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Proceedings

Joy Wade, Tim Jackson, Kathy Brewer Co- Editors

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Introduction from the President

The Aquaculture Canada Conference was held in St. Andrews, NB from June 1st to 4th, 2014 and represented the 30thAnniversary for the Aquaculture Association of Canada. As such, the theme for the conference was "AAC 30th Anniversary – Excellence in Research & Innovation". There were 325 delegates from Canada and countries around the world. Through 118 presentations, spanning 11 sessions, the conference highlighted the research excellence and innovation within the aquaculture industry over the past 30 years and the tremendous economic potential for Canada.

We would like to thank Fisheries and Oceans for supporting the Aquaculture Environment Monitoring Workshop and Climate Change Symposium via the Aquaculture Collaborative Research and Development Program (ACRDP). The proceedings provide an opportunity for presenters to showcase their work in a non-peer reviewed format. This allows for more flexibility in content and subject matter. Information which would not necessarily be shared formally can be presented in the proceedings to a wide audience.

Shelley R. King, President

AAC 30th Anniversary – Excellence in Research & Innovation

30e anniversaire de l'AAC - L'excellence dans la recherche et l'innovation

June 1-4, 2104

St. Andrews, New Brunswick

Contributed Papers

VALUE ADDED PRODUCTS FROM SEA SCALLOPS: TRANSFER OF KNOWLEDGE FROM FISH HARVESTERS

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Abstract

Non-conventional value-added products of sea scallops (*Placopecten magellanicus*) were produced: female gonads, male gonads and mantles canned in brine. Analyses of the nutritional content and heavy metal levels of products were conducted by the coastal Zone Research Institute Inc. Protein and omega-3 fatty acids are found in all three products. The products were prepared in brine resulting in relatively high sodium levels (170g to 300g/55g). Analyses of heavy metals showed high levels of beneficial minerals such as calcium, magnesium, potassium and zinc. Observed levels of harmful heavy metals were safe for human consumption based on Health Canada guidelines.

Introduction

Traditionally, New Brunswick (NB) scallop harvesters in Chaleur Bay, would bring whole sea scallops (*Placopecten magellanicus*) home and can the gonads and mantles in brine. This practice had to be curtailed when shucking wild scallops at sea became a requirement. Pétoncle Chaleur Scallop Ltée, an incorporated group of fish harvesters from Chaleur Bay, received development funds from the province of New Brunswick for various projects. One of the projects was to investigate the marketability of these non-conventional yet locally traditional value-added products from sea scallops.

Materials and Methods

Working under a "license to fish for scientific purposes", scallop harvesters selected live scallops with a shell height greater than 80 mm to bring back to the shore. Using their local canning recipe (Table 1), they produced about 30 jars of each of the following value added products: 1) male gonads (white) 2) female gonads (pink), and 3) mantles (Figure 1).

Table 1. Chaleur Bay scallop harvesters' traditional canning recipe.

Recipe for canning scallop gonads and mantles
1. Remove, separate and rinse the mantle, the pink and the white gonads
2. Place the mantles, pink and white gonads in separate sterilized jars
3. Add a pinch of salt to each jar
4. Seal the jars
5. Place jars in pressure cooker with 4.5 kg pressure
6. Cook for 1.5 hours

The jars of the value-added products were then brought to the Coastal Zones Research Institute Inc. (CZRI) in Shippagan, NB where the nutritional value and heavy metal levels of the each of the value-added products were analysed. Also, a label outlining nutritional value was created for each product.

Figure 1. Sea scallop value added products: 1) male gonads (white) 2) female gonads (pink), and 3) mantles.

Results

The nutritional values and heavy metal levels of the each of the value-added products can be found in Tables 2 and 3. The nutritional labels produced by the CZRI based on their laboratory analysis of the three value-added products, can be found in Figure 2.

Table 2. Nutritional value of the female (pink) and male (white) gonad and mantle canned in a brine solution.

Analysis	Female scallop gonad in brine		Male scallop gonad in brine		Scallop mantle in brine	
	Amount per 55 g	% Daily Value	Amount per 55 g	% Daily Value	Amount per 55 g	% Daily Value
Calories	70	---	60	---	40	---
Fat	3.0 g	5 %	1.0 g	2 %	0.3 g	0 %
Saturated	0.5 g	3 %	0.2 g	1 %	0.1 g	1 %
Trans	0 g		0 g		0 g	
Polyunsaturated	1.5 g	---	0.5 g	---	0.2 g	---
Omega - 6	0.1 g	---	0 g	---	0 g	---
Omega - 3	1.5	---	0.4 g	---	0.2 g	---
Monounsaturated	0.5 g	---	0.1 g	---	0 g	---
Cholesterol	20 mg	---	30 mg	---	30 mg	---
Sodium	300 mg	13 %	260 mg	11 %	170 mg	7 %
Carbohydrate	1 g	0 %	1 g	0 %	1 g	0 %
Fibre	0 g	0 %	0 g	0 %	0 g	0 %
Sugars	1 g	---	1 g	---	1 g	---
Proteins	10 g	---	13 g	---	9 g	---
Vitamin A	---	0 %	---	0 %	---	0 %

Vitamin C	---	0 %	---	0 %	---	0 %
Calcium	---	0 %	---	0 %	---	2 %
Iron	---	30 %	---	20 %	---	2 %

Table 3. Heavy metal levels in the female (pink) and male (white) gonad and mantle canned in a brine solution.

Analysis	Lowest detectable amount	Female scallop gonad in brine	Male scallop gonad in brine	Scallop mantle in brine
	mg /kg			
Aluminum (Al)	0.2	56.6	35.4	4.1
Antimony (Sb)	0.02	ND	ND	ND
Arsenic (As)	0.2	2.0	1.2	0.5
Barium (Ba)	0.2	0.4	0.2	0.5
Beryllium (Be)	0.02	ND	ND	ND
Bismuth (Bi)	0.2	ND	ND	ND
Boron (B)	0.2	3.1	3.4	1.3
Cadmium (Cd)	0.002	0.393	0.136	0.237
Calcium (Ca)	5	184	101	261
Chromium (Cr)	0.2	0.2	ND	ND
Cobalt (Co)	0.02	0.05	0.04	0.02
Copper (Cu)	0.2	3.3	0.9	0.4
Iron (Fe)	1	73	46	7
Lead (Pb)	0.02	0.27	0.13	0.02
Lithium (Li)	0.02	0.11	0.07	0.03
Magnesium (Mg)	1	571	543	373
Manganese (Mn)	0.2	5.6	1.8	0.4
Mercury (Hg)	0.01	ND	ND	0.01
Molybdenum (Mo)	0.02	0.04	0.03	0.03
Nickel (Ni)	0.2	ND	ND	ND
Potassium (K)	5	3,260	4,550	716
Rubidium (Rd)	0.02	1.48	1.86	0.25
Selenium (Se)	0.2	0.9	0.4	0.4
Silver (Ag)	0.02	0.02	0.02	0.05
Sodium (Na)	5	5,240	4,740	3,050
Strontium (Sr)	0.2	4.1	2.2	3.6
Tellurium (Te)	0.02	ND	ND	ND
Thallium (Tl)	0.02	ND	ND	ND
Tin (Sn)	0.02	0.16	0.14	0.06
Uranium (U)	0.02	ND	ND	ND
Vanadium (V)	0.2	ND	ND	ND
Zinc (Zn)	0.2	77.4	9.4	15.8

Female scallop gonad in brine		Male scallop gonad in brine		Scallop mantle in brine	
Nutrition Facts Per 55 g		Nutrition Facts Per 55 g		Nutrition Facts Per 55 g	
Amount	% Daily Value	Amount	% Daily Value	Amount	% Daily Value
Calories 70		Calories 60		Calories 40	
Fats 3.0	5%	Fats 1.0	2%	Fats 0.3	0%
Saturated 0.5 g + Trans 0 g	3%	Saturated 0.2 g + Trans 0 g	1%	Saturated 0.1 g + Trans 0 g	1%
Cholesterol 20 mg		Cholesterol 30 mg		Cholesterol 30 mg	
Sodium 300 mg	13%	Sodium 260 mg	11%	Sodium 170 mg	7%
Carbohydrate 1 g	0 %	Carbohydrate 1 g	0 %	Carbohydrate 1 g	0 %
Fibre 0 g	0 %	Fibre 0 g	0 %	Fibre 0 g	0 %
Sugars 1 g		Sugars 1 g		Sugars 1 g	
Protein 10 g		Protein 13 g		Protein 9 g	
Vitamin A 0 %	Vitamin C 0 %	Vitamin A 0 %	Vitamin C 0 %	Vitamin A 0 %	Vitamin C 0 %
Calcium 0 %	Iron 30 %	Calcium 0 %	Iron 20 %	Calcium 2%	Iron 2 %

Figure 2. Nutritional labels of the three value added products: Female scallop gonad, male scallop gonad and scallop mantle in brine.

Discussion

Harvesters from Pétoncle Chaleur Scallop Ltée that conducted this project had participated in scallop aquaculture studies (Nowlan *et al*. 2011) that had just ended. In that study the economic evaluation was based on the sale of meats only. Since they had traditionally canned scallop gonads and mantles, they projected that developing a cottage industry to utilise the gonads and mantle could increase the economic value of culturing scallops and of their scallop fishery. Therefore knowing the nutritional value of the value-added products and the level of heavy metals were important to determine the marketability of the products.

Female gonads, male gonads and mantles contained similar amounts of protein: 10, 13 and 9g/55g respectively. Omega-3 fatty acids are found in all three products. Products were in brine so it is not surprising that sodium is 7-13% of the daily value but normally the brine, as such, is not consumed. With respect to the analysis of heavy metals, beneficial minerals such as calcium, magnesium, potassium and zinc were found. The observed levels of harmful heavy metals were safe for human consumption. Mercury was not detected in two of the three products and the level in the third product, 0.1mg/kg is considerably lower that the Health Canada's Guidelines of 0.5/kg (http://www.hc-sc.gc.ca/fn-an/securit/chem-chim/contaminants-guidelines-directives-eng.php#guidelines). Arsenic levels, 2 mg / kg are relatively low according to Health Canada which cites arsenic level ranges from 0.4 to 118 mg / kg in marine fish sold for human consumption in Canada (http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/arsenic/index-

eng.php#a1). The World Health Organization has proposed a maximum tolerable weekly intake of cadmium of up to 8.3 mg / kg of the weight of the person (http://www.healthyeatingclub.com/info/books-phds/books/foodfacts/html/data/data5v.html). Observed cadmium levels (0.393 mg/kg) fell below Canadian guidelines and were low enough to permit sale in Europe. Presently, Pétoncle Chaleur Scallop Ltée aquaculture activities have terminated, but the results of their investigations are both useful and encouraging to other aquaculturists interested in the culture of sea scallops.

Acknowledgements

The funds for this project were provided by the province of New Brunswick (Restigouche-Chaleurs development funds). The work of Gabriel Guitard and Yvon Arseneau, members of the Pétoncle Chaleur Scallop Ltée, who directed the project, was exceptional. A special thanks to Jeannine Boucher for preparing the value added products. Jeannine also participated in harvesting the scallops with Yvon Arseneau. Also, our sincere gratitude is given to Nadejda Tchoukanova, director of laboratories and testing services at the Coastal Zones Research Institute Inc (CZRI) in Shippagan, NB for the analysis of the samples.

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IN-VITRO ASSESSMENT OF DIGESTIBLE PROTEINS IN AQUAFEED: FINDING AN EFFECTIVE ALTERNATIVE TO PROTEASE ACTIVITY ASSAYS

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Abstract

In-vivo studies are not a practical part of the QA/QC process therefore enzyme activity assays are commonly used to evaluate protease enzyme activity. However, these methods display limitations such as high sensitivity to exogenous factors. This study aimed at developing two alternative *in-vitro* techniques comparing digestibility and total soluble amino acid content of feeds containing a protease (Jefo Nutrition Inc., Canada) at varying inclusion levels (0-1000ppm). In the first method, the HCl-Pepsin method, feeds were incubated (16h) in a hydrochloric acid-pepsin solution (45°C) under constant agitation. Crude protein digestibility was determined from the difference in pre- and post-digestion N content of undigested solids. In the second technique, feeds were incubated (5h) at 40°C under alkaline condition and supernatant was analyzed for total amino acid content after hydrolysis. The ability of these tests to detect enzyme activity was confirmed by higher solubility and soluble essential amino acid concentrations in protease containing diets. In a separate study, enzyme kinetic analysis results of poultry feeds coincided well with those from the HCl-Pepsin method. Findings from this study demonstrated the potential of these *in-vitro* methods in assessing the effects of protease enzymes and the possibility to be used in lieu of enzymatic assays.

Introduction

In an effort to increase digestibility of proteins in animal feeds, treatments such as extrusion, pre-treatment of ingredients, and the reduction of plant proteins containing high levels of anti-nutritional factors have been used (Thiessen et al., 2003; Gomes et al., 1995; Adelizi et al., 1998). Although these methods have shown to be successful, digestive enzymes have begun to be added to feeds to further increase protein digestibility of the feeds. *In-vivo* studies in both poultry and swine have reported improved protein digestibility, feed efficiency and true nitrogen digestibility in animals fed diets containing protease digestive enzymes (O'-Doherty and Forde, 1999; Ghazi et al., 2003).

Quality assurance and quality control (QA/QC) practices are routinely implemented in feed mills to ensure ingredients and feed additives meet specifications. Enzyme kinetic assays are commonly used to evaluate protease enzyme activity and can be implemented as part of the regular QA/QC process in a feed mill. However, in addition to requiring specialized equipment, these assays are usually very sensitive to exogenous factors. An alternative to measuring the enzymatic activity is to measure the effect that the protease enzyme has on the feed. As protease enzymes are known to increase protein digestibility of feeds, *in-vitro* methods that are able to detect differences in protein digestibility between control feeds and those containing a protease enzyme, have the potential to be used in the QA/QC process in feed mills in lieu of enzyme kinetic assays.

Many *in-vitro* techniques including; pH stat, pH shift, SDS-page gel electrophoresis, HCL-pepsin protein digestion, and digestible amino acid analysis of feeds, have the potential to differentiate between control and protease containing diets. However, as the goal is to implement these *in-vitro* techniques as part of a regular QA/QC process in feed mills, only methods using machinery/equipment that is either readily available to a feed mill or found in a feed mill itself were determined to be viable candidates for testing in this study. On this basis two *in-vitro* methods, HCL-pepsin protein digestion and digestible amino acid analysis, were chosen as the specialized equipment that these methods require are commonly found in feed mills or the contracting laboratories used by feed mills as part of their QA/QC process.

The objective of this study was to develop and test these two *in-vitro* techniques in order to determine their ability to differentiate between control diets and those containing a protease enzyme. The first protocol, an HCL-pepsin digestibility protocol, analyses total nitrogen content of the residue of a feed sample post-digestion in an HCL-pepsin solution. Allowing the degree in which protein is digested in the diets to be calculated and compared. The second protocol measured total amino acid content of the soluble fraction of feed samples post incubation and hydrolysis in an alkaline solution. Diets containing the protease were expected to exhibit increased protein digestibility and increased total amino acids in the soluble fraction of the feeds when compared to equally formulated diets that did not contain the protease enzyme.

