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Land Based Multi-trophic Aquaculture Research at the Wave Energy Research Centre

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***Abstract*—The collapse of the Atlantic cod fishery in the 1990s devastated the economies of many coastal Newfoundland communities. While many have survived through a combination of a much reduced fishery, government funding, and off shore or out of province employment, none of these are sustainable long-term solutions. Sea-based aquaculture ("fish farming" in pens) has provided stable employment in some areas, but only where there are suitable sites with protected, deep inlets with significant tidal or river current flushing. These geographic characteristics are not usually compatible with prosecuting the inshore fishery. Sites that were close to the open fishing grounds with minimal near shore currents were prized by the small boat fishers, but wind and wave protection were a secondary concern. Thus there are many towns and villages that are significant distances from ideal sea-based aquaculture sites.**

While shore-based aquaculture would be possible in many coastal villages, the profitability of the industry is limited by the cost of pumping water to and through the shore based infrastructure. Many existing coastal settlements do have an abundance of energy available in ocean waves. The harnessing of this energy to pump water on shore at low cost will enable the development of profitable shore based aquaculture methods that will provide sustainable long-term economic activity for these communities. Shore-based aquaculture has the additional possibility of containing and directing effluent from the production on one species to another that can use it as a feed source (e.g., fish effluent delivered to filter feeders). This effectively "biofilters" the fish production effluent while producing other marketable product (scallops and seaweed, for example) at little or no extra cost.

This paper reports on a research project being conducted by College of the North Atlantic (CNA) in Lord's Cove, Newfoundland, which has the overall goal of developing a sustainable land-based aquaculture system utilizing wave energy.

Development of the pump is occurring concurrently with the design, installation and commissioning of a pilot cascaded Integrated Multi-trophic Aquaculture (IMTA) facility in Lord's Cove. In this pilot farm, the effluent from the finfish (the only organisms receiving external feed input) is directed to sea urchin production tanks. From there, water flows to scallop production tanks and finally algae culture. The algae produced is fed to the urchins, who consume this and organic sediment coming from the finfish. The suspended organic particulate in the urchin effluent will nourish the sea scallops, and the algae will reduce the dissolved inorganic load before the water is returned to the ocean (Fig. 1). Until the wave pump development is complete, water for the farm is being entirely supplied by electric pumping.

We are currently undergoing scale model and sea based prototype testing of the wave driven pump. As part of the design process for this pump, the wave energy resource and bathymetry at the site was measured and documented. As a result of these activities, CNA now operates the Wave Energy Research Centre (Fig. 2). This facility is now permitted for testing of wave energy absorbers and similar devices: it includes data acquisition (wave environment, weather and device performance monitoring) as well as the necessary infrastructure to support these studies and is ready to host other device developers.

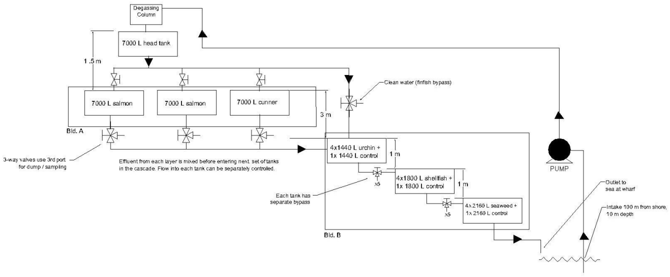

Fig. 1. Water flow schematic of pilot cascaded IMTA facility in Lord's Cove.

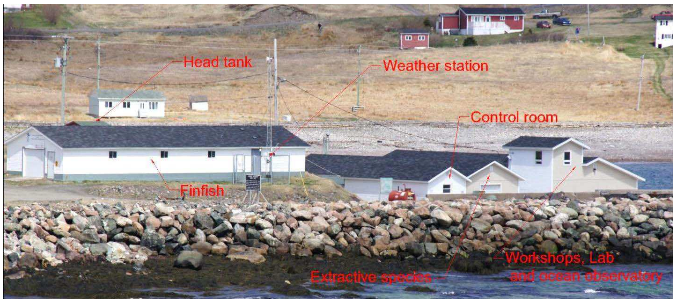

Fig. 2. The Wave Energy Research Centre in Lord's Cove.

