives which would allow end users the ability to formulate for desired dosages for their consumers and product positions. Given the technology, equipment and skills required to produce these products, initial production should likely be done through third party processors. This would allow for the volume potential of a given industry or channel to be tested, while giving the product all the technical support and credentials that industry would be looking for. Then, as a business case presents itself, additional investment could be made with those partners, or independently, for the infrastructure required to support the growth potential.

Using any number of raw material streams (i.e. waste from a crude extraction process, fresh whole plant material, pieces of wet raw material, etc.), the isolation and sale of specific actives would be the last step in the value chain. As these products require the greatest amount of scientific support (i.e. facility certification, process documentation, proof of purity, etc.), third party resources will likely be the best approach to develop a manufacturing process and to produce trial and early commercial quantities. It would make no sense to scale up any of these resources until there is substantial evidence of a higher return on investment to do so.

Conclusion

Given the amount of cultivated seaweed biomass that could be grown, and the limited consumption of seaweed currently in our food culture, a path that ultimately leads to the development of higher value-added products will be needed to provide a decent long-term financial return for sea farmers. This can be achieved by using third party resources and partnerships, those with the facilities, technologies, skills and credentials needed by the above product markets and channels. Only until such time as a business case can demonstrate a direct investment can deliver a higher rate of return per wet kg for sea farmers, should these products be made by third party partners.

SALAWEG: ADDING VALUE TO FARMED KELP

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Abstract

The Mi’gmaq Maliseet Aboriginal Fisheries Management Association (MMAFMA) is a non-profit Aboriginal organization serving three communities: the Mi'gmaqs of Gespeg, the Mi'gmaqs of Gesgapegiag, and the Maliseets of Viger. Our mission is to promote the sustainable management and conservation of aquatic and oceanic ecosystems on the territories of our communities, while promoting their interests and participation in co-management. The MMAFMA has initiated the SALAWEG project, to add value to locally farmed kelps by developing a range of seaweed-based products destined for human consumption (sea relish, tartar mix, spices for fish and meat). Due to the novelty of these products, we have focused our efforts on product development and marketing, rather than the aquaculture component itself; although we are currently working with partners to optimize the yields of farmed sugar kelp, *Saccharina latissima*, in the Baie des Chaleurs (Québec). Within the next years, MMAFMA aims are the acquisition and profitable operation of an aquaculture site, the development of skills, as well as job creation among the members of our communities, and the generation of revenues for MMAFMA to reinvest into our mission.

Context

The Mi’gmaq Maliseet Aboriginal Fisheries Management Association (MMAFMA) is a non-profit Aboriginal organization serving three communities since 2012: the Mi'gmaqs of Gespeg, the Mi'gmaqs of Gesgapegiag, and the Maliseets of Viger. These communities are located in the Lower St. Lawrence and in the Gaspé Peninsula (Fig. 1). Our mission is to promote the sustainable management and conservation of aquatic and oceanic ecosystems in the territories of our member communities, while promoting their interests and participation in co-

Figure 1
Locations of the Mi'gmaq Maliseet Aboriginal Fisheries Management Association (MMAFMA) three communities: the Mi'gmaqs of Gespeg, the Mi'gmaqs of Gesgapegiag and the Maliseets of Viger.

management. In 2012, we did a review of the underutilized marine species present in the ancestral marine territory of our three communities, and we found that there were many avenues for kelps found in abundance in the Baie des Chaleurs (Québec). A wild kelp inventory was held in 2013, from Miguasha to Bonaventure. Although important kelp beds, primarily composed of *Saccharina latissima*, were observed, we noticed that there was great heterogeneity in the size and state of individuals. After small-scale processing trials, we decided to turn to farmed seaweeds since aquaculture enables quality control, traceability and preservation of natural habitats offered by wild kelp beds. In 2014, we mandated a consultant in the bio-food marketing sector to assess the market potential of kelps and to help us develop a range of food products.

In the last 10 years, a considerable amount of research has been done to develop the kelp sector in Québec, mainly by Merinov, a Québec centre for fisheries and aquaculture innovation, through the Industrial Research Chair in the Conversion of Marine Macroalgae (Gendron et al., 2010; Tamigneaux et al., 2013; Licois et al., 2014; Côté-Laurin et al., 2016). Since 2015, MMAFMA is actively participating in sugar kelp cultivation under Merinov's OPTIMAL program. We are renting aquaculture lines from a mussel farmer in the Baie des Chaleurs (Éric Bujold from Ferme Maricole du Grand Large) to cultivate our sugar kelps.