Materials and Methods

Test Diets

In order to investigate the ability of the two *in-vitro* techniques in distinguishing between diets containing a protease enzyme, three distinctive groups of tests diets were tested. These three categories were chosen to be representative of diets found in feed mills namely; feeds in the mash form prior to being pelleted, feeds that have undergone cold-extrusion, and feeds that contain varying levels of the protease enzyme. The first category, feeds in the mash form, consisted of three uniquely formulated and manufactured fish feeds consisting of a control diet and a 'control + protease' (Jefo Nutrition Inc., Canada) diet, a total of 6 diets. These three diets, represented by diet A, B & C, were formulated to contain 30%, 25% and 30% crude protein with diet C differing from diet A as it contained additional supplemental synthetic lysine. To these three diets a protease enzyme was added at an inclusion rate of 175ppm resulting in a total of 6 test diets.

The second category of test diets were shrimp feeds that contained varying levels of a protease (Jefo Nutrition Inc., Canada) to test the ability of these *in-vitro* techniques to differentiate between diets containing various inclusion levels of a protease enzyme. One control diet was formulated to contain 36% crude protein with 175ppm and 1000ppm of a JEFO protease enzyme being added to this control diet resulting in three test diets containing increasing levels of protease inclusion.

The third category of diets were cold-extruded diets, again a control diet was formulated and a protease enzyme (Jefo Nutrition Inc., Canada) was added to the control diet at various levels resulting in three diets with 0, 175 and 1000 ppm of the protease enzyme.

Sample Preparation

Sample preparation followed the same steps for both protocols. Test diets were ground using first, a DuPont Instruments Sorvvall Omni-mixer, then ground by hand using a mortar and pestle. Diets were then sieved through a No. 20 (0.841 mm) sieve. Any portion of the diets that did not pass through the sieve, were reground using a mortar and pestle until the entire sample passed through the sieve. Diets were placed into a -20˚C freezer until analysis.

Protocol 1 – Hydrochloric Acid- Pepsin Digestion

The protocol used for Hydrochloric acid- pepsin Digestion was a modified version of the protocol developed by the association of analytical communities (A.O.A.C., 2012; Millet et al., 2002)

Ground and sieved diets were taken from the -20˚C freezer and lipids were removed using an ANKOM lipid extractor. After lipid removal, samples were reground using a mortar and pestle and sieved once more. For each diet 1g (in duplicate) of defatted sample were placed in a volumetric flask and 150ml of freshly prepared HCL-pepsin solution was added. To create the HCL-pepsin solution 1L of distilled water was placed in a warm water bath and warmed to 42°C-45°C, to this 6.2ml of 37% Hydrochloric acid was added. Immediately before use, the HCL solution was removed from the heat and 0.2 grams of pepsin (1:10 000 activity) was added and the mixture stirred. The flask containing the sample was placed in a shaking water bath (Thermo Scientific SWB25) and agitated constantly (n=90) at 45°C for 16 hours.

Undigested residue was separated from the HCL-pepsin solution using vacuum filtration with a California Buchrer. Resulting undigested residue was transferred into a clean crucible and placed in a drying oven at 105˚C for 30 minutes. The residue was then ground in preparation for nitrogen analysis using either the LECO or Kjeldahl method of nitrogen determination. The original non-digested diets were ground and also submitted for nitrogen analysis. The following calculations were used to determine protein digestion of samples:

Digestible protein = 100* (c-b)/c

Where c= nitrogen content of original non-treated sample

b= nitrogen content in residue after HCL-pepsin treatment

Protocol 2 – Total Amino Acid in Soluble Fraction of Feed and Feed Ingredients

Ground and sieved samples were removed from the -20˚C freezer and six grams per diet (in duplicate) were placed in a 100ml conical flask. To each flask, 30ml of a phosphate buffer was added. The phosphate buffer was created by dissolving 4g of NaCl, 0.1g of KCl, 0.72g of Na_2HPO_4 and 0.12g of KH_2PO_4 into 400 ml of distilled water. The pH of the buffer was adjusted to 7.4-7.6 by adding dilute HCl using a pipette. The total volume of the buffer was then adjusted to 500 ml by adding additional distilled water to the solution. Once the buffer solution was added to the sample the pH of the mixture was taken using a Fisher Scientific

accumet® pH meter50. Using a pipette the pH of the mixture was adjusted using a 0.4M NaOH solution. The NaOH solution was created by dissolving 1.6g of granular NaOH in 100 ml of distilled water. The mixture was then transferred into a pre-heated shaking water bath (Thermo Scientific SWB35 model) and incubated for 5 hours at 40 ˚C with constant agitation (n=90).

After the 5-hour incubation, contents of the flask were transferred into a falcon tube and centrifuged for 20 min at 1350g. The soluble supernatant was poured into a separate container and placed into a -20˚C freezer until Ultra Performance Liquid Chromatography (UPLC) for total amino acids was performed. Using a Waters Corporation UPLC machine total amino acid of the soluble fraction of feed was analysed following a standard protocol for total amino acids in plasma samples. Concentrations of amino acids in the soluble fraction of the feeds were then compared between diets.

Results and Discussion

The first set of diets tested for digestible protein using the HCL-pepsin protocol were fish feeds containing various levels of crude protein. Diets A, B and C were formulated to contain 30, 25 and 28% crude protein with digestible protein values determined to be 68.6, 66.1 and 70.1% respectively using the HCL-pepsin protocol. When 175ppm of a protease enzyme was added to diets A, B and C digestible protein content increased to 70.3, 67.8 and 71.1% respectively. Figure 1 displays the digestible protein content of the three control diets and three protease containing diets. The total amino acid content in the soluble fraction in these feeds was also measured. Most notably methionine and tryptophan concentrations were higher in the protease containing diets compared to the control diets, while other essential amino acid concentrations were not significantly affected by the protease treatment.

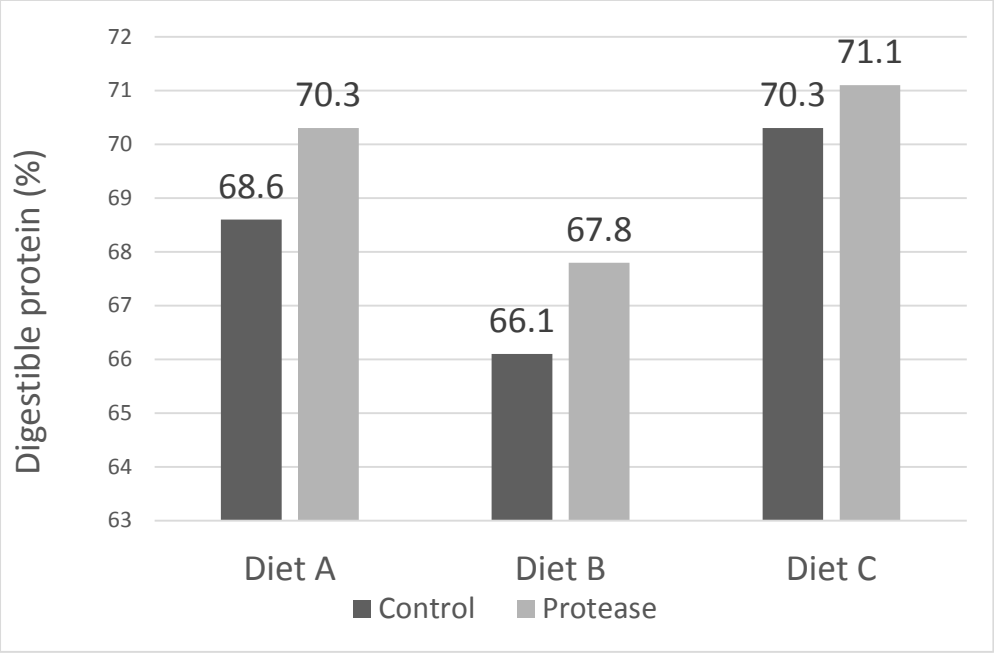

Figure 1. Digestible protein of three control and control + protease diets.

Digestible protein content of shrimp diets responded in a significantly linear manner (R^2=0.96) with increasing inclusion levels of the protease enzyme. Diets supplemented with increasing levels of the protease enzyme, 0, 175 and 1000ppm, resulted in increased digestible protein values of 65.9, 66.8 and 68.8%. Likewise, as displayed in figure 2, concentrations of the majority of essential amino acid in the soluble fraction of the feed also increased in response to increasing protease enzyme inclusion.

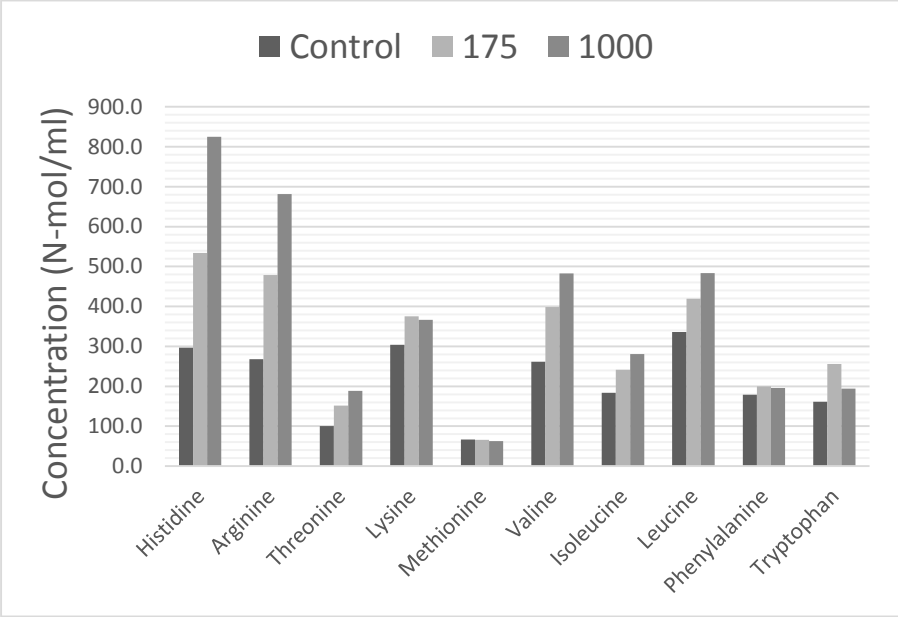

Figure 2. Essential amino acid content of the soluble fraction of feeds containing increasing levels of a protease enzyme.

The final diets tested were fish feeds that underwent cold extrusion prior to testing. Again digestible protein increased from 78.2 to 80.0 to 81.6%, with increasing levels of the protease enzyme. In order to compare the HCL-pepsin method to traditional enzyme activity assays these three diets were sent to an external laboratory to determine enzyme activity of the diets by measuring the conversion of N-SUCCINYL-ALA-ALA-PRO-PHE-P-NITROANILIDE to 4-nitroaniline (Sigma Aldrich). Figure 3 displays the positive linear relationship (R^2=0.999) between digestible protein measured by the HCL-pepsin method and enzymatic activity of the diets.

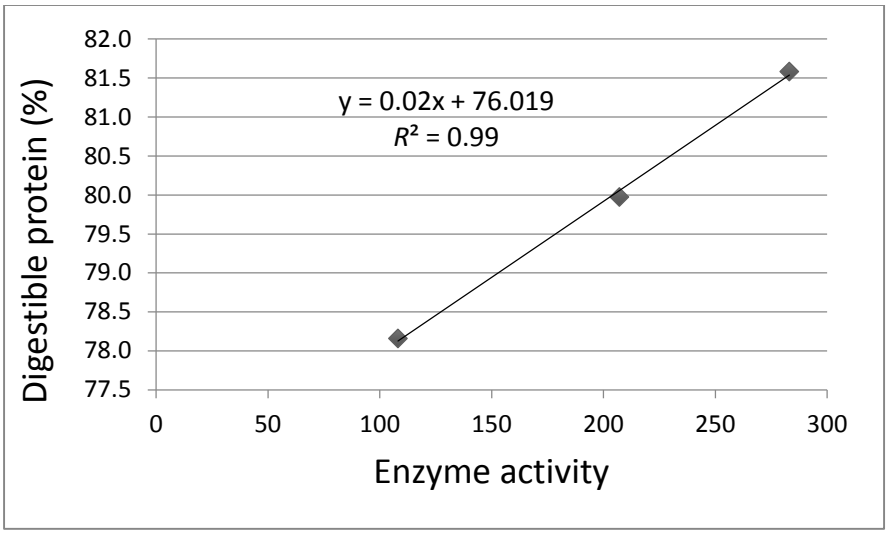

Figure 3: Relationship between digestible protein content measured by HCL-pepsin and enzyme activity in three protease containing diets.

Conclusion

Both methods tested in this study were able to distinguish between control diets and those containing protease diets, in addition these methods were able to distinguish between diets containing various levels of the protease enzyme. Findings of this study demonstrate the potential of these two *in-vitro* methods in assessing the effects of protease enzymes and the possibility of these methods to be used in lieu of traditional enzyme activity assays and possible incorporation in a feed mills regular quality control and quality assurance process.

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ADAPTING THE CONCEPTS OF TROPICAL INTEGRATED AGRICULTURE-AQUACULTURE (IAA) AND AQUAPONICS TO TEMPERATE-COLD FRESHWATER INTEGRATED MULTI-TROPHIC AQUACULTURE (FIMTA)

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Abstract

This paper aims to provide some insights on conceptual and technical aspects for converting tropical integrated agriculture-aquaculture and aquaponic systems to temperate-cold, land-based freshwater integrated multi-trophic aquaculture (FIMTA) systems. The main goal is to establish a natural productive balance between terrestrial/hydroponics plants and aquatic organisms in salmon-smolt hatcheries. A sustainable FIMTA system is more productive in a constant air-water temperature and the engineering design, optimal usage of natural sunlight, heating system, suitable humidity, temperature and water source are important factors in preparing FIMTA facilities in temperate-cold regions.

Introduction

The human population has increased fourfold in the past 100 years. This increase will result in the need for much more food and freshwater in the next decades (Anonymous, 2007). Only a few countries are capable of accelerating their food production and developing their natural resources to sustain their fast growing populations. Moreover, the most populous countries, which are located in Asia, Africa and Latin America, are facing severe food shortages and energy crises right now (Nellemann et al., 2009). Academic and industrial research activities in the field of crop science, fisheries and aquaculture are necessary to promote sustainable aquaculture and agriculture food production systems (Pillay & Kutty, 2005; Stickney, 2009). Aquaculture is presented as a promising solution to the socioeconomic problems of some communities, particularly in rural, coastal and inland freshwater areas. Most of the aquaculture operations have developed in freshwater environments and mainly in Asia (FAO, 2006). The development of inland aquaculture facilities is seen as an important source of food security, particularly in land-locked countries. Aquaculture still faces a number of issues, such as technology enhancement and financial resources, environmental impacts and diseases (Summerfelt et al., 2009). To improve aquaculture productions and optimize facilities for particular wastewater treatment, the main discharge parameters must be known (Tiehm et al., 1999; Timmons et al., 2002). Obviously, new and sustainable technologies need to be developed to assist the aquaculture industry, food supply and demand, and address some public concerns.