Keywords—aquaculture, wave energy, integrated multi-trophic aquaculture, IMTA

I. INTRODUCTION

Aquaculture, the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants is the fastest growing food production sector in the world. Global fish production continues to outpace world population growth; in 2012, marine capture fishery was stable at 80 million tonnes, while aquaculture was at 90 million tonnes [1]. World aquaculture production continues to grow and now provides almost half of all fish for human consumption [1]. In 2013, the Newfoundland and Labrador aquaculture industry reached record levels of production and market value for the second year in a row. The 2013 market value for provincial aquaculture increased to over $180 million (CAD), representing a rise of 50 per cent over the 2012 value which exceeded $120 million [2].

The majority of the operations in North America are monoculture (single species) industries. The environmental impacts of traditional sea based aquaculture are multifaceted and not completely understood. Various studies have shown that during monoculture of carnivorous species, 85 percent of phosphorous (P), 80 to 85 percent of carbon (C) and 52 to 95 percent of nitrogen (N) feed input may be lost into the environment through feed wastage, fish excretion, feces production and respiration [3]. A recent study found that of the total feed input, 70% C, 62% N and 70% P was released into the environment [4]. Feed accounts for about half of the cost in this type of aquaculture, yet over half of the feed becomes waste, leading to environmental impacts and rising feed costs, thus hampering industry expansion [5].

These problematic water quality issues may induce stress on the farmed organism, while successive years of farming may lead to the development of eutrophic zones beneath the net pens, significantly deteriorating the quality of the site, inducing more stress on the farmed organisms. Continued pressure from environmental groups and non-governmental organizations will eventually force aquaculture operations to treat and/or minimize their waste to achieve recommended water quality standards in effluent or surroundings. Regardless of the farm system employed, this is necessary if the aquaculture industry is to prosper and expand into an environmentally sustainable industry. There is no simple solution to this problem, but an avenue currently receiving research attention is the use of extractive species as “biofilters”. Biofilter technology reduces pollutant loading in the environment, increases biomass production and improves water quality.

College of the North Atlantic (CNA) is developing the Wave Energy Research Centre (WERC) in Lord’s Cove, on the south coast of Newfoundland: it includes an aquaculture centre being developed in parallel with an ocean wave-powered supply pump. The goal is to develop a sustainable land-based aquaculture system utilizing wave energy. This paper describes the aquaculture methods used at the centre and the progress to date on the wave pump.

II. INTEGRATED MULTI-TROPHIC AQUACULTURE

Polyculture utilizes the waste products from the primary farmed species to increase productivity of supplemental species, thereby increasing economic efficiency and reducing environmental impacts [6]. Integrated multi-trophic aquaculture (IMTA) is the modern offspring of traditional aquatic polyculture [5]. The principle concept is that the energy and nutrients unused by single species culture of fed organisms are in readily useable forms for use by other economically valuable extractive aquatic organisms. The environmental and economic consequences of this approach are better understood when the organisms are categorized into fed and extractive species [7]. Fed organisms are nourished by feed: shrimp, salmon and halibut are all examples. Extractive organisms extract nourishment from their environment. For example, scallops utilize suspended organic particles while algae utilize dissolved inorganic nutrients to build their biomass.

Integrated aquaculture allows intensive management of several species of fed and extractive organisms, all connected by nutrient transfer through water [7]. Ideally, extractive species in an IMTA system will be marketable, representing another source of revenue for the operation [8].

All aquaculture is based on an underlying requirement for a clean environment for two very practical reasons. First, the product must meet high standards of quality for human consumption; second, production is highest when environmental stress to the cultured organism is minimal. As aquaculture operators are forced to internalize the cost associated with ecological sustainability, IMTA will increase the economic potential of the farm while performing bioremediation.

Polyculture systems have been in use for centuries, with successful stocking ratios determined mainly through trial and error for co-habitation relationships within ponds or marine net pens. Fish effluents produced by land-based systems are easier to treat than those from open systems [9]. Study at a land based IMTA facility revealed that 63 percent of the nitrogen in the feed can be harvested, 26 percent as fish yield, 14.5 percent as bivalve yield and 22.4 percent as seaweed yield [3]. Land based IMTA will not be economically viable if the secondary biomass production does not add to the overall economic value of the farm.