In 2015 - 2016, we compared two cultivation sites in the Baie des Chaleurs (Cascapedia and Tracadigache), tested two different strains of *S. latissima* and compared two dates of launching at sea (September and November). We also took part, in 2016 - 2017, in a project on the settlement of the bryozoan *Membranipora membranacea* on farmed sugar kelps, initiated by Fisheries and Oceans Canada. The cultivation results are very promising in terms of the technical capacity to cultivate sugar kelps in the Baie des Chaleurs.

The beginnings of SALAWEG

In June 2016, we secured, with our first harvest, 100 kg of frozen, dried and smoked kelps. The harvest was stored in the Gesgapegiag community facilities and during the 2016 - 2017 winter, we conducted a wide range of recipe trials in order to select and standardize our four first products. We selected products that had a high added value, were easy to integrate to the North American diet, were easy to process locally, did not require refrigeration and could meet the requirements of different markets. The markets we aim for are retail and the hotel, restaurant and institution (HRI) sectors.

Figure 2
Involvement of community members in kelp farming activities (photo credit: Marie-Hélène Rondeau).

Kelp-based food is an emerging sector in Québec and in North America in general. For that reason, we are putting a lot of effort in our marketing to ensure sale volumes. We are focusing on our project's appealing story, our sustainable production method and our reinvestment of profits into fulfilling our mission. The story behind our products is based on a solid collaboration between non-native and Aboriginal people. The production method, kelp aquaculture, is an environmentally friendly practice that avoids the use of land and water and the harvest of wild kelps that are an important habitat in the St. Lawrence ecosystem. SALAWEG, which means salty in the Mi'gmaq language, promotes the hiring and training of community members at all stages of the project (during wild kelp inventories, at-sea kelp farming steps, kelp processing and marketing) (Fig. 2). We also received the support of the Gesgapegiag community during critical steps such as harvest and transportation of fresh kelps. In addition, any surplus generated by this business will be reinvested into MMAFMA to fund projects that are related to sustainable management and conservation of coastal and marine resources. Knowing that the consumer wishes to express his/her values through consumption, MMAFMA is meeting this challenge. We are focused on collective rather than personal wealth creation.

Figure 3
SALAWEG's first line of kelp-based food products: from left to right, meat spices, tartar mix, sea relish and fish spices (photo credit: Félixe Waalwijk).

In the spring of 2017, we launched our line of four seaweed-based food products under the name SALAWEG. The line consists of a sea relish, a tartar mix, fish spices and meat spices (Fig. 3). The packaging is tailored to both the HRI and retail markets. Since each market needs differ, packaging is adapted accordingly. The development of these four products enables us to stimulate interest with

Figure 4
First processing of kelps at a fish plant (photo credit: Marie-Hélène Rondeau).

restaurants and processors, as well as larger-scale distributors, specialty grocery and health stores. The line is developed to engage a diverse clientèle and, thus, work on several market segments simultaneously. Offering prices that are more affordable than other local wild kelp-based products will help us remain competitive on the retail market.

We did our second harvest in June 2017 and scaled up the production capacity by renting the installations of a fish processing plant for blanching and freezing 450 kg of sugar kelp (Fig. 4). We are presently working with the community of Gesgapegiag to develop a multi-purpose processing unit that will be highly efficient for most of our secondary processing activities.

Next steps

In 2018, we plan on doubling our kelp harvest and optimizing our processing activities to maximise yields. We are also in the process of acquiring our own aquaculture site in the Baie des Chaleurs, in partnership with our member communities in order to secure our kelp supply. We plan to continue to move forward on two fronts: 1) the development and marketing of kelp-based products, and 2) the development of kelp aquaculture on our own farming site. SALAWEG aims to keep moving forward and to become a Québec leader in kelp-based food products.

Acknowledgements

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GONAD PRODUCTION OF GREEN SEA URCHINS (*STRONGYLOCENTROTUS DROEBACHIENSIS*) FROM EASTERN NEWFOUNDLAND FED NATURAL KELP DIETS

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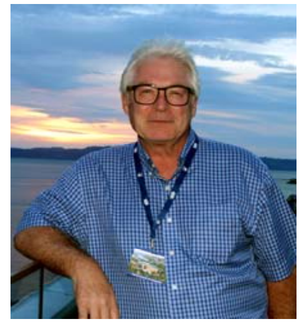
Abstract

The green sea urchin, *Strongylocentrotus droebachiensis*, is abundant throughout eastern Newfoundland, and holds a large potential for aquaculture; however, no such industry has been developed despite initial research attempts in the late 1990s.