Integrated agriculture-aquaculture (IAA) systems

Over the last three decades, there has been increased interest in integrated aquaculture systems, in line with increased activities for sustainable agriculture in developing and developed countries (Langdon et al., 2003; Schuenhoff et al., 2003). Integrated agriculture-aquaculture (IAA) systems have a proven track record over the past several centuries and have usually been classified according to the farming combinations being practiced. For example, typical classifications include rice-fish, pig-fish, poultry-fish and multi-component systems, usually crop-livestock-fish (Mukherjee et al., 1992). The original integrated farming methods can be traced back to the floating gardens of the Aztecs, hanging gardens of Babylon and Chinese farms (Crossley, 2004). Ancient Chinese designed IAA systems in which fish, ducks, aquatic plants and vegetables were co-cultivated in a symbiotic relationship (Chopin, 2013). The water from the catfish ponds was used to irrigate rice and vegetable crops. Ancient food-growing techniques of the Aztecs and Chinese are being revamped for modern sustainable growing of aquatic species and vegetables (Boutwelluc, 2007).

Aquaponics

The term “aquaponics” has also been used to describe operations where fish and vegetables are cultivated together. One can consider that aquaponics is, in fact, a variation on the over-arching IMTA theme. In such systems, fish feed, solids and liquid wastes provide most of the nutrients required for vegetable growth through a continuous loop (Rakocy et al., 2006; Wilson, 2006). The microbial activity (digestion of fish feed and organic wastes) also produces some liquid nitrogenous compounds (NH3) and minerals, which provide the essential nutrients for plant growth. In tropical climates, aquaponics is mainly practiced on a limited scale compared to that of IAA systems (Endut et al., 2011; Khoda Bakhsh & Chopin, 2013). The bioremediation cycle can present several advantages for recirculating aquaculture systems, which utilize excess soluble nutrients to grow secondary by-products (edible plants). Indoor aquaponics is one of the most widely used technologies to grow fish, healthy indoor-outdoor plants and premium grade vegetables, fruits and herbs (Lennard & Leonard, 2004; Savidov, 2005). All physiological requirements of fish and plants can be met with engineered designs and proper use of culture media and natural or artificial light.

Moving towards integrated multi-trophic aquaculture (IMTA) at sea and in freshwater

The establishment of large and modern hatchery operations in Europe, North America and South America has been a key instrument responsible for the fast growth of cold-water aquaculture (FAO, 2008). These intensive productions may have an impact on water quality through some biological, physical and chemical activities (among others: respiration, nitrogen and phosphorus metabolism and waste generation). In cold and temperate environments, aquaculture effluents are difficult to treat and the operation of wetlands is not as effective as in warmer climatic regions. Depending upon the receiving water regimes, the total nutrient mass loading (especially of nitrogen and phosphorus) may contribute significantly to environmental degradation. Many chemical/physical factors should be considered while

testing, analyzing and treating the water from fish production. Assessments of innovative techniques, equipment, clean watering systems and filtration at different stages of the production cycle are needed. For example, in marine ecosystems, Integrated Multi-Trophic Aquaculture (IMTA) has been examined extensively over the past decade using a wide variety of system designs, aquatic species and experimental protocols (Neori et al., 2004; Reid et al., 2013). Salmon spend the early part of their life cycle in freshwater hatcheries (9 to 18 months) before being transferred to seawater sites. Due to the possibility of hatcheries discharging dissolved nutrients (i.e. phosphorus), and the risk of eutrophication in inland freshwater bodies, the principles of IMTA can also be applied to land-based, closed-containment and freshwater IMTA (FIMTA) systems. The extractive species and infrastructures are different from what have been developed so far for salmon sites at sea. From an economic, marketing and environmental perspective, it would be most interesting to develop an overall system where salmon would be FIMTA-IMTA produced from the egg to the plate, as this would help considerably the Canadian aquaculture industry in certification schemes and obtaining premium prices. FIMTA is the combination of aquaculture, microbial digestion and phytoremediation of aquaculture effluents. Sequentially, the excess nutrients and minerals are removed very efficiently to achieve the required effluent quality in freshwater hatcheries (Levine et al., 1985; Adler, 1998).

FIMTA development in temperate-cold regions

In tropical climates, hobby and commercial FIMTA systems can be installed outdoors with a simple shade structure to protect fish and plants from rain or excessive direct sunlight. However, in temperate environments, food production sectors (agriculture and aquaculture) are influenced by changes in seasonal air and water temperatures. FIMTA systems are generally more constant and versatile in a controlled air-water temperature system; however, a suitable structure is generally recommended and necessary. Various structures have been used (indoor hatcheries and greenhouses) to manage the growing conditions in order to increase control over quality and productivity. In cold conditions, greenhouses provide the controlled environment for the cultured species and all related facilities are being designed to achieve optimal growth conditions for the crops, as well as to mitigate physical and biological damages to the organisms, diseases and extreme weather events. Indoor hatcheries and greenhouses are being constructed essentially to bridge the gap in establishing year round fish and vegetable productions.

In FIMTA systems, greenhouses become an important approach in conjunction with indoor production of aquatic animals and plants together. There are different types of greenhouses with different covering materials, such as glass or plastic, for the roofs and walls. Research and commercial greenhouses are often high-tech production facilities for vegetables or flowers. The greenhouses are filled with different equipment (lighting and heating), which may be automatically controlled by sensors and computers. The important factors for preparing greenhouse facilities for FIMTA in tropical and temperate-cold regions are summarized in Table 1.

Table 1: Important factors to consider for greenhouse facilities in tropical and temperate-cold regions.

Greenhouse facilities	Tropical regions	Temperate-cold regions
Engineering design process	✓	✓
Optimal use of natural sunlight		✓
Heating system		✓
Cooling system	✓	
Suitable humidity		✓
Air ventilation	✓	
Temperature	✓	✓
Water source	✓	✓

✓: Essential

The engineering design, optimal usage of natural sunlight, heating system, suitable humidity, temperature and water source are important factors in preparing indoor FIMTA facilities. A general comparison of facilities in the two different climates indicates that there are several technico-biological concepts that must be considered to convert tropical FIMTA systems to temperate-cold ones. Along with the proper location, the whole production units must be designed to develop an ecosystem approach to growing food and utilizing liquid wastes as resources. The overall biological and environmental advantages of FIMTA are:

- Organic and inorganic (phosphorus and nitrogen) wastes from fish are used as nutrients for the hydroponic component.
- CO_2 produced by the fish is absorbed by the plant roots (reducing ambient CO_2 levels).
- Water conservation (quality and quantity) is practiced through recirculating process.
- Heat from the sun is captured during the day to maintain air and water temperature (12-17°C) during the night.
- Environmentally friendly green products are harvested.
- Sustainable, economic and organic food production schemes can be developed for consumers.

FIMTA and commercial freshwater fish and invertebrate species

In tropical weather, a range of complementary techniques have been used to produce different fish and a wide variety of crops depending on local climates and available supplies. FIMTA systems have been developed more often in tropical than in temperate regions. Warm and humid conditions, reduced installation costs and ease of operation are the most important reasons. Other geo-social and technico-social reasons may also have their roles:

- History
- Population, resources and rural community interests
- National policy and international organization investments
- Technological patterns of the systems

- Variety of species to choose from
- Research and development opportunities
- Environmental regulations and standards for development

Fish act as the engine in integrated systems, providing nutrients and food (proteins) for the autotrophic and heterotrophic consumers. There are many varieties of fish and invertebrates for FIMTA operations in tropical climates compared to FIMTA in temperate ecosystems. So far, the promising candidate species for temperate-cold FIMTA are trout, salmon, arctic char, sturgeon, perch, carp, eel, koi, freshwater mussels and crayfish (Table 2). Aquaculturists should consider a few aspects before choosing the aquatic species for their FIMTA operation, including 1) will the initial design of the system be for hobby or commercial production, 2) will it be an indoor or outdoor facility, 3) will the aquatic organisms be edible or used to extract certain compounds or be ornamental species, 4) will the selected organisms be native and local species (not exotic and introduced), 5) will there be a reliable supply of fish and invertebrates by certified hatcheries all year round?

Table 2: Fish and invertebrate candidates for FIMTA operations in tropical and temperate-cold regions.

Tropical (15-30°C)	Temperate-cold (5-20°C)
Tilapia	Trout
Catfish	Arctic char
Carp	Silver perch
Sea bass	Yellow perch
Barramundi	Salmon
Climbing perch	Sturgeon
Jade perch	Carp
Murray cod	Eels
Goldfish	Koi
Koi	Crayfish
Freshwater prawn	Freshwater mussels
Red claw crayfish	
Yabbies	

Research and development on artificial propagation, rearing, stocking techniques and equipment should be sufficiently developed for the selected commercial species. Improved hatchery practices and processes, contributing to increasing productivity, should provide sufficient commercial aquatic resources for indoor/outdoor FIMTA operations.

FIMTA and commercial plant species

There are many species of vegetables, fruits, herbs, ornamental and medicinal plants (Anonymous, 2014) that can be grown in temperate-cold FIMTA systems (Table 3). However, very cold-water systems (< 10°C)

will make the selection of plants more limited. All cultured plants need appropriate light, temperature and nutrition (macro- and micro-elements) for optimal growth. Some vegetables may need special nutritional requirements, based on their natural habitat and growth characteristics. Full-size varieties of plants may require larger areas and more nutrients with very thick bed of aggregates (e.g. tomatoes and root plants).

Table 3: Plant candidates for FIMTA operations in temperate-cold regions.

Vegetables		
Artichokes	Asparagus	Beans
Beets	Bok choy	Broccoli
Brussels sprouts	Cabbages	Carrots
Cauliflowers	Celery	Collard greens
Cucumbers	Eggplants	Kale
Kohlrabi	Leeks	Lettuces – salad greens
Mustard greens	Onions	Parsnips
Peas	Potatoes	Pumpkins
Radishes	Rapini	Rhubarb
Salicornia	Spinach	Squash
Swiss chard	Tatsoi	Yams
Fruits		
Bananas	Blackberries	Blueberries
Cantaloupe	Dwarf citrus trees	Grapes
Lemons	Pineapples	Raspberries
Strawberries	Tomatoes	Watermelon
Herbs		
Basil	Chervil	Chives
Cilantro	Dill	Fennel
Garlic	Lemon balm	Marjoram
Mints	Oregano	Parsley
Rosemary	Sage	Sorrel
Tarragon	Wasabi	Watercress
Ornamental plants		
Calendula	Carnations	Coleus
Cosmos	Dianthus	Marigold
Pansy	Petunia	Roses
Snapdragons	Sunflower	Tulips
Yarrow	Zinnia	
Medicinal plants		
Dandelions	Echinacea	Horse heal
Nasturtium	St. John’s wort	Yarrow

Conclusions

Many different treatment methods, from very simple low-cost technologies to the highest level of sophistication, are available and have been recommended to treat aquaculture wastewaters to an adequate level. Until now, IMTA has been developed mostly for open-seawater systems. However, it can be extended to temperate-cold, land-based freshwater systems (FIMTA), such as fish hatcheries, by adapting some of the knowledge gained from tropical systems. Several unknown technico-biological issues remain to be addressed through cooperation among agronomists, microbiologists and aquaculturists to identify the best varieties and combinations of fish, plant and microbial species to develop the most efficient FIMTA systems in temperate-cold regions.

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Environmental Monitoring Session

OVERVIEW OF THE 2014 AQUACULTURE ENVIRONMENTAL MONITORING SESSION AND FACILITATED DISCUSSION

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Abstract

An Aquaculture Environmental Monitoring (AEM) Session and a separate Facilitated Discussion were held during the 2014 Aquaculture Association of Canada (AAC) annual conference. The objective of the AEM Session was to assemble stakeholders (industry, researchers and regulators) and deliver presentations to highlight prospective tools, methodologies and emerging AEM related science to increase stakeholder knowledge and share the most recent information for improvement of policy, best practices and AEM programs. Twelve presentations were delivered during the AEM Session covering a range of topics including: sulfide analytical research, sulfide modelling, ecosystem modelling, sediment profile imaging, far-field environmental effect studies, remote sensing benthic assessments, dissolved organic nutrient monitoring, AEM program comparisons and regulatory program updates. The AEM Facilitated Discussion was a platform, which allowed for AEM stakeholder dialogue exchange and brainstorming to highlight AEM strengths and weaknesses and allow scientific research gaps to be identified. Thirty-five individuals representing industry (23%), academia (29%), government (46%) and NGOs (3%) attended the AEM Facilitated Discussion. Topics that were discussed included: sediment sample collection, geochemical and visual indicators of organic enrichment, spatial variation between sampling designs, specific tools for different seafloor substrates, near versus far-field monitoring, oxygen probes, water quality monitoring, molecular tools, modelling and management/regulator objectives. It was expressed that management objectives need to be clearly defined in order for R&D gaps to be prioritized. Discussions emphasized that new tools must be developed in a Canadian context before they are incorporated as a management tool. Practicality and cost-effectiveness of new tools was described as an important consideration during the assessment and development process. The continued coordination of workshops and meetings were noted as essential to maintain momentum and require continued support from industry, academia and government.

Introduction

Aquaculture Environmental Monitoring (AEM) programs assess the impact of aquaculture production on the environment, such programs are implemented in British Columbia, New Brunswick, Nova Scotia and

Newfoundland, with management led provincially or federally. AEM programs are unique to each Province; however there are similar components amongst programs. All programs typically require a video survey of the benthos, sediment sampling and subsequent geochemical and/or taxonomic analyses. The primary difference between monitoring programs is the intensity to which aquaculture sites are monitored. Differences of intensity include: spatial and temporal sampling, the number and type of monitoring parameters and site classification standards. Monitoring results are used to determine the degree of environmental impact from aquaculture production. Increasing the knowledge of aquaculture impacts to the environment is of high priority to aquaculture stakeholders (industry, researchers and regulators). Communicating scientific knowledge provides growers with the means to improve Best Management Practices, while regulators benefit by ensuring their respective AEM programs are continually evolving and are based on the most up-to-date, available information. It is of extreme importance to stakeholders to identify the outstanding science-based research and development (R&D) gaps pertaining to aquaculture impacts on the environment. AEM programs are a management tool designed to ensure industry accountability and environmental sustainability. Forming collaborations and conducting research required to address R&D gaps will provide regulators with the opportunity to update and enhance AEM programs to uphold the integrity of management decisions and effectively assess aquaculture's impact on the environment.

An AEM Session and Facilitated Discussion were held during the Aquaculture Association of Canada's (AAC) Annual Conference in St. Andrews, New Brunswick from June 1 – 4, 2014. The Aquaculture Collaborative Research and Development Program (ACRDP) provided partial funding of the costs associated with the AEM Session and Facilitated Discussion. The AEM Session and Facilitated Discussion addressed the ACRDP priority of "Environmental Impacts - from aquaculture to the environment" and the goal of "Increasing knowledge and understanding of how aquaculture finfish operations impact the environment, and developing the means to manage, mitigate and control these impacts." The objective of the AEM Session was to assemble stakeholders and deliver presentations to highlight prospective tools, methodologies and emerging AEM related science to increase stakeholder knowledge and share the most recent information for improvement of policy, best practices and AEM programs. The AEM Facilitated Discussion was a platform, which allowed for AEM stakeholder dialogue exchange and brainstorming to highlight AEM strengths and weaknesses, allowing scientific research gaps to be identified.