III. THE WAVE ENERGY RESEARCH CENTER

In September 2011, the CNA Burin Campus was awarded a College-Community Innovation – Innovation Enhancement (CCI-IE) grant from the Natural Sciences and Engineering Research Council (NSERC) and additional funding from the Research and Development Corporation of Newfoundland and Labrador (RDC) to develop a wave-powered pump coupled to a shore based IMTA farm. The research resulted in the establishment of the CNA Wave Energy Research Centre (WERC) in Lord’s Cove, Newfoundland and Labrador, in 2011. The WERC pilot farm is designed to demonstrate the viability of cascaded IMTA in an open flow-through tank system while taking advantage of the reduced costs of pumping provided by the wave powered pump.

The shore facilities at the WERC consists of four buildings on or near the wharf (Fig. 2 in abstract), including 180 square metres for finfish production, 240 square metres for extractive species production, with the remaining space occupied by offices, labs and workshops.

Ocean water is currently pumped into the facility from 120 metres offshore at a 10-metre depth using one of three redundant electric pumps. The water is filtered to 200 microns before passing through a degassing column on the way to a 7000-litre header tank. The finfish building houses three 7000-litre cylindrical tanks, while the extractive building contains fifteen 2000-litre rectangular tanks. In addition to redundancy provided by the three electric pumps the site has a gas powered pump and an emergency water intake line. The site is equipped with an emergency back-up power supply sufficient to run the farm and data acquisition equipment and high speed data connections allowing off-site monitoring and control of equipment.

The site is plumbed so that, once water is delivered to the header tank, it flows by gravity through successive layers of cascaded tanks, allowing the effluent from one layer to be the feed water for the next (Fig. 1 in abstract). Clean sea water is delivered directly to the finfish and (optionally mixed with finfish effluent) to the sea urchin tanks. If necessary, the effluent from the finfish can bypass the extractive species (e.g., in case of disease or drug treatment). Effluent from each layer is thoroughly mixed in a common head pipe before being directed through a valve system to either bypass or enter the next tank layer. The effluent from the finfish (the only organisms receiving external feed input) carries uneaten feed, and organic and inorganic waste. The algae produced is fed to the urchins, who consume this and organic sediment coming from the finfish. The suspended organic particulate in the urchin and finfish effluent will nourish the sea scallops, and the algae will reduce the dissolved inorganic load before the water is returned to the ocean. This IMTA approach maximizes the conversion of feed into marketable product while ensuring that the effluent from the farm contains a minimum load of organic and inorganic material. Integrating economically valuable extractive species will increase the value of the farm output without any increase in feed cost.

A wave-powered pump is being designed in collaboration with the National Research Council of Canada for local sea conditions to reduce the electrical cost of pumping water up to the header tanks. The first prototype is in the full scale design and fabrication stage and will be tuned to the most common wave periods observed in the first year of operation. Other wave pumps tuned to different waves may be added at any of six mooring sites at Lord's Cove that have been approved under the Canadian Navigable Waters Protection Act.

IV. FINFISH

The fish farm was commissioned in September 2012, and 20 cunners, *Tautogolabrus adspersus*, were introduced into a finfish tank in January 2013 to test the system. The cunners thrived: by October 2013 we had sufficient confidence in the system operations to add 387 Atlantic salmon, *Salmo salar*, to the two additional tanks. We had 26 salmon die in the first 14 days. We attributed this mainly to stress from the 12-hour transfer from Northern Harvest in Stephenville to the WERC in Lord's Cove. Over the next 2.5 months only four salmon were lost. The salmon settled in well and started feeding nicely consuming 0.75 grams of feed per day per fish.

A number of storms in late December and early January forced us to shut the pumps down for safety reasons (high seas causing flooding of mechanical rooms and filter service area), stopping flow in the finfish tanks. During that same time, the finfish tank temperature fell to between 0° and 1° Celsius and the salmon feed consumption was reduced to 0.30 grams per day per fish; the fish ceased feeding by early February. These circumstances may have contributed to an increase in mortality, 23 morts in January and 33 in February. With the cold tank temperatures, salmon not being fed, intake temperature around -1° Celsius and increasing mortality rate, a decision was made to reduce flow to maintain tank temperature above 4° Celsius on February 10, 2014. Cunners appeared to be able to tolerate these cold temperatures in a torpid state.