To highlight the use of kelps as a feed option for urchin quality, we carried out an 8-month experiment during which groups of green sea urchins from southeastern Newfoundland were maintained in flow-through tanks at ambient sea temperature and fed *ad libitum* with one of three locally abundant kelp species: *Alaria esculenta*, *Laminaria digitata*, and *Agarum clathratum*. Gonad index and some quality parameters were assessed from a subset of individuals halfway through the experiment, and at the end of the experiment all gonad quality parameters (colour, taste, texture, and gametogenesis) and index were assessed.

Preliminary data analysis suggests that sea urchins fed *A. esculenta* and *L. digitata* had much higher gonad index and quality than those fed *A. clathratum* and those from the original source population. Sea urchins fed *L. digitata* produced the best quality gonads after short term feeding (off season), and long term feeding (on season). Collectively, results suggest that sea urchins fed locally abundant and easily accessible kelp species will produce large volumes of high quality gonads.

AN EVALUATION OF INDONESIA SEAWEED FARMING – FUTURE PROSPECTS AND CONSTRAINTS



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Abstract

Seaweed farming and output is increasing rapidly on a global scale, and Indonesia is one of the largest producers. Global trends for seaweed production show an increasing demand for seaweeds for food security and for high-end seaweed food products. Raw carrageenan demand does not appear to be growing, and alternate, higher-end extracts and products from seaweeds will lead the future. The majority of seaweed farms in the world are smallholder farms consisting of a few ponds or a few hectares of the sea for farming purposes. They are mostly family-type businesses, disconnected from markets, and their growth and success are constrained by a variety of factors. These impediments include: lack of access to capital or technical support, lack of market insight, a poor understanding of the value and supply chains for seaweed products, and a changing climate that is impacting production in a variety of ways. Moreover, up to 80% of the world's seaweed production occurs with ongoing disease management issues, and a lack of new seed stocks to address climate change impacts. Indonesia seaweed farming suffers from the same constraints as the rest of the world. A recent evaluation of the status of seaweed farming in South Sulawesi is presented, and some potential solutions to improving seaweed farming outcomes for farmers are proposed.

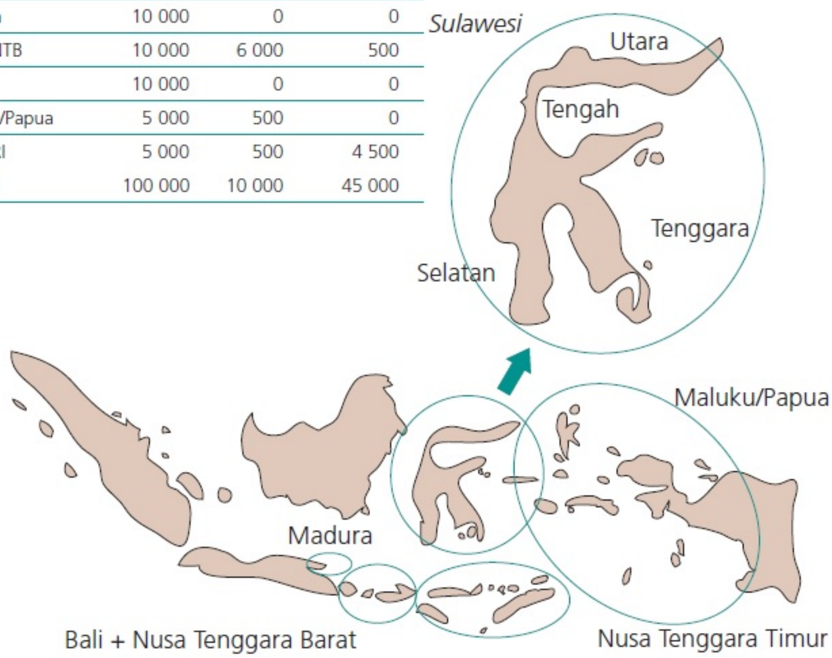
Background on Indonesia seaweed farming

Indonesia is the world's largest archipelago with over 14,000 islands, and a rapidly growing population (4th largest country population in the world with 250 + million inhabitants). By virtue of its island nature, it has a long maritime culture that transcends all facets of society, i.e. coastal dwellings, culture,