AEM Session

Twelve presentations were delivered by individuals representing government, academia and industry. Topics covered included: analytical research, sulfide modelling, ecosystem modelling, sediment profile imaging, far-field environmental effect studies, remote sensing benthic assessments, dissolved organic nutrient monitoring, AEM program comparison and regulatory program updates.

FISHERIES AND OCEANS CANADA'S ENVIRONMENTAL MONITORING REQUIREMENTS FOR AQUACULTURE UNDER THE NEW FISHERIES ACT REGULATIONS

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AN UPDATE ON THE NOVA SCOTIA AQUACULTURE ENVIRONMENTAL MONITORING PROGRAM

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RESEARCH ON FACTORS AFFECTING THE CALIBRATION OF ELECTRODES USED FOR SEDIMENT SULFIDE ANALYSES AT FISH FARMS

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PREDICTION OF SEDIMENT SULFIDE FROM DIAGENETIC MODELLING: PRELIMINARY RESULTS

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ALTERNATIVE METHODS FOR AQUACULTURE IMPACT ASSESSMENT IN NOVA SCOTIA, CANADA

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EVALUATION OF BENTHIC EFFECTS FROM AQUACULTURE WITHIN THE LETANG INLET, NEW BRUNSWICK

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CONTRIBUTION OF SEDIMENT BIOCOMPLEXITY TO BENTHIC NUTRIENT AND OXYGEN FLUXES IN COASTAL SEDIMENTS: FIELD OBSERVATIONS AND COMPUTER SIMULATION.

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REMOTE SENSING APPROACHES FOR MONITORING MARINE LANDSCAPES AND ASSESSING AQUACULTURE-ENVIRONMENT INTERACTIONS

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MONITORING THE INVISIBLE WITH HIGHLY VISIBLE CONSEQUENCES: LET"S NOT FORGET THE DISSOLVED INORGANIC NUTRIENTS

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COMPARATIVE STUDY OF THE ENVIRONMENTAL MANAGEMEDNT PROGRAMS FOR MARINE FINFISH AQUACULTURE IN CANADA AND OTHER JURISDICTIONS: TIME TO GO BEYOND SEDIMENT RELATED MONITORING AND CONSIDER APPROPRIATE TOOLS FOR WATER COLUMN AND ECOSYSTEM RELATED MONITORING

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ECOSYSTEM MODELLING FOR AQUACULTURE SUSTAINABILITY

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AEM Facilitated Discussion

The AEM facilitated discussion occurred throughout a two and a half hour period and was attended by thirty-five individuals representing industry (23%), academia (29%), government (46%) and NGOs (3%). Participation was all-inclusive and discussions were guided based on two major topics.

1. Explain which tools and methodologies **currently used** in AEM programs demonstrate practicality and usefulness. Is further research and development (R&D) required?

2. Identify **"new"** monitoring tools and methodologies with potential to enhance understanding of aquaculture-environmental interactions. Are other Provinces, Countries and/or industries using these tools and methods? Is R&D required?

The first topic, herein referred to as *Existing Monitoring Tools and Methodologies,* was dominated by discussions of sediment sample collection, geochemical and visual indicators of organic enrichment, spatial variation between sampling designs and sediment consistency variations between sites. The second topic, herein referred to as *Potential Monitoring Tools and Methodologies,* brought forth discussions of oxygen probes, water quality, molecular tools, near versus far-field monitoring, models, and management/regulator objectives. A list of potential research topics are detailed below.

Existing Monitoring Tools and Methodologies

<u>Spatial sampling designs</u>

- Importance of reference stations
- Transects vs. single-point stations
- Spatial variability of organic deposition

<u>Sediment sample collection</u>

- Sediment sampling equipment
    - Grab type (suitability to sampling conditions)
    - Grab performance (maintenance of sediment-water interface)

    - Standardized indicators of acceptable grab sample (e.g., appearance, volume, orientation etc.)
- Comparison between homogenized vs. non-homogenized sediment samples on geochemical analyses (ACRDP Proposal: M-14-01-001)
- Sediment storage conditions (sub-sampling receptacles, storage temperature, darkness, air-tightness, handling of samples, and duration of storage) (ACRDP Proposal: M-14-01-001)

<u>Geochemical analyses</u>

Oxidation Reduction Potential (ORP or Redox potential)

- Lack of redox-sulfide relationship
    - Effect of sample age on ORP values (measurement upon retrieval or in a lab setting)
    - Effect of probe condition (platinum surface)
    - Influence of electrode design on oxidation reduction potential (ORP) values (Orion vs. Hanna, gel-filled vs. refillable)
    - Influence of metals on measured vs. actual Eh values
- Correlation ORP:
    - visual indicators (beggiatoa and Opportunistic Polychaete Complexes (OPC))
    - biodiversity
    - organic matter
    - porosity

Sulfide

- Identify concentration confidence limits
- Efficacy as a tool for mixed or hard substrates
- Influence of pore water volume vs. sediment volume on sulfide concentrations
- Influence of metal sulfides on measured vs. actual sulfide concentrations (influence on redox-sulfide relationship)
- Acid volatile sulfides (AVS) (vs. total sulfides)
- Correlate sulfide and:
    - visual indicators (Beggiatoa and OPC)
    - biodiversity
    - organic matter
    - porosity

Porosity

- Accuracy of wet-dry weight method

Organic Matter

- Optimal temperature and duration for combustion of organic carbon
- Distinguishing between environmental and aquaculture-derived organic carbon sources

Metals

- Identify concentration confidence intervals
- Identify concentration thresholds

Underwater video footage

- Oblique perspective of seafloor (BC) vs. vertical perspective (Atlantic Canada)
- High definition (HD) camera systems

Visual Indicators

- Standardized methods for quantitative analysis (videos, drop cameras, ROVs)
- Identify thresholds for each indicator to classify sites
- Interpretation of presence/absence data and the limitations
- Correlation between visual indicators and biodiversity
- *Beggiatoa*
- OPC
    - Epifaunal vs. infaunal complexes
    - OPC species identification
    - Definition of a complex - how to determine percent coverage

Potential Monitoring Tools and Methodologies

Spatial sampling designs

- Near field (site-by-site basis) vs. far field (bay scale) sampling
- Allowable zone of impact (cage edge vs. “downstream” impacts)

New tools/analyses

- Specific indicators for soft, hard and mixed sediment bottoms
- Applying analytical measures upon sample retrieval (ACRDP Proposal: M-14-01-001)
- Identifying aquaculture tracers
- Alternative methods to measure sulfide concentrations
    - Direct UV spectrophotometry (Program for Aquaculture Regulatory Research (PARR) proposal submitted)
    - Methylene Blue method
- Direct measurement of oxygen and pH in sediment porewater
- Meta-analysis using physical and biological indicators
    - E.g., Modelling-Ongrowing fish farm-Monitoring (MOM) system (potential to use in the interim until sufficient tools are developed)
- Water quality (dissolved inorganic nutrients) – how to deal with temporal variability
- Measure changes in seaweed communities as an indicator of dissolved nutrient levels
- Molecular tools (bacterial assays, DNA to identify microbial communities)
- Measuring positive influences on environment

Modelling

- Modelling what organic input means at different bottom types
- Modelling assimilative and carrying capacities
- Sampling must occur to validate model predictions

Conclusions

A common topic throughout the Facilitated Discussion was the need for regulators to work towards standardizing management objectives, AEM sampling designs, parameters and indicator thresholds. It was expressed that the first step would be for regulators to review and clearly outline management objectives. The next step would involve research and development to enhance current tools, or develop new ones, to ensure compliance is measured appropriately against management objectives. That being said, assigning priority to R&D gaps may be difficult due to the current differences which exist among management objectives and AEM programs.

In terms of new tools, it was noted that research and development must be conducted in a Canadian context prior to incorporating as a management tool, and to also assess the practicality and cost-effectiveness. It should be noted that research results may be available to address R&D gaps listed above. The above list was not cross-referenced with a literature search and therefore this report does not address the current Canadian status, nor the extent to which any research already completed might address the gaps listed.

It was suggested that a network be established to effectively and routinely communicate developments related to aquaculture environmental monitoring, similar to the Canadian Integrated Multi-Trophic Network (CIMTAN). Such a network would have national and potentially international membership and could act as a liaison among stakeholders and would coordinate regularly scheduled meetings to share R&D progress, discuss outstanding R&D gaps, while increasing opportunities for collaborations.

The attendance at both the 2014 AAC - AEM Session and Facilitated Discussion is a testament to the interest of various stakeholders in aquaculture environmental monitoring and provides grounds to continue holding workshops and meetings to discuss the current and growing knowledge surrounding aquaculture-environmental interactions. The continued coordination of workshops and meetings are essential to maintain momentum and require support from industry, academia and government, with respect to physical and monetary participation, in order to ensure aquaculture environmental monitoring in Canada is continually evolving and is based on the most up-to-date, available science.

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COMPARATIVE STUDY OF THE AQUACULTURE ENVIRONMENTAL MONITORING PROGRAMS FOR MARINE FINFISH IN CANADA AND OTHER JURISDICTIONS: TIME TO GO BEYOND SEDIMENT RELATED IMPACT MONITORING AND CONSIDER APPROPRIATE TOOLS FOR WATER COLUMN AND ECOSYSTEM RELATED IMPACT MONITORING

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Abstract

Canada's finfish aquaculture environmental monitoring programs (AEMPs) need to be updated to better reflect the current advances in both aquaculture practices and monitoring techniques. To further these goals, we conducted the following study:

1. Identify which aspects of the environment finfish aquaculture can potentially impact and establish categories to which the development of monitoring tools can be directed.
2. Review salmon AEMPs in different jurisdictions and identify current tools used to monitor aquaculture sites, including the measurement of far-field effects.
3. Identify the existing gaps in the Canadian approach to aquaculture monitoring.
4. Make recommendations for tools to further explore and implement in a growing and increasingly competitive aquaculture industry.

We found three categories of finfish aquaculture related impacts: Sediment Related Impacts (SRI), Water Column Related Impacts (WCRI), and Ecosystem Related Impacts (ERI). The review of aquaculture monitoring tools in different jurisdictions identified tools that could be applied in a Canadian jurisdictional context of several types of coastal ecologies, a diversity of species to consider both cultured and wild, a range of regulatory leads and different stakeholder interests and needs. Existing gaps in Canada AEMPs are mostly related to WCRI and ERI.

We recommend incorporating more physical and chemical parameters to monitor WCRI and to conduct more research to develop innovative ERI tools. By implementing these recommendations, the AEMPs would improve their ability to monitor aquaculture activities for a broader range of environments. Expanded monitoring would allow current regulatory models, prioritized on near-field bottom impacts, to evolve into a more holistic management strategy including how aquaculture practices interact with the surrounding ecosystem and other coastal activities.

Introduction

Salmon aquaculture is a fast growing industry contributing to Canada's economy. In 2012, Canada produced 108,118 tons of Atlantic salmon worth 599,437,000 USD (FAO, 2012). Depending on the species raised and the intensity of the operations, there can be a variety of negative impacts associated with inadequate site management or poorly located salmon aquaculture farms. Intensive finfish operations, without proper management practices, can lead to organic and inorganic nutrient loading (Wildish et al., 1999), macrofaunal community changes (Borja et al., 2009), microbial community changes (Vezzulli et al., 2002), noise (Olesiuk et al., 2012), escapees (Holmer et al., 2008), disease proliferation, poor animal health and less valuable products (Borja et al., 2009). Because of the varied range of potential impacts, comprehensive and meaningful monitoring programs are critical to ensure environmentally sustainable limits are not exceeded. New techniques are continually being developed to make finfish aquaculture more efficient and environmentally friendly with foreseeable benefits for both the environment and stakeholders. For example, Integrated Multi-Trophic Aquaculture (IMTA) is a practice that is being explored for commercial use in Canada. This integrated approach seeks to copy some of the diversity found in nature so as to improve the localized ecosystem services. Its goal is to exploit the nutrients released from finfish operations in order to co-culture other valuable organisms and reduce the overall impact of finfish sites. Monitoring programs developed around multiple levels of impacts can help to determine the effectiveness of IMTA, providing a more complete set of information upon which to measure performance (CIMTAN, 2012).

Various data gathering techniques have been explored in order to contribute to an holistic "Weight of Evidence" approach to monitoring aquaculture's impacts (Wilson et al., 2009; Carballeira et al., 2012) Aquaculture related impacts are measured with scientifically proven methods in order to provide aquaculture managers and decision makers with the best possible information (FAO, 2009; Wilson et al., 2009; Carballeira et al., 2012). The challenge of this approach for aquaculture in Canada stems from the fact that aquaculture sites in Canada often have very different environmental characteristics, different stakeholder needs, yet, in order to be viable and competitive, all need to be operated and managed under a consistent, predictable and comparable monitoring program. Successful aquaculture operations under different environmental parameters and needs, yet treated equally within a broad regulatory framework, is what we define as "Canadian context" for aquaculture.

This paper will focus primarily on monitoring the environmental impacts associated with cultured stock management after the site has been established. It includes a review on monitoring far-field effects of salmon aquaculture with the Weight of Evidence approach in mind. It will classify components of the environment that finfish aquaculture can potentially impact and establish categories of monitoring tools. A review of salmon aquaculture monitoring in different jurisdictions will identify feasible and practical tools currently used to monitor aquaculture sites, including the measurement of far-field effects. It will identify the existing gaps in Canada's aquaculture monitoring and offer recommendations for adopting tools that would be relevant to monitoring programs in a Canadian context.

Environmental Considerations of Finfish Aquaculture

Finfish aquaculture activities in the environment

Finfish, like all animals, digest and metabolize their food and excrete waste as they grow. In open water aquaculture, feed waste enters the environment in two forms. The first is organic, solid and semi-solid faeces and uneaten food particles, which either settle immediately or travel a short distance before settling on the benthos (Hargrave, 1994). The second form of waste is inorganic nutrients, in particular nitrogen and phosphorus, dissolved directly into the water column (Chopin et al., 2001). The organic and inorganic inputs of fish farming have the potential to cause impacts on the levels of organic matter and inorganic nutrient loading in coastal areas (Beveridge, 1984; Brown et al., 1987, Gowen & Bradbury, 1987; Rosenthal et al., 1988; Folke & Kautsky, 1989; Handy & Poxton, 1993; Hargrave et al., 1998, Chopin et al., 1999; Karakassis, 2000; Hyland et al., 2005). These introduced nutrients have the potential to affect sediments beneath the salmon cages and to change the composition of the water column. Enhanced sediment metabolism, anoxia, sulfate reduction and sulfide accumulation, acidification, high levels of nitrogen and phosphorus and increased turbidity are some of the most studied effects (Troell & Berg 1997; Chopin et al., 2001). The changes in water quality can also lead to changes in primary productivity such as increased growth and mortality of plankton and shifts in community composition including harmful algal blooms (Milewski, 2001).

In addition to feeding, site managers must also care for the health of the fish themselves. Farming finfish in high densities can increase risks of disease and parasite proliferation (Murray & Peeler, 2005). Site managers, in order to protect their animals, may then rely on the application of antibiotics, pesticides, disinfectants and anti-foulants. The application of antibiotics creates potential to expose wild species and affect changes in the bacterial community (Kümmerer, 2009). Pesticides, disinfectants and anti-foulants used in the salmon industry have the potential to cause direct mortality and sublethal effects on non-target species (Burridge & Van Geest, 2014). Well-managed farms in Canada take steps to mitigate the spread of these chemicals, but often there is some degree of leakage and persistence in the surrounding environment that should be monitored (Milewski, 2001).