The water flow was increased in mid-April, maintaining a tank temperature above 4° Celsius, and feeding resumed on April 24, 2014. March and April saw a reduction in mortality rate and only 10 morts were reported. Since feeding was resumed, there have been no mortalities reported and the salmon were consuming 2.0- 2.5 grams of feed per day per fish by early July 2014 (Fig. 3).

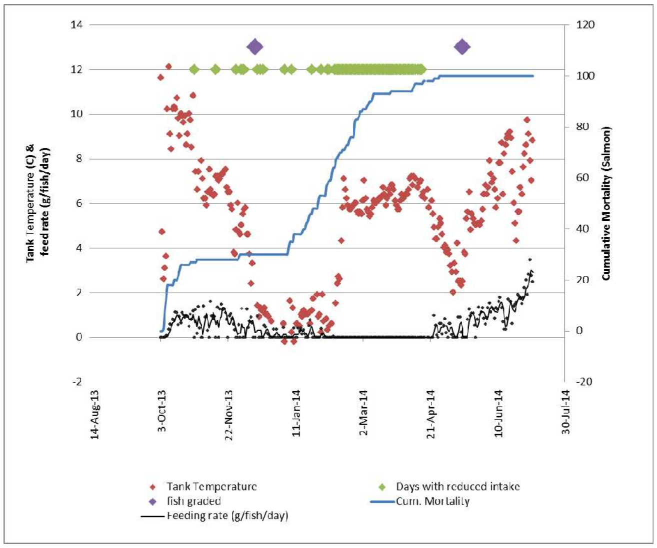

Fig. 3. Farm environmental data, salmon feeding rate and mortality during the 2013-2014 winter. The "feeding rate" line is a 3-day running mean; points are daily feed amounts. Salmon were fed to satiation.

The salmon averaged about 70 to 80 grams per fish when purchased from Northern Harvest Sea Farms in October; in December, 40 fish were sampled and the average mass of those fish was 123.2 grams per fish. On May 15, 2014, the salmon where graded with 150 grams as the grading value: 100 salmon above 150 grams had an average mass of 184 grams per fish and 182 salmon below 150 grams had an average mass of 127 grams.

The amount of waste produced from 41 kilograms of fish (282 salmon at 147 gram per fish average) is relatively small and will not support a large number of extractive organisms. On June 18, 2014, 184 cunners were transferred from Department of Fisheries and Oceans in St. John's to the WERC in Lord's Cove. As of July 2014, the site has 201 cunners, consuming 1.5-2.5 grams of herring per fish. We expect that these fish will significantly increase and diversify the nutrient content in the finfish effluent.

V. BIOFILTERS

The WERC incorporates a chain of organisms as biofilters. If an additional commercially important species that will consume the solid fish waste is added to an IMTA system, the economic potential of the culture is further increased and environmental impact drops. The goal is to create a self-sustaining, simplified food chain so that each organism lives and grows off of the waste products of another [10]. The species in our system at the WERC were selected to conform to recommendations of Barrington et al. 2009 [11]: in particular, these are local species with market value having complementary trophic levels and consuming dissolved, suspended and sedimentary nutrients.

The extractive species identified for trial at the WERC include: the green sea urchin, *Strongylocentrotus droebachiensis*, the sea scallop, *Placopecten magellanicus*, a brown alga, *Laminaria digitata*, a red alga, *Palmaria palmata*, and a green alga, *Ulva lactuca*.

Sea urchin gonads (about 20 percent of the total biomass) have high market value and are considered a delicacy in Japan and many other countries around the world. There is currently a demand that is not being met [12].

The green sea urchin is a benthic omnivore grazer, and is commonly associated with Laminarian kelps. At high densities the urchins destructively graze on the kelp beds. At 10° Celsius a medium sized sea urchin (60 grams) will consume 0.4 to 0.5 grams feed per urchin per day [13]. A recent study found that sea urchins consumed any solid waste produced by cunners, *Tautogolabrus adspersus*, resulting in increased growth of the urchins [14]. In addition to consuming waste feed and fish feces, urchins eat kelp species that can be grown in the same system, which again cuts costs and boosts profit.