FIGURE 1

Estimated annual production of RAGS, 2009 (tonnes in dry weight)

Location	Cottonii	Spinosum	*Graciliria*
Sulawesi Selatan	20 000	1 500	40 000
Sulawesi Tenggara	35 000	1 500	0
Sulawesi Tengah	4 000	0	0
Sulawesi Utara	1 000	0	0
Madura	10 000	0	0
Bali + NTB	10 000	6 000	500
NTT	10 000	0	0
Maluku/Papua	5 000	500	0
Other RI	5 000	500	4 500
Total RI	100 000	10 000	45 000



Sources: Seaplant.net; JaSuDa farmer network.

Figure 1
Location of seaweed farming regions in Indonesia. South Sulawesi is the largest producing province in the archipelago (from Neish 2013).

transportation, food production, etc. That is, livelihoods depend considerably on the sea. It is the third largest seafood producing nation next to China and India (FAO, 2016) and it is the largest seaweed farming nation for industrial, non-direct consumption applications.

Farming seaweeds began fifty years ago or more in Indonesia with the main products used for the extraction of hydrocolloids such as carrageenans and agars. Over 20 species and strains of seaweeds are produced around Indonesia, mostly red seaweeds of the genera *Euchema*, *Kappaphycus* (carrageenophytes) and *Gracilaria* (agarophytes). Many of the species farmed are non-native to the regions where they are produced in Indonesia, and were introduced at various times by hydrocolloid traders to increase production of desirable species. Much of the seaweeds produced in Indonesia are exported in the raw, dried form for hydrocolloid extraction by a small number of companies and countries, who essentially have control over the markets for these products.

Development of the industry was aided to some extent by hydrocolloid traders from Canada, France, Switzerland, the USA and the Philippines, and more recently from China. These countries largely control the hydrocolloid extraction markets. Today, there are over 50,000 smallholder seaweed farmers spread throughout the various islands with the largest production area located in South Sulawesi (Figs. 1 and 2), accounting for about 40% of the annual national output. The structure of the industry is such that the farmers are disconnected from the markets (not aware of market trends or have no control of market prices), have difficulty in financing their production (mostly through middlemen, a.k.a. loan sharks), and there is very little in terms of technical or extension support to address some of the production concerns. Farm production has declined in several areas owing to changing climatic conditions, lack of biosecurity practices, and to some extent uncontrolled and un-regulated growth (Cottier-Cook et al., 2016; Neish, 2013). Moreover, the market for carrageenophytes appears to be saturated or nearly so, based on export figures from government.

Figure 2
Composite of seaweed farming activities in South Sulawesi. Clockwise from top left: traditional seed tying on seaweed growout lines; harvested *Kappaphycus alvarezii* (var. Sacol) used for carrageenan extraction; *Caulerpa* sp. (local name lawi lawi) farmed in ponds for food; close up of Sacol, clean, free of pests or parasites.

Addressing constraints to production

One of the stated goals of the country development plan is to become the largest seaweed producer in the world by 2019 (Antara News, 2015). However, there is no obvious clear plan how to achieve this goal in the time frame noted, with the exception perhaps of encouraging more farming in rural areas. Market access issues will continue to be a concern. This alone (growing more seaweeds) will not enhance output significantly given the constraints noted previously in terms of industry structure, access to capital, adaptation to climate change, and innovation to enhance or diversify production.

A newly established national seaweed center of excellence has been established at Hasanuddin University in Makassar (http://fikp.unhas.ac.id), South Sulawesi, with a focus on extracting value from seaweeds, developing better farming practices, developing IMTA systems, and essentially enhancing the value chain within Indonesia. As well, the government has made it a priority to support processing and extraction of carrageenans and agars within the country, rather than promoting export of raw materials for extraction. Further support is expected on a warehouse receipt system to allow farmers to access capital at reasonable market rates.

Concomitant with these efforts, the Canadian government via Global Affairs Canada (GAC) has funded a small project with the Cooperative Development Foundation of Canada (CDFC) to aid small-scale seaweed producers adopt the integrated co-operative business model to improve livelihoods of men and women sea farmers in South Sulawesi. For a project outline, visit http://cdfcanada.coop/our-projects/invest-co-op-indonesia/. This latter project, while fairly small in scale, will address some of the constraints to expansion of seaweed farmers including market access, enhanced value-chain participation, product diversification (including IMTA and alternate crops), access to capital, best aquaculture practices, as well as other constraints facing smallholder farmers in eight localities in South Sulawesi, the hub of Indonesian seaweed production, but also one of the poorest regions of the country.