Categories of finfish aquaculture related impacts

Based on the aforementioned activities of salmon aquaculture operations, three categories of finfish aquaculture related impacts can be established: Sediment Related Impacts (SRI), Water Column Related Impacts (WCRI), and Ecosystem Related Impacts (ERI). The SRI are in reference to any physical or chemical changes to the benthic zone beneath, or adjacent to, salmon farm sites. The WCRI are in reference to any physical or chemical changes that take place in the water column surrounding, or adjacent to, salmon farm sites. The ERI are in reference to the overall health of the management area in which the site, other sites, other activities and services occur. This last category was established to encompass all of the potential far-field effects of aquaculture and to reflect any overall changes to the ecosystem and community structure as a whole.

Jurisdictions selected for comparison

Norway, Chile and the United Kingdom are the top three salmon farming nations in the world and are in direct competition with Canada on the global market for farmed salmon. Norway produces the most Atlantic salmon, followed closely by Chile. The United Kingdom and Canada are the next two largest producers, but they do so at roughly 1/10th the scale of the two aforementioned nations (FAO, 2010). In addition, these nations are culturing salmon in a variety of ecosystems that naturally require diverse monitoring regimes (Wilson et al., 2009). These nations will be compared on the basis of their monitoring programs, as well as their environmental performance and stakeholder acceptance, in order to evaluate techniques that could be incorporated into the Canadian context for salmon aquaculture.

Monitoring Requirements and Available Tools from Different Jurisdictions

Site specific information

Site specific aspects such as local bathymetry, hydrography, depth, currents, tides, sediment profiles, habitat profiles and benthic species richness and abundance should be assessed. In addition, farm specific aspects such as biomass on site, farm volume, food conversion ratios, length of farm activity, harvesting schedules and cage configuration should be documented and used within a monitoring program. Detailed site characteristics can be used to develop computer models of how each site interacts with the surrounding environment. Understanding individual site characteristics improves management at the larger scale such as Bay Management Areas (BMA). The more often this information is gathered and validated with other environmental parameters, the more prepared decision makers will be to decide on optimal exploitation levels and best practices without exceeding environmentally sustainable limits (Brune & Tomasso, 1991; Wildish et al., 1999; Heinig, 2001; Telfer & Beveridge, 2001; Fernandes et al., 2001; Chou et al., 2002; Aguado-Giménez & García-García, 2004; Anderson et al., 2005; Borja et al., 2009; Phillips et al., 2009; Telfer et al., 2009; Carballeira et al., 2012).

Acceptable limits

An effective monitoring program should have a set of acceptable limits that are specific to the managed activity (*i.e.* something that the aquaculture industry has control over yet closely linked with environmental sustainability) and should address stakeholder needs so as to be meaningful in a broader ecosystem context. These acceptable limits should be clearly identified and include, but not be limited to, setting specific Environmental Goals (EGs). An effective monitoring program should also have Environmental Quality Standards (EQS) and Environmental Quality Objectives (EQO) or Acceptable Zones of Effects (AZE), as well as Carrying Capacities (CC). If monitoring programs are to be effective, there need to be clear guidelines implemented within a decision framework as to when preventative, restorative or mitigative actions should take place. Limits should be site specific with each BMA having its own set of EGs, EQS/EQO and/or AZE to account for the variability that exists in the range of ecosystems where finfish aquaculture is taking place (Borja et al., 2009; Telfer et al., 2009; Carballeira et al., 2012). Since acceptable limits are an important part of an effective monitoring program, new monitoring tools should be able to contribute to the improvement of the EGs and EQS/EQO and help refine the AZE.

Available tools to monitor sediment related impacts (SRI)

There are a wide variety of tools and measureable characteristics being employed in other finfish producing jurisdictions. For the purposes of this paper, the tools selected were chosen on the basis that they are in use in at least one of the top 4 salmon producing jurisdictions and have been identified in at least two separate publications.

Tools that pertain to SRI are both quantitative and qualitative in nature (Table 1). Quantitative tools are assessment of organic sediment loading, video transects, pH and redox measurements, organic content/total organic content, particle size (granulometry), in-feed medicine residues, copper and zinc levels, total volatile solids, total nitrogen content, free sulfide levels and the presence of feed pellets or faeces (Hargrave et al., 1998; Wildish et al., 1999; Yokoyama et al., 2006; Borja et al., 2009; Telfer et al., 2009; Wilson et al., 2009; Carballeira et al., 2012). Qualitative tools are assessment of sediment colour, odour, presence of gas, consistency and thickness. These qualitative tools give a good indication of how a finfish farming operation is affecting the benthos beneath cage sites (Borja et al., 2009; Carballeira et al., 2012).

Available tools to monitor water column related impacts (WCRI)

Parameters to monitor WCRI are oxygen concentration, salinity, temperature, ionized and unionized ammonia, turbidity, biochemical oxygen demand (Brune & Tomasso, 1991; Wilson et al., 2009; Carballeira et al., 2012), nitrate and nitrite, dissolved reactive phosphorus, chlorophyll “a”, copper, therapeutants and other aquaculture specific compounds (Cefas, 2007; Wilson et al., 2009; Carballeira et al., 2012), and nitrogen 15 signaling (Costanzo et al., 2004; Lojen et al., 2005; Dolenec et al., 2007; Lin & Fong, 2008; Dailer et al., 2010; Carballeira et al., 2012).

A review and comparison of Norway, Chile, the United Kingdom, British Columbia and New Brunswick’s monitoring programs regarding WCRI (Table 2) indicates that the United Kingdom includes all available determinants in their monitoring programs. Norway, Chile, New Brunswick and British Columbia monitor some of the identified determinants, but at the discretion of managers or not at all.

Table 1. Summary of tools employed by different jurisdictions to monitor the sediment related impacts (SRI) of Atlantic salmon aquaculture (Henderson & Davies, 2000; Carroll et al., 2003; Government of British Columbia, 2005; Telfer et al., 2009; Wilson et al., 2009; FAO, 2010).

Jurisdiction	Sediment Related Impact (SRI) Tools
Norway	- Organic sediment loading (every 1, 2, or 3 months, depending on level of exploitation) - Presence of macro-infauna, pH and redox, total organic carbon, particle size (every 1 or 2 years, depending on level of exploitation) - Qualitative description of colour, odour, presence of gas, consistency and thickness (every 1, 2 or 3 years, depending on level of exploitation)
Chile	- Video transect survey - Presence of macro-infauna, pH and redox, total organic carbon, particle size (annually, during peak season) - Qualitative description of colour, odour, presence of gas, consistency and thickness (annually, during peak season)
United Kingdom	- Video transect survey - Presence of macro-infauna, pH and redox, total organic carbon, particle size, in-feed medicine residues, copper, zinc, total volatile solids, total nitrogen, free sulphide, presence of feed and faeces (annually, between May 1 and October 31, within 1 month of peak biomass; extent of survey level dependant on biomass and flushing time) - Qualitative description of colour, odour, presence of gas, consistency and thickness (annually, between May 1 and October 31, within 1 month of peak biomass; extent of survey level dependant on biomass and flushing time)
Canada (New Brunswick)	- Video transect survey - Presence of macro-infauna, pH and redox (annually, between August 1 and October 31, part of the visual survey), free sulphide, presence of feed and faeces (annually, between August 1 and October 31) - Qualitative description of colour, odour, presence of gas, consistency and thickness (annually, between August 1 and October 31, part of the visual survey)
Canada (British Columbia)	- pH and redox, total organic carbon, particle size, copper, zinc, total volatile solids, free sulphide (annually, within 30 days of peak biomass)

	Sediment Related Impact (SRI) Monitoring				
Jurisdiction	Treatment Trigger Levels	Environmental Quality Standards	Statutory / Voluntary	Personnel Involved	Feedback Mechanism
Norway	Yes	Yes	Statutory	Consultants	Yes
Chile	Yes	Yes	Statutory	Consultants	Yes
United Kingdom	Yes	Yes	Statutory	SEPA*	Yes
Canada (New Brunswick)	Yes	Yes	Statutory	Consultants	Yes
Canada (British Columbia)	Yes	Yes	Statutory	Consultants	Yes

***SEPA: Scottish Environmental Protection Agency**

Table 2. Summary of tools employed by different jurisdictions to monitor the water column related impacts (WCRI) of Atlantic salmon aquaculture (Henderson et al., 2000; Carroll et al., 2003; Government of British Columbia, 2005; Telfer et al., 2009; Wilson et al., 2009; FAO, 2010).

Jurisdiction	Water Column Related Impact (WCRI) Tools
Norway	- Oxygen concentration (at discretion of authorities)
Chile	- Oxygen concentration (annually) - Salinity, temperature, ionized and unionized ammonia, nitrate and nitrite, dissolved reactive phosphorus, chlorophyll "a", copper, medicines and chemicals (at discretion of authorities)
United Kingdom	- Oxygen concentration (bi-annually: 1 winter survey and 1 summer survey) - Salinity, temperature, ionized and unionized ammonia, nitrate and nitrite, dissolved reactive phosphorus, chlorophyll "a", turbidity, copper, medicines and chemicals (bi-annually: 1 winter survey and 1 summer survey)
Canada (New Brunswick)	None
Canada (British Columbia)	None

	Water Column Related Impact (WCRI) Monitoring				
Jurisdiction	Treatment Trigger Levels	Environmental Quality Standards	Statutory / Voluntary	Personnel Involved	Feedback Mechanism
Norway	Yes	Yes	Statutory	Consultants	Yes
Chile	No	No	Voluntary	Consultants	No
United Kingdom	Yes	Yes	Statutory	SEPA*	Yes
Canada (New Brunswick)	N/A	N/A	Voluntary	N/A	N/A
Canada (British Columbia)	N/A	N/A	Voluntary	N/A	N/A

***SEPA: Scottish Environmental Protection Agency**

Available tools to monitor ecosystem related impacts (ERI)

The ERI can be subdivided into ecological integrity and trophic and toxic effects (Table 3). Such impacts can be monitored effectively, but are usually highly dependent on the ecosystem being monitored and the values placed on them by the local stakeholders. For example, organic enrichment and particle size of the sediments beneath a cage site would not be a good measure of ecosystem health in an area with naturally hard bottom where sediment samples cannot be easily obtained or even representative of the activity being monitored. In addition, the goals of regulators and stakeholders could vary in different jurisdictions. Consequently, there are currently no obvious tools to assess ERI in any given area. Rather, there are a set of tools that can be assessed for use in the Canadian context in terms of their ability to track changes in a range of ecosystems. These tools have been shown to be reliable measures of ecosystem health in other jurisdictions.

Table 3. Summary of tools employed by different jurisdictions to monitor the ecosystem related impacts (ERI) of Atlantic salmon aquaculture (Henderson & Davies 2000; Carroll et al., 2003; Government of British Columbia, 2005; Telfer et al., 2009; Wilson et al., 2009; FAO, 2010).

	Ecosystem Related Impact (ERI) Tools	
Jurisdiction	Presence of sulfur reducing bacteria (*Beggiatoa* sp.)	Quantitative and qualitative assessment of benthic fauna
Norway	No	At discretion of authorities
Chile	No	Annually (during peak biomass)
United Kingdom	Annually, between May 1 and October 31, within 1 month of peak biomass; extent of survey level dependant on biomass and flushing time	Annually, between May 1 and October 31, within 1 month of peak biomass; extent of survey level dependant on biomass and flushing time
Canada (New Brunswick)	Annually, between August 1 and October 31, part of the visual survey	No
Canada (British Columbia)	No	Annually, within 30 days of peak biomass

Opportunistic macroalgal cover is based on an analysis of the assemblage of wild macroalgae within the ecosystem containing the aquaculture site. Different species flourish under different conditions and changes in species assemblage, distribution and growth under nutrient enrichment and habitat alteration can act as an indicator of an aquaculture site's impacts (Edgar et al., 2005; Carballeira et al., 2012). It is unknown how native algal species distributions or assemblages are affected by salmon farming operations. Therefore this tool would require some validation prior to being inserted into a Canadian monitoring program. However, as many algae are ubiquitous in the environment, it has the potential to monitor a variety of different ecosystem types.

Other tools to monitor ecosystem health are variations in primary productivity (Brune & Tomasso, 1991; Carballeira et al., 2012), algal growth bioassays (Lukavský, 1992; Carballeira et al., 2012), bacterial bioassays (van der Grinten et al., 2010; Carballeira et al., 2012), bacterial growth indicators (La Rosa, 2004; Zaccone et al., 2005), nematode/copepod indices (Riera et al., 2012), microalgae bioassays (Caruso et al., 2003; Carballeira et al., 2012) and the sea urchin embryo test (Nacci et al., 1986). Such tools are emerging in other jurisdictions, but are still in a formative stage.

There are also indices of ecosystem "health" based on taxonomic assemblages. Other jurisdictions compare biodiversity indices against benthic enrichment gradients present around aquaculture facilities. These indices have the potential for use in future AEMPs (Keely et al., 2012).

Other aspects of ERI, such as trophic and/or toxic effects, could use bacterial assembly analysis (Caruso et al., 2003; Borja et al., 2009), the presence of sulfur reducing bacteria (Borja et al., 2009; Carballeira et al., 2012), bacterial mat coverage (Edgar et al., 2005; Carballeira et al., 2012), quantitative and qualitative assessment of benthic fauna, benthic fauna identification, univariate and multivariate analyses of

microbial species composition (Carballeira et al., 2012; Guilpart et al., 2012). These tools are effective means of determining trophic and/or toxic effects of aquaculture in different jurisdictions (Table 3).

Monitoring should also include the use of advanced computer models, as they are becoming an ever more important aspect of environmental monitoring programs (Hargrave et al., 1994; Ervik et al., 1997; Jusup et al., 2009). Models can help in demonstrating the use of indicators in AEMPs because they help describe deposition and dispersal patterns around cage sites, are farm and site specific, predict the impacts of finfish operations before they occur, and estimate the environmental CC of a site or set EQS. Although models operate on select assumptions and are only as good as the information put into them, they are also continually updating. The more data included and the longer a model has been used for a specific site, the better its predictive capability. (Munday et al., 1992; Hargrave et al., 1994; Ervik et al., 1997; Henderson et al., 2001; Cromey et al., 2002; Jusup et al., 2009). New monitoring tools should be developed to be compatible with modelling programs.

The Canadian Approach to Finfish Aquaculture Monitoring

New Brunswick and British Columbia are the two largest salmon producing provinces in Canada (DFO 2006). In these two geographically distinct areas, the industry is economically viable having undergone several decades of development, growth and maturation. In addition, these provinces have a well-documented evolution of their regulatory history and stakeholder needs. These aspects represent the Canadian context for aquaculture environmental monitoring.

New Brunswick salmon aquaculture environmental monitoring program (AEMP)

In New Brunswick, an Environmental Impact Assessment (EIA) is required prior to approval of most new sites or the modification of existing sites. The computer model DEPOMOD is currently used to estimate the impacts of salmon aquaculture operations. Baseline data are required prior to development and include site specific bathymetry, hydrography, prevailing currents, tides, sediment profiles and benthic habitat profiles (species richness and abundance). Farm specific information such as biomass on site, farm volume, food conversion ratios, years of farm activity, harvesting schedules, cage configuration and depth of sampling locations are available for managers (Government of New Brunswick, 2012a).