Sea urchins performed best at a stocking density of 116 urchins per square metre, provided sufficient nutrition exists [15]. Our sea urchin tanks are 4 square metres, theoretically we have enough physical space to hold 464 urchins per tank, 1856 urchins in total. Although we have space for 1800 to 1900 urchins, we are unsure of neither the nutrient availability from the finfish effluent nor the growth rate of the algae in our system. This number of urchins would require 1 kilogram of feed per day. In July 2014, 600 sea urchins were added to four tanks, giving a density of 37 urchins per square metre. If there is surplus feed, the density can be increased.

Sea scallops are benthic suspension feeding bi-valves: in nature they are exposed to a food supply that fluctuates unpredictably in both quantity and quality. Scallops are known to consume sestons ranging in size from 2 to 60 microns. Scallops will benefit from the diverse suspended particles in the effluent – salmon feed, salmon faeces, cunner feed, cunner faeces, sea urchin faeces and waste algae from the sea urchins [16]. A recent study showed that about 19% of feed C, 15% of feed N and 44% of feed P were released as particles from a salmon farm [4].

In nature, scallops are randomly spaced, 5 to 15 cm apart [17]. Our tanks will accommodate 500 scallops, leaving room for growth. If there is insufficient feed in the effluent stream, suspended algae particles will be added as supplemental feed.

Studies have shown that algae growth is limited by the amount of inorganic nutrient in the water. However, if algae were grown in an integrated system with finfish and sea urchins, there would be plenty of dissolved inorganic nutrients. Increased growth rates of kelps (46 percent [18]) and mussels (50 percent [19]) cultured in proximity to fish farms, compared to reference sites, reflect the increase in food availability and energy [11]. A recent study showed that around 40% of feed C was respired as carbon dioxide, and 39% of feed N and 24% of feed P were excreted as dissolved inorganic nutrients from a salmon farm [4].

In IMTA systems, algae are very useful as biological filters, absorbing and utilizing nitrogenous fish wastes to perform photosynthesis [20]. Many different species of seaweeds can be used in an aquaculture system but *Porphyra yezoensis*, *Chondrus crispus* and certain kelps (*Saccharina latissima* and *Laminaria digitata*) are considered ideal because of their tough morphology and ease of production [21].

A brown alga, *Laminaria digitata*, a red alga, *Palmaria palmata*, and a green alga, *Ulva lactuca*, were added to the WERC pilot farm in July 2014. The species that grows best under our local conditions will be identified. Production of all three species may continue, as each species may thrive at different temperatures and conditions throughout the year. Three species of algae will also diversify the diet of the sea urchins making it more representative of a natural diet.

Light is supplied by 32-Watt, 5000 Kelvin white T8 fluorescent lamps with a 16-hour light, 8-hour dark photoperiod.

With the addition of algae to a land based IMTA farm, it has been shown that a farm can operate successfully at 50 percent re-circulation, and even higher recirculation (up to 100 percent) can be sustained for shorter periods [11]. The re-circulation through seaweed tanks/ponds also has the potential to raise water temperature, which may be beneficial during our cold winters.

VI. CLOSING REMARKS

Under normal circumstances the sea water intake at the farm provides adequate service, but certain weather conditions can cause suspension of large amounts of sediment and seaweed. This suspended material rapidly restricts flow at our intake filters. During winter, intake water temperatures at the WERC have reached as low as -1.5° Celsius for several weeks.

Recirculation can solve these problems in a land based IMTA facility, but it is energetically expensive: unless significant investments are made in sterilization equipment, it runs the risk or re-introducing (and therefore concentrating) any disease agents that may be present in the system. Although recirculation should be avoided on the basis of these economic and biological arguments, there will be times when the only alternative is to let the water become stagnant or too cold. Both of these situations will result in a far higher likelihood of increased mortality.

In the winter of 2013-2014, we were successful in reducing mortality by implementing small scale recirculation during periods of extremely cold water. It should be noted that we continued to add clean sea water to the system, but at a much reduced rate. This reduced water exchange rates from approximately 15 changes per day to 1 change per week.

The WERC pilot farm commissioning is nearly complete. There is no doubt that there is room to improve feed conversion to maximize yield of marketable product. In the short term, we will attempt to identify areas where there is excess or insufficient nutrition and use this information to modify the stocking density and species composition.