Future prospects

It's not all doom and gloom. The attention and approaches to improving production by Indonesian universities, the Indonesian government, as well as the Canadian government, should result in positive change in the seaweed industry in Indonesia in the near future; certainly a foundation for further growth should result from these interventions. Of course, there is risk in any intervention, especially in the seaweed industry (Mulyati & Gelderman, 2017); however, if carefully planned, risk management measures can be adopted to ensure success.

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TO ENABLE INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA) AND THE SEAWEED SECTOR TO DEVELOP IN CANADA, REGULATORY ISSUES WILL NEED TO BE SERIOUSLY ADDRESSED

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Abstract

A major rethinking is needed regarding the functioning of an "aquaculture farm". It should be managed using an integrated coastal area management (ICAM) strategy, according to the movement of the different elements considered. Different nutrients mean different spatial and temporal recovery strategies. There is, consequently, a need for amendments to regulations to remove regulatory hurdles and enable the development and implementation of innovative aquaculture practices, such as integrated multi-trophic aquaculture (IMTA), new industries, new products and new markets.

Need for an integrated coastal area management (ICAM) strategy

A major rethinking is needed regarding the functioning of an "aquaculture farm" and innovative practices need to be developed. It would be a complete illusion to think that an aquaculture farm only functions within the limits of a few buoys, arbitrarily placed in the water by humans, or a few GPS coordinates on a map. Therefore, its management should be based on an integrated coastal area management (ICAM) strategy, considering different spatial and temporal recapturing strategies to recover the different types of nutrients:

- large particulate organic nutrients should be managed within the farm,
- small particulate organic nutrients should be managed within the farm or around its immediate vicinity,

- dissolved inorganic nutrients should be managed at the ICAM scale, either when produced directly or after re-mineralization of the organic matter.

The “integrated” in integrated multi-trophic aquaculture (IMTA) should be understood as cultivation in proximity, not considering absolute distances, but rather connectivity in terms of ecosystemic functionalities at the ICAM scale. This means that entire bays/coastal areas/regions could be the units of IMTA management, not the relatively small finfish sites. IMTA was never conceived with the idea of being viewed only as the cultivation of salmon, kelps, blue mussels and other invertebrates, in temperate waters, and only within the limits of existing finfish aquaculture sites. That is how we started in Canada (Fig. 1), in order to be able to conduct experiments at sea, within the limitations of the regulations presently in place, rather than extrapolating from small tank experiments in laboratory conditions, which may not reflect what really occurs in the environment.

Figure 1
Integrated multi-trophic aquaculture (IMTA) site in the Bay of Fundy, Canada: from left to right, six salmon cages, two mussels rafts and two kelp rafts (photo credit: Chuck Brown).

We know that IMTA systems should and will continue to evolve. Because the IMTA concept is extremely flexible and can be applied worldwide to open-water and land-based systems, marine and freshwater environments, and temperate and tropical climates, there is no ultimate IMTA system to feed the world.

Different climatic, environmental, biological, physical, chemical, economic, historical, societal, political and governance conditions will lead to different choices in the design of the best-suited IMTA systems.

It is not enough to consider multiple species (like in polyculture); they have to be at multiple trophic levels, based on their complementary functions in the ecosystem. They should also have an economic value.

There is nothing that says that only one company should be in charge, producing all the IMTA components. There may need to be several companies coordinating their activities within the ICAM.

Need for enabling regulations instead of maintaining regulatory hurdles

It is time to open the Pandora's Box of regulations and develop new ones based on the recognition of the ecosystem scales at which aquaculture sites operate. It is interesting to note that the ICAM scale is already accepted for managing disease vectors and parasites. So, what is the hurdle to apply a comparable strategy for nutrients?

For IMTA to be developed, implemented and scaled up in Canada (and other jurisdictions) some seriously impeding regulations will need to be addressed and changed into enabling and flexible regulations, so that they do not continue to be unnecessary, hampering, regulatory hurdles.

Regulations governing aquaculture are often designed with a single species/group of species in mind, just like fishery regulations, and can inhibit a more holistic approach by not considering species interactions and an ecosystem-based management approach.