In New Brunswick, SRI are monitored as part of its salmon AEMP (Table 1). Video transect surveys are conducted annually and the presence of macro-infauna is assessed. Quantitative measurements of pH, redox and free sulfides are conducted on the sediments beneath cage sites annually from August to October. Benthos is assessed for the presence of feed pellets and faeces annually. Sediments are also qualitatively assessed annually as part of a visual survey in terms of colour, odour (presence of hydrogen sulfide gas), consistency and thickness (Government of New Brunswick, 2012b).

Acceptable limits are in place for SRI in the form of treatment trigger levels and EQS (Table 1). The monitoring requirements in New Brunswick are statutory and the personnel involved are third party

consultants. A feedback mechanism is in place between farmers, monitoring agencies and regulators to promote the spread of information (Government of New Brunswick, 2012b).

There are no water column related characteristics required to be monitored as part of the New Brunswick salmon AEMP (Table 2). The water column is monitored, but only in terms of oxygen concentration, salinity and temperature within the salmon cages and solely at the discretion of farm managers. As stated within the salmon AEMP, criteria for selecting tools are as follows: "scientific confidence in the parameters and methods of sampling analysis to describe changes to the benthic community structure, repeatability and consistency in sampling and analysis, clear specification of spatial and temporal bounds, and cost effectiveness". With regards to choosing sediment sulfide concentrations as a monitoring tool over any other available techniques, it states "other indicators, such as oxidation-reduction potential, or those related to water quality, may also satisfy one or more criteria in the above list, but none to the extent of the benthic environmental indicator chosen for this EMP (Environmental Management Plan)" (Government of New Brunswick, 2012b).

The New Brunswick AEMP for finfish also specifically states that "the monitoring program will undergo review and adjustment as our knowledge and understanding of environmental conditions in the marine environment surrounding marine finfish cage aquaculture sites evolves. Review and adjustment will be triggered when it is demonstrated that there is a need, based on the progress of scientific research, or shifts in farm management strategies" (Government of New Brunswick, 2012b). The salmon AEMP also makes allowances for ongoing and future initiatives in the industry by stating "As research continues and additional data becomes available, it is expected that models will eventually be developed to account for a broader spectrum of potential effects. As new knowledge is acquired, the EMP (Environmental Management Program) may be adjusted to reflect new capability to identify parameters appropriate for assessing additional near-field and far-field effects of marine finfish cage aquaculture operations. In addition, as information becomes available, other indicators of environmental impact may be incorporated into the EMP" (Government of New Brunswick, 2012b).

It seems that we have now reached this time for review, adjustment and incorporation of new monitoring tools, as scientists, aquaculturists, consultants and regulators all agree that the over-emphasis on sediment monitoring has shown its limitations.

The New Brunswick government has a mitigation and remediation process built into the management program. This process relies on compliance with EQO in terms of sediment sulfide concentrations. If a site received a poor rating, a number of options are available to farm managers. These options can be to increase environmental monitoring, change site management or operations, review harvesting strategies or retrain the staff working on the site. The implementation of such plans has been fairly successful and has resulted in improved benthic conditions beneath sites (Wilson et al., 2009; Government of New Brunswick, 2012b).

New Brunswick is monitoring for ERI (Table 3). However, they are restricted to the benthos at aquaculture sites. Sulfur reducing bacteria are assessed annually as part of the visual monitoring survey, but no other ERI tools have been included in the monitoring program.

British Columbia salmon aquaculture environmental monitoring program (AEMP)

In British Columbia, an EIA is required prior to the approval of a new site or modification of an existing site. Computer models are included in the monitoring program and DEPOMOD is used to estimate the impacts of salmon cage sites. Baseline data are required prior to development with site specific bathymetry and hydrography being observed. In-depth site specific analysis is obtained for currents, tidal flows, sediment profiles and benthic habitat profiles (species richness and abundance). Class and family level abundance is observed for both mega- and macro-fauna species. Farm specific information includes biomass on site, farm volume, food conversion ratios, years of farm activity, harvesting schedules, cage configurations and depth of sampling locations.

In the category of SRI, organic sediment loading is monitored and computer modelling is applied to the data (Table 1). Video transect surveys are conducted beneath cage sites and the presence of macro-infauna is analyzed. The levels of pH and redox, total organic, particle size of sediments, copper, zinc, total volatile solids, free sulfides are taken annually within 30 days of peak biomass (Heaslip, 2008; Government of British Columbia, 2011). There are currently treatment trigger levels in place for all measured parameters with associated EQS that cannot be exceeded without mitigation.

Currently, there are no WCRI monitored in British Columbia with respect to salmon farming operations (Table 2). In terms of ERI (Table 3), a quantitative and qualitative assessment of benthic fauna is conducted annually within 30 days of peak biomass and the benthic fauna is identified to the family level (Government of British Columbia, 2005; Heaslip, 2008).

In British Columbia, the mitigation plans are based on maximal allowable chemical standards. These parameters may not be exceeded at peak production and if they are, the site is not allowed to re-stock until levels have returns to below acceptable limits. In some cases, this has led to “extensive operational adjustments” to ensure the site remains below acceptable levels (Wilson et al., 2009).

Existing Gaps in the Canadian Approach to Aquaculture Monitoring

In Canada, the responsibility for aquaculture activities is split between federal and provincial governments. The prevailing opinion is that an optimal suite of measurements is taken to protect the environment and to meet current regulations. However, the need to be globally competitive, innovative and environmentally sustainable often seems to evolve at a much faster rate than regulations. To support this trend, the AEMPs could be improved through the addition of a wider range of measurements and effect monitoring, as part of the EIA process (Wilson et al., 2009).

In terms of feedback mechanisms, industry representatives think that well-located farms have good environmental performance and that this has been confirmed through monitoring. It is believed that this has contributed to improved site selection. However, criticism has been directed at the industry because optimal production levels appear to be determined by "trial and error" (Wilson et al., 2009).

Some of the suggestions to improve Canada's monitoring program are to increase the number of sampling events per year. This could be useful in determining if management practices are effective and if the production levels of a given site are appropriate. It is also suggested that if provinces and federal government were brought together under a single governing structure for aquaculture, it would lead to a more effective feedback mechanism, reduced redundancy, harmonized guidelines and regulations, all resulting in improved site selection and farm development (Wilson et al., 2009).

In Canada, the perception of industry representatives is that all reasonable steps are currently being taken in order to assess the environmental impact of aquaculture activities. Most of the companies are of the opinion that they operate within the environmental regulations in order to protect the environment they work in. However, it should be noted that critics believe the current monitoring process acts solely to restrict aquaculture expansion rather than to improve actual management practices (Wilson et al., 2009).

Based on the tools identified in this study, the Canadian approach to monitoring salmon aquaculture is appropriate for monitoring SRI of intensive finfish farming operations. Through the use of sulfide measurements and video transect surveys, data are obtained in areas that lend themselves to sediment grabbing techniques. However, under the current monitoring program, areas with rocky substrates cannot be appropriately monitored. These areas will pass, for example, sulfide tests, regardless of what impacts they are having on the surrounding environment because sediment grabs are ineffective in "rocky" conditions. As a result, it is impossible to quantify the impacts of feeding on hard bottom, and the surrounding environment, with this method alone.

The Canadian approach to monitoring intensive finfish aquaculture is lacking regarding WCRI. Current salmon AEMPs do not require the monitoring of any of the identified water column related characteristics. Far-field effects of aquaculture on the water column are not well understood nor is it required to monitor them in the Canadian regulatory and stakeholder context. If no direct attempt is made to observe how aquaculture sites interact with the surrounding water column, the historical/baseline data will not be available for site managers or regulators should a broader water column or ecosystem related requirement arise in the future.

The Canadian approach to monitoring the ERI is limited, as it is solely focused on the impacts on the benthos directly beneath cage sites. The benthic indicators describe appropriately how salmon aquaculture operations interact with the environment in the "near-field". However, monitoring "far-field" impacts are not required. Any changes in the integrity of the ecosystem in the "far-field", or with regard to organisms in the water column, are not well understood and the tools to record them have not been established.

The Canadian approach to assessing the level of trophic or toxic effects is also limited. There are limits placed on what type of medicines and chemicals to be used in the day to day operations of managing an intensive fish farming operations; however, there are no considerations included for the monitoring of how these chemicals persist in the ecosystem or how far their effects might spread. Trophic effects are monitored, but only in the context of the benthos directly beneath cage sites. Tests such as bacterial assembly analysis in the form of sulfur reducing bacteria counts give an accurate reflection of how finfish operations can influence the benthos. However, these ERI tools do not provide insight as to how sites alter the ecosystem in the water column or in the "far-field" or BMA context (Wilson et al., 2009).

Recommendations

The existing gaps in the Canadian AEMPs are mostly related to WCRI and ERI. Recommendations include the incorporation of one or more physical-chemical parameters to monitor WCRI. Oxygen, salinity, temperature, ionized and unionized ammonia, turbidity, biochemical oxygen demand, nitrate and nitrite, dissolved reactive phosphorus, chlorophyll "a", copper, medicines (specific to each site/organization) and chemicals (specific to each site/organization) and/or nitrogen 15 signaling (Lojen et al., 2005; Dailer et al., 2010) have been adopted in other jurisdictions and could be incorporated into the Canadian approach to aquaculture monitoring.

The inclusion of almost all of the parameters is likely to be both cost and effort prohibitive, but would most likely give the most accurate representation of the state of the environment and form the basis for developing a comprehensive yet site-relevant suite of parameters. For example, Norway has decided that oxygen concentration is the most important water quality characteristic to monitor and that it alone can accurately represent the condition of the environment (Wilson *et al.* 2009; Bergheim, 2012). We recommend that research be conducted to select which water column related parameters would best reflect how aquaculture operations interact with the environment in the "far-field" and to act as representatives of water column integrity. It is possible that, in the Canadian context and at sites with varying characteristics, different water quality parameters will be found to most accurately reflect the state of the environment.

Research is required to develop innovative tools that are specific enough to provide relevant information for a variety of ecosystems yet broad enough to meet stakeholder needs. Biological indicators could also be used within an AEMP, as organisms living in the surrounding environment can integrate periodic and seemingly unrelated changes over time and offer a measure of overall ecosystem health (Vernberg et al., 1981; Jørgensen et al., 2005). This closer link to ecosystem functions, as well as the possibility of integrating over time, would suggest that biological tools may supplement or replace traditional physical-chemical measurements of the environment if monitoring for ERI. Innovative biological tools are needed to ensure that AEMPs are as efficient and cost effective as possible. As some biological measurements are likely to be site and location specific, much work remains to be conducted to establish an effective suite of tools for Canada-wide use that would meet the challenges of site specificity, regulatory consistency, cost efficiency and evolving stakeholder needs.

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MONITORING THE INVISIBLE WITH HIGHLY VISIBLE CONSEQUENCES: LET'S NOT FORGET THE DISSOLVED INORGANIC NUTRIENTS SO WE CAN USE THEM EFFICIENTLY

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Abstract

In Canada, aquaculture environmental monitoring regulations are quite unbalanced. In the marine environment, there is a disproportionate emphasis on sediment monitoring, with an almost disregard for processes taking place in the water column, especially regarding dissolved inorganic nutrients. In the freshwater environment, the situation is reversed, with much emphasis on water quality monitoring and little attention to sediment impacts. Scientists, aquaculture practitioners, monitoring consultants and regulators are starting to realize the limits of policies/regulations focusing almost entirely on sediment monitoring in the marine environment, and the fact that converting chemically dissolved forms into precipitates is not solving an issue but shifting it from the water column to the sediments in the freshwater environment. It is time to revise and improve policies/regulations with a more balanced approach to aquaculture environmental monitoring, with appropriate tools allowing the measurement of parameters in the sediments and water column in both environments, and by supporting biomitigation practices, such as integrated multi-trophic aquaculture, which take advantages of the nutritional benefits of the water used to grow fish to cultivate additional commercial crops while reducing nutrient levels in the environment.

Introduction

At a time when scientists, industry practitioners, third-party monitoring companies and regulators seem to finally be able to discuss the limitations of marine aquaculture regulations in Canada, which have been over-emphasizing sediment monitoring for almost two decades, it seems appropriate to also reconsider the type of wastes (or nutrients) to monitor, and why nutrient regulations vary so widely between the marine and freshwater environments.

Questioning regulations, based almost entirely on sediment monitoring, because of their dependency on sulfide and redox level analyses, was almost taboo during that period because the method had been internally recommended within the federal regulatory agency, Fisheries and Oceans Canada (Wildish et al., 1999) and had become a kind of dogma. If that method had its merits (discontinuing operations at inappropriate "depositional" aquaculture sites), it is now revealing itself ineffective at "erosional" sites, with hard bottom, and where sediments do not accumulate. Moreover, not having sediments accumulate at a site does not necessarily mean that the issue is solved; it could have been exported/shifted to

somewhere else and/or the accumulated compounds could now be in different chemical forms. As the French physicist Antoine Laurent de Lavoisier wrote, more than two centuries ago: “Rien ne se perd, rien ne se crée, tout se transforme”, i.e. “Nothing is lost, nothing is created, everything is transformed”.

Aquaculture monitoring in Canada is really a case of two extremes:

- In the marine environment, aquaculture environmental monitoring programs (AEMPs) are focusing on sediment monitoring and what happens in the water column is mostly ignored.
- In the freshwater environment, AEMPS are focusing on monitoring the water column and what happens to stream/lake bottoms is mostly ignored.

There is no real reason for such a regulatory disparity between the two environments, except for the particularity of this Canadian “historical” context.

Monitoring in the marine environment

Monitoring is not an end point; it quantifies some parameters to measure, in this case, the health of the ecosystem. In fact, the ultimate goal is to dispose of the deposed. Mitigating wastes by transforming them into valuable nutrients [biologically through IMTA, for example (Chopin 2013 a, b)] requires having the right organisms to convert, ultimately, all the organic matter so that it re-enters the overall nutrient cycle as inorganic matter and back into the production of living matter. This means that the receiving ecosystem needs to have the corresponding inorganic assimilative capacity, and that is only provided by organisms such as seaweeds (marine benthic macroalgae), microalgae and bacteria.

A major rethinking is needed regarding how an aquaculture farm operates. If large and smaller organic particles fell generally within, or not very far beyond, the site limits indicated on a map and a few buoys on the water at the site, dissolved inorganic nutrients travel farther away and their management should be considered with an aquaculture bay management area (ABMA) strategy, as is already done for pathogens and diseases. Moving over longer distances, they can easily, during their tidal excursions, move to other places and sites. In an extremely dynamic environment like the Bay of Fundy, it may be very difficult to track the site of origin of any particular inorganic nutrient molecule. It can be argued that it is, in fact, not necessary to push the resolution to that level, as seaweeds are not selective in their absorption of inorganic nutrients, such as nitrogen and phosphorus, and will absorb any, irrespective of their origin (being from aquaculture operations, terrestrial farming, industrial activities, urban activities, etc.). Consequently, one has to think that, at the time of harvesting seaweeds (cultured or wild), what can be calculated is the number of equivalents, of a particular nutrient, that have been sequestered in the particular ABMA and compare them to what has been added by the different activities.