Our goal is to provide a design for an easily manufactured and commissioned, cold water, wave-powered, land based IMTA system. This system would produce economically viable extractive species without any extra feed inputs and minimal energy costs.

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REFERENCES

[1] FAO, 2014. The state of World Fisheries and Aquaculture 2014.

[2] Government of Newfoundland and Labrador, Department of Fisheries and Aquaculture News Release, January 2, 2014.

[3] Wu, R. S. S., 1995. The Environmental Impact of Marine Fish Culture: Towards a Sustainable Future. Marine Pollution Bulletin. Vol.31, Nos. 4 – 12, pp. 159 -166.

[4] Wang X, Olsen LM, Reitan KI, Olsen Y (2012) Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. Aquacult Environ Interact 2: 267?283

[5] Neori, A., et al., 2007. The need for a balanced ecosystem approach to blue revolution aquaculture. Environment. Vol 49 pp36-43.

[6] Lutz, G. C., 2003. Principles of Polyculture. Aquaculture Magazine. Vol. 29 n. 1, pp. 34 – 39.

[7] Chopin, T., et al. 2001. Integrating seaweeds into marine aquaculture systems: A key toward sustainability. Journal of Phycology. Vol. 37 pp. 975 – 986.

[8] Reid, GK., et al, 2008. A review of the biophysical properties of salmonid faeces. Aquacuture Research.

[9] Seymour, E. A., A. Bergheim, 1991. Towards a reduction of pollution from intensive aquaculture with reference to farming of salmonids in Norway. Aquacultural Engineering. vol. 10 issue 2 pp 73 – 88.

[10] Chopin, T. 2006. Integrated Multi-Trophic Aquaculture. What it is and why you should care… and don't confuse it with polyculture. Northern Aquaculture 12 (4): 4.

[11] Barrington, K., Chopin, T. and Robinson, S. 2009. Integrated multi-trophic aquaculture (IMTA) in marine temperature waters. In D. Soto (ed.). Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. No. 529. Rome, FAO. Pp 7-46.

[12] Robinson, S.M.C. 2004. The evolving role of aquaculture in the global production of sea urchins. In: Sea Urchins – Fisheries and Ecology: Proceedings of the International Conference on Sea Urchin Fisheries and Aquaculture, Puerto Varas, Chile, March 25-27, 2003: 343-358. J.D. Lawrence (ed.). DEStech Publications Inc., Lancaster.

[13] Siikavuopio, S.I., 2009. Green Sea Urchin in Aquaculture: the effects of environmental factors on gonad growth. University of Tromso.

[14] Baldwin, R., Siskey, M., Intergrated Multi-Trophic Aquaculture, University of New Hampshire 2011.

[15] Dagget, T.L., et al. 2006. Containment systems for cultured Sea urchins. Aquaculture Research, 37, pp 339-350.

[16] MacDonald, B. A., & Ward, J. E. 1994. Variation in food quality and particle selectivity in the sea scallop Placopecten magellanicus. Marine Ecology Progress Series 108: 251-264

[17] Mackenzie, C. L. 2008. The Bay Scallop, Argopecten irradians, Massachusetts Through North Carolina: Its Biology and the History of Its Habitats and Fisheries. Marine Fisheries Review 70(3-4): 5-79

[18] Chopin, T., Robinson, S., Sawhney, M., Bastarache, S., Belyea, E., Shea, R., Armstrong, W., Stewart, I. & Fitzgerald, P. 2004. The AquaNet integrated multi-trophic aquaculture project: rationale of the project and development of kelp cultivation as the inorganic extractive component of the system. Bulletin of the Aquaculture Association of Canada 104 (3): 11-18.

[19] Lander, T.R., Barrington, K.A., Robinson, S.M.C., MacDonald, B.A. & Martin, J.D. 2004. Dynamics of the blue mussel as an extractive organism in an integrated multitrophic aquaculture system. Bulletin of the Aquaculture Association of Canada 104 (3): 19-28.

[20] Chopin, T. 2006. Integrated Multi-Trophic Aquaculture. What it is and why you should care… and don't confuse it with polyculture. Northern Aquaculture 12 (4): 4.

[21] Carmona, R., Kraemer, G.P., & Yarish, C. 2006. Exploring Northeast American and Asian species of Porphyra for use in an integrated finfish-algal aquaculture system. Aquaculture 252: 54-65.