To move toward an ICAM approach to aquaculture, effective and coordinated regulations that enable new practices, new industries, new products and new markets will be needed:

- co-cultivated species infrastructures will need to be placed appropriately, not necessarily confined to the leased area of an existing finfish and/or shellfish site;
- different species, with different production cycles, will require the issuance of multi-species and multi-year licences; the concept of crop rotation and fallowing schemes will need to be revisited;
- interprovincial regulations will need to be harmonized, distinguishing between what has been historically implemented and what makes biological common sense;
- harmonization and coordination between provincial and federal regulations and between departments/agencies will also be necessary;
- the status of transportation of algal spores, animal spats and eggs between regions/provinces should be clarified;
- the process for water classification (protocol and delegation of authority for sampling) will need to be improved;
- as seaweed production increases and seaweed products are developed, seaweed regulations also need to be developed, proactively;
- the new Safe Food for Canadians Regulations (SFCR) will need to be amended, as it is, presently, completely silent on seaweeds; we cannot

continue to read in magazines “Seaweeds are the next superfood” and do nothing in our own “sea backyard”;

- the proposed Aquaculture Act will have to be skillfully prepared, avoiding the previous pitfalls of the obsolete *Fisheries Act*, especially regarding the monospecific approach to management, the lack of consideration of species interactions, and the lack of appreciation for a balanced ecosystem-based management approach to aquaculture.

It is important to engage regulators early on, as trends start to appear, so that regulations are well thought-out, instead of rushed at the last minute, which inevitably leads to delays in commercialization.

Conclusion

Moving IMTA along the Research & Development & Commercialization continuum, in Canada and the western world, will require profound regulatory changes. While it may be frustrating to witness how slow progress has been in recent years, it is important to remain patient, determined and persistent. Science and society need time to think and evolve. IMTA will not happen overnight, especially in the western world, which presently prefers monocultures, linear processes, and short term profits.

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IMTA = C_{at}IMTA + A_{na}IMTA AND THE LINK BETWEEN THE TWO TYPES OF IMTA IS AUTOTROPHIC ORGANISMS SUCH AS MACRO-ALGAE, MICRO-ALGAE AND AQUATIC PLANTS

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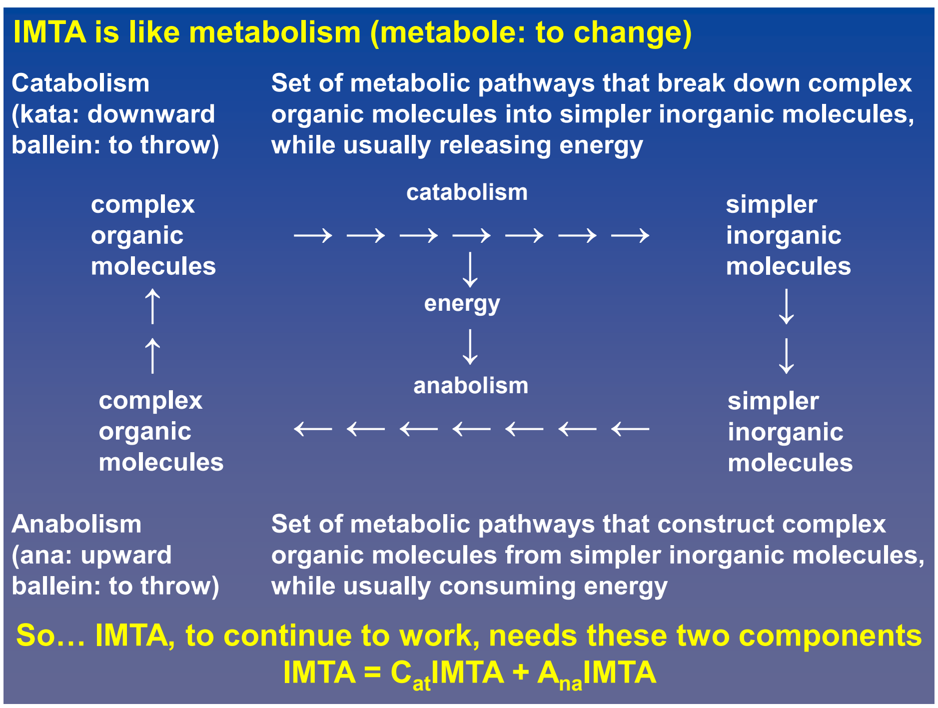

Figure 1
Integrated multi-trophic aquaculture (IMTA), like metabolism, is made of two parts: catabolic IMTA and anabolic IMTA. For an IMTA system to continue to operate, the two components need to work in a circular pattern.