We could, then, develop the idea that in an ABMA, with several finfish and/or invertebrate aquaculture sites already, some sites could be developed into “seaweed nutrient scrubbing stations”, which means that the idea of seaweed aquaculture sites needs to start to become acceptable in the minds of provincial and federal regulators.

Presently, in New Brunswick, kelp rafts have to be installed within the existing boundaries of salmon sites, which are already well occupied spatially by salmon cages. In an area with multiple fish farms in a bay, considerations of proximate culture location for the seaweed rafts may need to reflect the spatial scale at which the loading occurs more than to locate seaweed rafts within the confinement of arbitrary lines drawn on a map, but not necessarily reflecting how the ecosystem functions. One option could be the deployment of appropriately positioned seaweed rafts within a cluster of fed aquaculture sites, instead of immediately adjacent to fish cages. These "seaweed nutrient scrubbing stations" would then work at the bay management area level instead of the site level.

In southwest New Brunswick, there are presently 96 finfish aquaculture sites. Because of the 3 ABMAs system that was put in place in 2007 (Chang et al., 2007), two thirds of the sites should be active on any given year, i.e. 64 sites. However, only approximately 45 sites are generally active, which leads to question of whether the remaining 19-20 sites would not be available for other activities, including biosequestering dissolved inorganic nutrients through seaweed aquaculture. It is, consequently, time to consider "seaweed only" sites, within an integrated ABMAs strategy. It is time to think out of the box to recapture nutrients along the flow and diversify crops with complementary functions in the ecosystem, as practiced with IMTA (Chopin et al., 2013).

Cultivating seaweeds may be hard to conceptualize in the western world; however, seaweed aquaculture represents approximately half of the world mariculture production (49.1%; fish represent only 11.4%; Chopin, 2014). It is mostly concentrated in 6 Asian countries (96.3% of the production occurs in China, Indonesia, the Philippines, the Republic of Korea, Japan and Malaysia), hence the lack of appreciation for this resource in the western world. Moreover, seaweeds provide significant ecosystem services (e.g. nutrient biomitigation, oxygen provision, carbon sequestration and reduction of ocean acidification), which should be valued by the animal aquaculture sector and society, and lead to the establishment of nutrient trading credits used as financial incentive tools (Chopin et al., 2010).

The term "seaweeds", which is a particularity of the English vocabulary because it is the only language in which there is an added connotation of "weeds of the sea", could be scary, as the public hears in the news about "green tides" and can look at disturbing pictures coming from China (Fig. 1), France, England, Italy, and also, to a lesser extent, from Prince Edward Island (Fig. 2). Interestingly, in places with large seaweed cultivation areas, like Sanggou Bay in China (Fig. 3), there are no green tides, most probably because there is already too much competition for nutrients among the kelps.

Figure 1: Large green tide of *Ulva prolifera* in Qingdao, China. This phenomenon got a lot of attention in 2008 because of the presence of international journalists for the Olympic Games sailing competition, but has been a recurrent event since 2007 (photo credit: Weijun Duan).

Figure 2: Small green tide of *Ulva lactuca* in Basin Head, Prince Edward Island, Canada (photo credit: Thierry Chopin).

In the area of southwest New Brunswick, where salmon aquaculture is located, there are also around 158,811 renewable tonnes [fresh weight (FW)] of the brown seaweed Ascophyllum nodosum (rockweed) covering a significant portion of the intertidal zone (Ugarte and Sharp, 2012). The biomasses of extensive subtidal kelp beds in the region – mostly of the species Saccharina latissima, Alaria esculenta, Laminaria digitata and Agarum cribrosum – and of other key species in the intertidal zone – several species of the genus Fucus, Palmaria palmata (dulse), Ulva lactuca (sea lettuce) and Chondrus crispus (Irish moss) – have never been estimated, but they also play the role of significant nutrient scrubbers and certainly contribute to the assimilative capacity of the ecosystem. Moreover, the regular harvesting of Ascophyllum nodosum (12,436 tonnes FW harvested in 2013; R. Ugarte, pers. comm.) is equivalent to "squeezing the nutrient scrubber/sponge" regularly so that nutrient sequestration (i.e. nutrient soak up) can continue as new rockweed biomass is regenerated and nutrients accumulated in its tissues. All this aquaculture-grown and wild-grown seaweed biomass sequesters dissolved inorganic nutrients not only from fish aquaculture sources, but also from other marine and terrestrial sources; it is also, then, maybe not surprising that the Bay of Fundy has been spared from large green tides events. It is, however, important to remain vigilant, as small, sporadic accumulations of Ulva lactuca can be spotted, mostly during the summer months (Fig. 4).

Figure 3: Satellite view of Sanggou Bay, China, displaying intensive seaweed (*Saccharina japonica*) aquaculture mixed with some invertebrate aquaculture (photo credit: Google earth).

Figure 4: Occurrence of green seaweeds (*Ulva* sp.) in the intertidal zone at Maces Bay, New Brunswick, Bay of Fundy, Canada (photo credit: Thierry Chopin).

If monitoring nutrients directly is quite difficult, could proxies be developed?

Measuring nutrient concentration in seawater, especially in a complex and dynamic environment such as the Bay of Fundy, can be a logistical nightmare, time consuming and expensive. Taking a sample, always at the same time and at the same place, is not a recipe for analyzing comparable samples: tides change every day; currents, winds, waves, swell, feeding regimes and quantities too. To describe what happens to dissolved nutrients at an aquaculture site would require a considerable number of samples, stations, and people to end up with a multitude of samples, taking a lot of time to analyze, becoming a financially prohibitive program.

Unfortunately, to this day, no reliable nutrient probe has been developed for the seawater environment (too many ionic interferences remain to trust the readings). In these conditions, automated measurements of series of samples accumulated in data loggers is not conceivable.

If instantaneous nutrient concentration determinations are not possible, one possibility is to look at nutrient accumulation over time by organisms that could be appropriate “nutrient sentinels” or “nutrient canaries”. Seaweeds could be that type of indicator, as they are well-known for performing luxury absorption of certain elements such as nitrogen and phosphorus (Hurd et al., 2014). Measuring their nutrient contents can, then, offer a possible method for tracking the nutrient regime they have been exposed to over a determined time period.

If using organisms that can integrate the nutrient regime they have been exposed to over time would be a significant improvement over a multitude of water samples, some will argue that tissue analyses are still time consuming and expensive.

The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) is presently working on the development of a new biological tool: the possibility of correlating seaweed thallus colour (lightness, chroma and hue) to tissue nitrogen content with a handheld sphere spectrophotometer (X-Rite SP60, Grand Rapids, Michigan, USA). It is hoped that this tool will be faster and cheaper than traditional methods (for example, CHN elemental analyzer and digestion and colorometric techniques) and could act as a proxy for tissue nutrient analyses. Data remain to be fully analyzed, but preliminary results indicate that this tool could be quick, easy to use and could allow researchers and regulators to monitor cumulative aquaculture-based nutrient effects integrated over time.

Monitoring in the freshwater environment

In the freshwater environment, the most troublesome element is not nitrogen, as in the marine environment, but phosphorus. Solid aquaculture effluent phosphorus, from faeces and large particulates, can be minimized with the use of physical treatments such as filters and settlings ponds. Soluble aquaculture effluent phosphorus can be reduced by improving feed formulations, then, further chemical or biological methods are needed.

Systems removing phosphorus by chemical precipitation are expensive and complex to be adjusted properly. They can reduce dissolved phosphorus in the water column and help reach present monitoring guidelines; however, the element becomes bound to ferric sulfates and polymers and converted into precipitates sinking to the bottom. Clearly, the issue is not really solved but shifted from the water column to the sediments. Moreover, it begs the question of whether phosphorus (and other nutrients) could not be put to better use.

Developing freshwater integrated multi-trophic aquaculture (FIMTA) as a biomitigation tool

Rather than treating and releasing the wastewater and wasting potential nutrients, it could become a source of irrigation water, nutrients and media for additional commercial crops through the development of freshwater IMTA (FIMTA) systems. FIMTA (sometimes called aquaponics) is the combination of animal aquaculture, microbial digestion and plant hydroponic cultivation. Just like in saltwater operations, the nutritional benefits of the water that has been used to grow fish are considered. From an environmental perspective, it is the same strategy of recapturing lost nutrients and energy and converting them into biomass of commercial value. FIMTA has several advantages over other recirculating aquaculture systems (RAS), hydroponics (which needs to add fertilizers) and wetlands (with limited efficiency during the cold winter period in Canada). FIMTA should increase water reuse, demand no extra farm soil and produce high yields of fresh, nutritious additional crops of commercial value in the form of vegetables, fruits, herbs, ornamentals, and more (Fig. 5). From a marketing perspective, it would be most interesting to extend the IMTA approach by developing an overall system wherein salmon would be IMTA-produced from land-

based, closed-containment, freshwater hatcheries (FIMTA) to open-water marine sites (MIMTA), taking the IMTA concept literally from the egg to the plate.

Figure 5: Some of the plants cultivated at the freshwater integrated multi-trophic aquaculture (FIMTA) pilot-scale system operated at the University of New Brunswick in Saint John. These plants are being selected for growing and extracting nutrients at temperatures experienced in salmon hatcheries (photo credit: Thierry Chopin).

It is also worth noting that the New Brunswick Department of the Environment is very interested in our initiative to develop FIMTA. At a time when the industry is moving toward a performance-based standard approach to freshwater aquaculture, FIMTA could be a very efficient strategy for effluent biotreatment of land-based facilities and could become an important component of the Environmental Management Program. In particular, using plants to extract phosphorus from effluent waters could prevent eutrophication and help farmers meet water quality guidelines.

Conclusions

The out of sight, out of mind attitude needs to change. Dissolved inorganic nutrients are difficult to document (they cannot be video-taped) and to measure. However, processes in the marine and

freshwater environments need to be understood with an ecosystem approach in mind, and there is a need to go beyond monitoring only sediment related impacts to include water column related impacts and ecosystem related impacts (Day et al., 2015). This approach in monitoring programs should also be consistent for both the marine and freshwater environments.

Biological tools may supplement or replace traditional physical-chemical measurements of the environment. Innovative biological tools - such as the handheld sphere spectrophotometer mentioned above to measure the colour of seaweed thalli as a proxy for their nitrogen content, reflecting the nutrient conditions they have been exposed to integrated over time - are needed to ensure that aquaculture environmental monitoring programs are as efficient and cost effective as possible.

In the Bay of Fundy, highly visible consequences of nutrification, like significant green tides, have not been seen, most probably because the underestimated assimilative capacity of a highly seaweed rich intertidal and subtidal zone, playing a significant nutrient scrubbing role, has not yet been exceeded. It is, however, important to remain vigilant.

Nutrients should not necessarily be considered wastes and their biorecovery, through practices such as IMTA, should be recognized as recycling methods whose implementation should be encouraged, with an integrated ABMA strategy in mind for open-water marine sites at sea. The IMTA concept can also be extended to freshwater systems (FIMTA) such as land-based, closed-containment, freshwater hatcheries. It would, then, be possible to develop an overall system wherein salmon would be IMTA-produced from the egg to the plate.

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Climate Change Session

AAC AND WAS SPECIAL SYMPOSIUM ON CLIMATE CHANGE AND AQUACULTURE

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Introduction

The topic of climate change's inevitable threat to the sustainability of aquaculture is drawing increasing attention; two Atlantic Region industry associations had identified "climate change" as a 2014 R&D priority, the PEI Aquaculture Alliance held a one-day members workshop in March, 2014 and the annual World Aquaculture 2014 in Adelaide held the session Climate Change Ready-Management Strategies for the Future in June. As a joint initiative of the AAC and WAS, in the spirit of strengthening their Affiliate relationship, in 2013 the two organizations agreed to combine forces to organize a symposium on Climate Change and Aquaculture as part of the 30th Anniversary Aquaculture Canada 2014 conference in Saint Andrews, NB. The workshop was Co-Chaired by myself and Dr. Juan Pable Lazo Corvera (Director – WAS; Scientist – CICESE, Ensenada, MX) with significant input provided by Dr. Gregor Reid (Senior Research Scientist – UNB, Canadian Integrated Multi-Trophic Aquaculture Network).

The topic of climate change and aquaculture is a broad and emerging area including meteorology, oceanography, engineering, ecosystem modelling, biology, and genetics. As organizers we felt that the approach should be on two fronts:

1. To inform (by presentations) the audience of the current state of climate knowledge, to situate that in the Canadian Marine context, to present on current projects, initiatives and science and technical capacity, and to offer an industry perspective.

2. To provide a forum for Q&A and discussions between the audience and presenter and among the presenters on what is needed to further support this important convergence of fields and what would be priority areas for investigation.

The symposium was open to all attendees and featured 10 presentations, one of the largest sessions held to our knowledge on this emerging topic. Dr. Keith Brander (co-recipient of the 2007 Nobel Peace Prize) kicked-off the symposium with his over-arching talk, *Climate Change and Aquaculture – Including Issues from the IPCC Reports* spoke on the findings related to aquaculture in the '07 and upcoming '14 IPCC reports, the notion of mitigation vs. adaptation as well as potential benefits and challenges that climate change might bring. Dr. Gregor Reid (UNB) spoke on what might be expected regionally related to climate change and the likely biological implications for fish and shellfish. Peter Warris of the PEI Aquaculture Alliance summarized the 1 day March workshop organized by the PEIAA on this topic and Atlantic

Canadian industry perspectives on climate change effects. Dr. Adam Fenech (Director - UPEI Climate Research Lab) presented recent climate changes and climate trends for Atlantic Canada. Dr. Lara Cooper (DFO-SABS) gave an overview of DFO's Atlantic Climate Change Adaptation Services Program and examples of past and present DFO climate change and aquaculture related projects. Ron Pelot (Dalhousie U.) provided information on the Marine Environmental Observation, Prediction and Response NCE and discussed projects under this NCE related to reducing marine hazards for ocean industries. A few talks such as those provided by Drs. Sarah Stewart-Clark (Dalhousie U.), Scott Applebaum (U. of Southern California) and Helen Gurney-Smith (Vancouver Island U.) spoke to specific projects related primarily to shellfish resilience and physiological stress measurement in response to climate change-related stressors – the shellfish sector in North America has been the most visibly affected by climate change (ocean acidification, high termperature). And finally Dr. Helen Gurney-Smith gave a talk prepared with three industrial co-authors on some immediate examples of climate change impacts on the shellfish industry and proposing a "call to action" for industry, regulators and academics to engage in science and policy directly applied to climate change.

A lively discussion followed the presentations which covered the recent history of perspectives on climate change impacts on aquaculture, how much does industry know related to its needs, what is improving on climate modelling and how is it ensured that modelling improves going forward. It was also reinforced that the science is underway and results and improvement in modelling are forthcoming. Nonetheless, improvement is still needed and how to see that that improvement takes place is still an outstanding question (e.g. funds to establish and maintain an ocean monitoring network). There were no specific recommendations or conclusions from this discussion.

Along with on-going projects on both Canadian coasts and elsewhere and a follow-up Atlantic Region workshop taking place in St. Andrews in April 2015, we will advance on providing new information to help the aquaculture sector adapt their activities in order to persist and thrive in an increasingly challenging environment.