Because of societal obsession with observable organic "waste" accumulation at aquaculture sites, and associated regulations, we risk not understanding the implicit need for integrated multi-trophic aquaculture (IMTA) to be circular.

To date, we have mostly focused on the catabolic (to throw downward, in Greek) aspects of IMTA: the set of ecosystemic and metabolic pathways that break complex organic molecules down to simpler inorganic molecules, while usually releasing energy (Fig. 1). This is, however, not "mission accomplished".

If we want IMTA to continue to operate (be sustainable), we have to compare it to a cascade, that continues to operate only if the natural cycle of water is occurring, or, in the case of an artificial cascade, if hydraulic systems have been engineered to send the water back up. So, some serious bio-engineering will also be necessary for IMTA to continue to operate.

If we, one day, succeed in developing very efficient catabolic IMTA systems, we could end up with a large amount of inorganic molecules, visually not easy to document, but potentially exceeding their levels of being beneficial nutrients and, then, be used by nuisance species.

Figure 2
The sugar kelp *Saccharina latissima* grown at a marine integrated multi-trophic aquaculture (MIMTA) site in the Bay of Fundy, New Brunswick, Canada (photo credit: Thierry Chopin).

Out of sight should not be out of mind. It is, consequently, very important to work on, understand and use efficiently the anabolic (to throw upward, in Greek) aspects of IMTA: the set of ecosystemic and metabolic pathways that construct complex organic molecules from simpler inorganic molecules, while usually consuming energy.

Receptors are needed for the inorganics generated by bioturbation and decomposition at the bottom. Only photosynthetic organisms have the ability to use solar energy to metabolize these inorganics back to organic molecules so that the cycle of life can continue to operate. The organisms capable of this conversion are cultivated, or naturally occurring, autotrophs, such as macro- and micro-algae and aquatic plants, which can form the crucial inorganic extractive component of IMTA (Figs. 2 and 3). Proper bio-engineering will be to select commercially opportune species instead of letting the nuisance, opportunistic, species prevail in the competition for nutrients.

Figure 3
Yarrow, mint, lettuce, chamomile and nasturtium grown for six weeks, in effluent collected at a commercial salmon hatchery, in the freshwater integrated multi-trophic aquaculture (FIMTA or aquaponics) pilot-scale system at the University of New Brunswick, Saint John, Canada (photo credit: Thierry Chopin).

It is important to put IMTA in its context of biologically inspired design, biomimicry, law of conservation of mass, circular economy and integrated coastal area management (ICAM), to understand its full long-term relevance and design appropriate regulations.

CONCLUDING REMARKS ON THE CANADIAN SEAWEED SYMPOSIUM HELD DURING THE AQUACULTURE CANADA & SEA FARMERS 2017 CONFERENCE, ON MAY 31, 2017

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Workshop summary

Global seaweed trends and markets were summarized during the symposium, demonstrating the versatility of the various products derived from farmed seaweeds for human and animal health and nutrition. Not only do they produce interesting compounds for medicine, health, nutrition of animals, they are increasingly consumed by humans as a vital source of essential nutrients around the planet. Seaweeds are increasingly employed in integrated multi-trophic aquaculture (IMTA) applications around the world, as environmental remediators, as ecosystem-service providers, and to improve the environmental performance of fed-aquaculture species. Farmed seaweeds are even being recognized as potential modulators of some of the impacts of climate change including ocean acidification, hypoxia and habitat alterations. As such, seaweeds and seaweed farming are really what must be considered a "green technology".

Seaweed cultivation is well established in Asia and needs little explanation/justification there. In the western world, a renewed interest in seaweed mariculture has been triggered by their cultivation in IMTA systems, the emerging understanding of the ecosystem services they provide, and the development of novel uses/applications.

Systematically, green, red and brown algae do not have much in common and are an unnatural (polyphyletic) grouping. They have very different life histories and, consequently, their culture techniques vary widely. Therefore, it is imperative to know the biology, physiology, biochemistry, etc. of these organisms very well before attempting their cultivation, as they are definitely not the “low-hanging fruits” of aquaculture.

Some Canadian producers have been leading the charge in terms of developing new products for markets in medicine and animal and plant health. A few producers are providing sea vegetable preparations for the local markets in Atlantic Canada and Québec, including a First Nations based operation. The farming of some seaweeds has received certification under the Canadian Organic Aquaculture Standards. However, the sector is still very much at a small scale, with niche market levels. The expansion of the sector will require future R&D&C (C for commercialization) to develop reliable “seed” sources (seaweeds do not produce seeds, but spores and gametes), "hatchery" [in fact, more appropriately, "spore-gametory" (see p. 6)] and farming operations, product development, and markets. There is interest in seaweed aquaculture in every coastal province of Canada; however, a variety of regulatory and research barriers exist and must be overcome in order to fully commercialize the industry.

Hopefully, as people in the western world begin to recognize the benefits seaweeds offer them and the environment, we will see the emergence of this aquaculture sector, in particular in Canada, instead of sitting on a missed opportunity. We cannot continue to read in magazines “Seaweeds are the next superfood” and do nothing in our own “sea backyard”.

Beyond the complexity of growing a new biomass, successful commercialization will depend on creating efficient logistics to move and process the biomass (who does what?), fully utilizing it as a resource, and choosing the right channels to enter and products to develop. It will be important to optimize the economic return on investment for all parties involved.

Conclusions and future research directions

A variety of seaweeds can be cultivated in Canadian waters on all coasts. Future efforts should focus on high-value food species, high-value extractive products from farmed seaweeds, market development for products, and removal of regulatory hurdles to allow seaweed farming to progress.

Future R&D&C directions are required in the following areas, to name a few:

- Development of reliable “seed” production in "hatcheries" ("spore-gametories") for a variety of species.

- Development of efficient methods for deployment of the seaweeds at aquaculture sites, cultivation, harvesting and processing.
- Continued evaluation of seaweeds as food/feed sources of proteins, carbohydrates, lipids and oils, pigments and essential nutrients (to humans, fish, invertebrates, ruminants and plants).
- Development of nutritional profiles for sea vegetables.
- Development of high-value nutraceuticals, prebiotics (gut microbial effects), probiotics, functional foods, cosmeceuticals, pharmaceuticals, etc. There is a dearth of clinical trials around seaweeds, even if there are many claims made about them (weight loss, skin effects, anti-inflammatory properties, anti-cancer properties, etc.).
- Development of new products and markets for farmed seaweeds. It will be important to evolve from a linear approach to move toward the integrated sequential biorefinery (ISBR) approach, in which there are no longer by-products, but co-products within a circular economy framework.
- Improvement of consistency and availability. The emerging niche, low volume and seasonal nature of the present small number of products makes consistency and availability of supply an issue at the local, regional and national levels (ultimately the international level).
- Increase education of the western consumer, who, generally, knows very little about seaweeds, their benefits (nutritional, environmental, etc.) and their possible inclusion in everyday diets. Marketing efforts may need to be substantial.
- Certification of seaweeds within existing standards [e.g. Canadian Organic Aquaculture Standards, Seaweed Standard of the Aquaculture Stewardship Council (ASC) and the Marine Stewardship Council (MSC)] and increased traceability.
- R&D on, and valuation of, the benefits (ecosystem services) of seaweeds and their role as coastal marine environmental health modulators in a changing climate. These services should be appropriately valued and used as financial and regulatory incentive tools.
- Removal of the regulatory barriers to seaweed farming by inclusion of seaweeds in a variety of amendments to federal and provincial regulatory frameworks, policies and programs (e.g. Safe Food for Canadians Regulations, Canada’s Food Guide, Canadian Shellfish Sanitation Program, Introductions and Transfers, *Fisheries Act*, proposed Aquaculture Act, etc.). In the western world, the chance of success in the development of seaweed farming seems to be increased if considered as part of IMTA projects, instead of a standalone activity, within an integrated coastal area management (ICAM) strategy, which, in many places, remains to be designed and put in place.

- Harmonization and coordination between provincial and federal regulations, and between departments and agencies, will be key to remove current hampering regulatory hurdles and put in place regulatory changes enabling the development and implementation of innovative aquaculture practices, such as IMTA (both the catabolic and anabolic parts), and the diversification of the aquaculture industry in Canada beyond what is overwhelmingly fish aquaculture.

The Aquaculture Association of Canada is now accepting nominations for **2018 Lifetime Achievement Award**. Details on how to nominate someone for this award can be found on our website here http://www.aquacultureassociation.ca/awards/research-award-of-excellence/research-award-of-excellence-nominations/. Please send your nomination and supporting letters to Matthew Liutkus, Chair of the AAC Awards Committee at aacawards@gmail.com. The deadline for nominations is **March 16, 2018**.