THE CHANGING OCEANS: CAUSES, EFFECTS AND MITIGATION FOR SHELLFISH IN ACIDIFYING TIMES

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Introduction

Marine shellfish are major components of coastal and estuarine ecosystems in both northern and southern hemispheres, providing essential ecological services including habitat structure (Gutiérrez et al., 2003; Zippay, Helmuth, 2012), water purification (Whitman Miller et al., 2009) and a food source to other organisms (Gazeau et al., 2013). Such species are also highly economically important in worldwide aquaculture production, as well as in commercial and recreational fisheries (Whitman Miller et al., 2009), and therefore any declines can have major consequences for coastal biodiversity, ecosystem function and services (Gazeau et al., 2007). In marine ecosystems rising atmospheric carbon dioxide (CO_2) and climate change are associated with concurrent shifts in other parameters such as temperature, circulation, stratification, nutrient input, oxygen content and ocean acidification (Doney et al., 2012). Climate change is occurring on local and global scales, and temperature has already caused shifts in marine ecosystem composition and function (Pörtner, 2008). Such population-level shifts occur due to physiological intolerances to new environments, altered dispersal patterns and changes in species interactions which, when combined with local invasions and extinctions, result in altered community structure and the possible emergence of novel ecosystems (Doney et al., 2012). Ecosystem evolution over the next decades will be driven by many factors including climate change, ocean acidification, modification to fishing pressures, pollution and eutrophication (Blackford, 2010).

Ocean acidification

Atmospheric increases in anthropogenic carbon dioxide are creating massive changes in the marine carbonate system by increasing the concentration of hydrogen ions, and therefore lowering seawater pH, in the Earth's oceans. This is a phenomenon known as ocean acidification, and the buffering ability of seawater is decreased with increasing atmospheric concentrations of CO_2 (Pörtner, 2008). Predictions integrating the continued use of fossil fuel calculate atmospheric CO_2 increases from 380ppm (current levels) to 750ppm (under the IPCC 1S92a scenario (Intergovernmental Panel on Climate Change, 1990) or >1000ppm (Royal Society, 2005) in 2100, to more than 1500ppm in the next century (Wigley et al., 1996). Ocean pH has already declined by 0.1 unit compared with pre-industrial values (Orr et al., 2005) and is predicted to decrease by another 0.4 unit by the end of this century (Caldeira, Wickett, 2003), which may result in substantial ecological and economic effects (Green et al., 2009). Coastal and estuarine pH and CO_2 levels are more variable than the open ocean due to natural variability, eutrophication and net heterotrophy (Borges, Gypens, 2010; Kemp et al., 2005), acid-forming compound deposition (Doney et al., 2012), regional changes in land use (Green et al., 2009), and watershed inputs (Dove, Sammut, 2007; Salisbury et al., 2008). Therefore shallow water location can be inundated with rising CO_2 levels, resulting in increased vulnerability and disturbances in ecosystem services (Barton et al., 2012; Cooley, Doney, 2009; Feely et al., 2012), causing ocean acidification to occur sooner in coastal and estuarine areas than

in the open ocean (Waldbusser et al., 2011). The involvement of multiple processes also creates difficulty in measuring and predicting ocean pH in these highly variable areas (Blackford, Gilbert, 2007; Borges, Gypens, 2010; Soetaert et al., 2007).

Effects on shellfish

Ocean acidification is already a major issue globally for both wild and cultured populations of marine shellfish. Saturation states (Ω) of calcium carbonate ($CaCO_3$) in seawater are used as a proxy for the ease in which calcifying biota such as bivalves can deposit calcium carbonate (Fabry et al., 2008; Feely et al., 2009; Feely et al., 2004; Millero, 2007), where increased partial pressures of CO_2 (pCO_2) diminish the seawater saturation states of aragonite and calcite, the two most commonly biomineralized forms of $CaCO_3$ (Whitman Miller et al., 2009). Even moderate changes in pH can cause shell dissolution or have physiological impacts on larval and adult organism stages(Dove, Sammut, 2007; Gazeau et al., 2007; Kurihara et al., 2007; Parker et al., 2009; Talmage, Gobler, 2009; Whitman Miller et al., 2009).

As oysters, mussels, clams and other bivalves form the basis of the global aquaculture and fisheries industries, the discussion here will focus on commercially important bivalve species. Initially bivalve larvae deposit a predominantly amorphous calcium carbonate (ACC) shell, which is then partially transformed to aragonite (Weiss et al., 2002). Juvenile and adult bivalve shells predominantly contain calcite, which is less soluble than aragonite (Orr et al., 2005), which in turn is less soluble than AAC. Therefore the AAC larval shell is the most susceptible stage to dissolution from ocean acidification (Watson et al., 2009). As the aragonite becomes less saturated at high pCO_2 levels, the energetic costs for shell biomineralization should become progressively more expensive (Whitman Miller et al., 2009). As the larval stage contains AAC, it may be expected that this stage would be the most sensitive to dissolution from ocean acidification (Waldbusser et al., 2010), and negative responses have been reported in the large majority of studies on commercial species to date (Gazeau et al., 2013), see Figure 1. This includes the Pacific oyster *Crassostrea gigas* (Barton et al., 2012; Kurihara et al., 2007; Parker et al., 2010; Timmins-Schiffman et al., 2013), the Eastern oyster *C. virginica* (Talmage, Gobler, 2009; Whitman Miller et al., 2009), the Sydney rock oyster *Saccostrea glomerata* (Parker et al., 2009; Parker et al., 2010; Parker et al., 2012; Watson et al., 2009), the blue mussel *Mytilus edulis* (Gazeau et al., 2010), the Mediterranean mussel *M. galloprovincialis* (Kurihara et al., 2008), the bay scallop *Argopecten irradians* (Gobler, Talmage, 2013; Talmage, Gobler, 2009; 2011) and the hard clam *Mercenaria mercenaria* (Gobler, Talmage, 2013; Talmage, Gobler, 2009; 2011). See Gazeau et al 2013 and Parker et al 2013a for comprehensive summaries of research on the effects of ocean acidification on the fertilization, embryonic and larval development of commercial and non-commercial gastropod species and mollusc species. Responses of bivalve larvae are species-specific, and can range from negative to non-significant to positive (e.g. no reduction in calcification rates of *C. ariakensis* compared to negative results in *C. virginica* (Whitman Miller et al., 2009), as shown in Figure 2). In these cases of poor larval performance, larval shells were deformed, growth rates were low and / or high mortalities were observed.

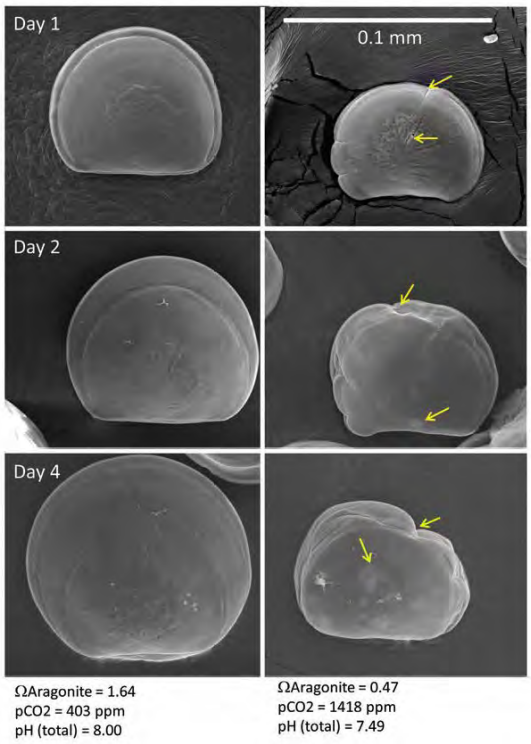

Figure 1. Pacific oyster larvae from the same spawn, raised by the Taylors Shellfish Hatchery in natural waters of Dabob Bay, WA having favorable (left column, pCO2 = 403 ppm, Waragonite = 1.64, and pH (total) = 8.00) and unfavorable (right column, pCO2 = 1418 ppm, Waragonite = 0.47, and pH (total) = 7.49) carbonate chemistry during the spawning period. Similarly unfavorable water conditions occur at Dabob Bay and Netarts Bay, OR, due to regional upwelling of high pCO_2 waters to the surface. Images are Scanning Electron Microscopy (SEM) of representative larval shells from each condition from 1 to 4 days post-fertilization. As the sampling is destructive, each larva shown is a different organism, and should not be interpreted as the same larvae ageing through time. Under more acidified conditions, right column, development of shell is impaired; arrows show defects (creases) and some features (light patches on shell) that are suggestive of dissolution. The scale bar in the upper right panel is 0.1 mm, or approximately the diameter of a human hair. *Photo credit- Brunner/Waldbusser, used with permission.*

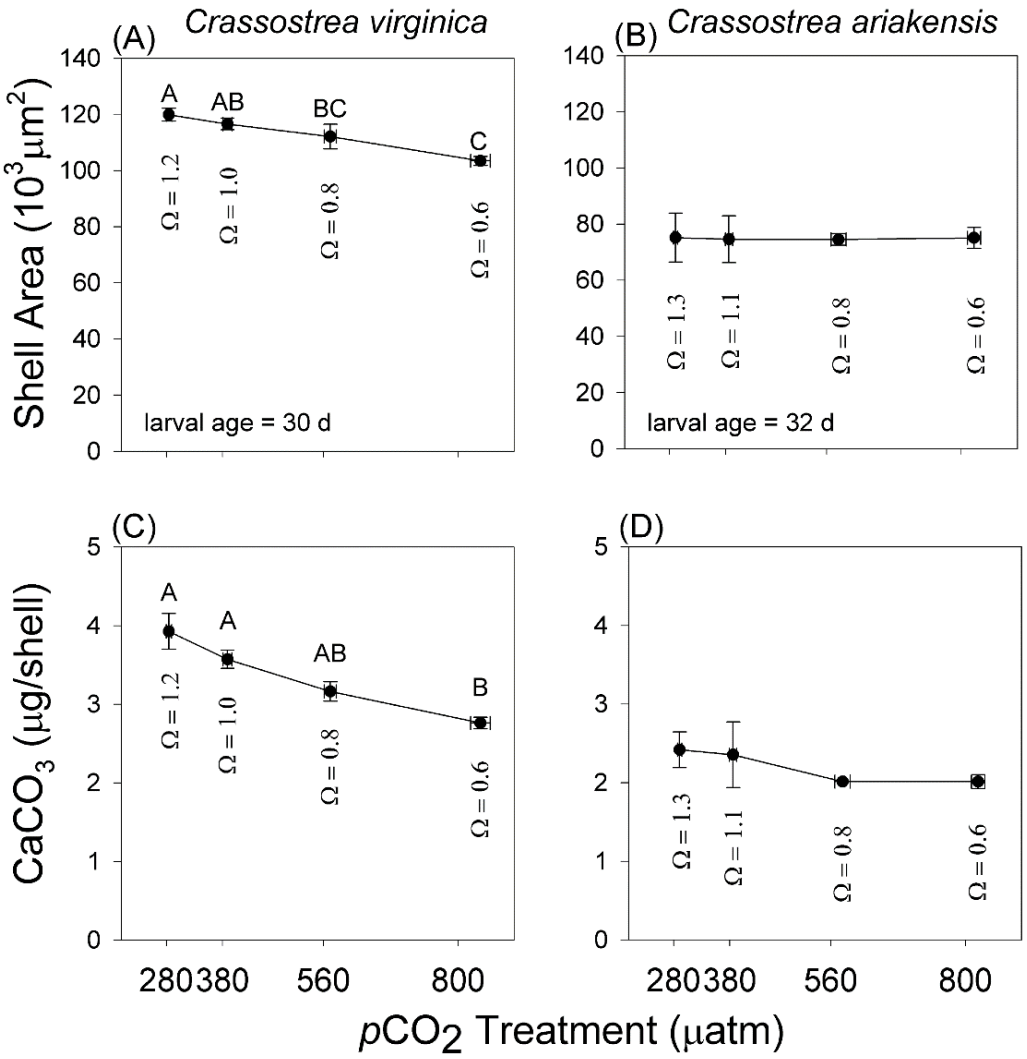

Figure 2. Effects of pCO_2 treatment on larval shell growth and calcification. Mean shell areas±SEM (μm^2) (panels A and B) and mean shell $CaCO_3$ content±SEM (μg/shell) (panels C and D) reported by pCO_2 treatment±SEM (μatm) for two oyster species. Corresponding aragonite saturation states (Ω_{arag}) are indicated for each treatment. Statistical differences determined by ANOVA and Tukey HSD tests. From (Whitman Miller et al., 2009), doi:10.1371/journal.pone.0005661.g002.

The extreme post-settlement loss of juveniles has often been attributed to factors such as predation (Ólafsson et al., 1994), competition (Ahn et al., 1993) and hydrodynamic dispersion (Roegner et al., 1995), but until recently had not addressed dissolution mortality (Green et al., 2009). Studies on the impact of lowered pH on post-larval hard clams (*Mercenaria mercenaria*) have found a size-dependent mortality factor, where larger individuals were able to withstand dissolution through increased rates of calcification (Talmage, Gobler, 2011; Waldbusser et al., 2010), or by reaching a size at which corrosive conditions survival was unaffected (Green et al., 2009). In addition, linkages are being made between parental effects on offspring tolerances; adults exposed to elevated pCO_2 during reproductive conditioning had positive carry-over effects on oyster larvae (Parker et al., 2012). In juvenile and adults responses to acidification are again likely to be species-specific or even vary within species due to localized acclimation,

adaptation and food availability and quality (Thomsen et al., 2010). Such variability of species responses can also be caused by 1) the differential capacities of the organisms to regulate pH at the site of calcification, 2) the structure of shell layers, and 3) shell mineralogy (Reis et al., 2009). Studies of adult mussels (*Mytilus galloprovincialis* and *M. edulis*) all show high resilience to the predicted pH for the end of the century, whereas oysters appear less resilient despite producing less soluble shells (Gazeau et al., 2013).

Interaction with other variables

Coastal and estuarine habitats are dynamic areas, where shore-line organisms typically encounter variations in salinity, desiccation and predation pressures, seasonal effects, food availability, temperature and hypoxia. Temperature influences strong ecosystem changes, due to physiological impacts and species thermal windows, which may be further narrowed in the presence of increased carbon dioxide levels (Pörtner, 2008). Salinity can be an important driver for species distribution, as seen by correlations between ambient salinity and mussel population speciation (Braby, Somero, 2006). Increases in CO_2 and other greenhouse gases will also elicit global warming, and therefore increased freshwater inputs into the marine system exposing organisms to hypo-osmotic stress (Somero, 2012). Aragonite saturation states are highly seasonal (Evans et al., 2012), with the frequency and duration of upwelling differing inter-annually over temporal scales of between 6 hours to 3 days (Harris et al., 2013). Increased food availability and quality have been seen to improve Pacific oyster tolerances to salinity and temperature variability (Barton et al., 2012), and have resulted in unexpected observations of low pH and increased calcification in oyster larvae over the short-term (Timmins-Schiffman et al., 2013). Mussels (*Mytilus edulis*) were also found to tolerate high ambient pCO_2 when accompanied by an abundant food supply (Thomsen et al., 2013) indicating that food availability may co-determine the maximum species performance and resistance (Gazeau et al., 2013).

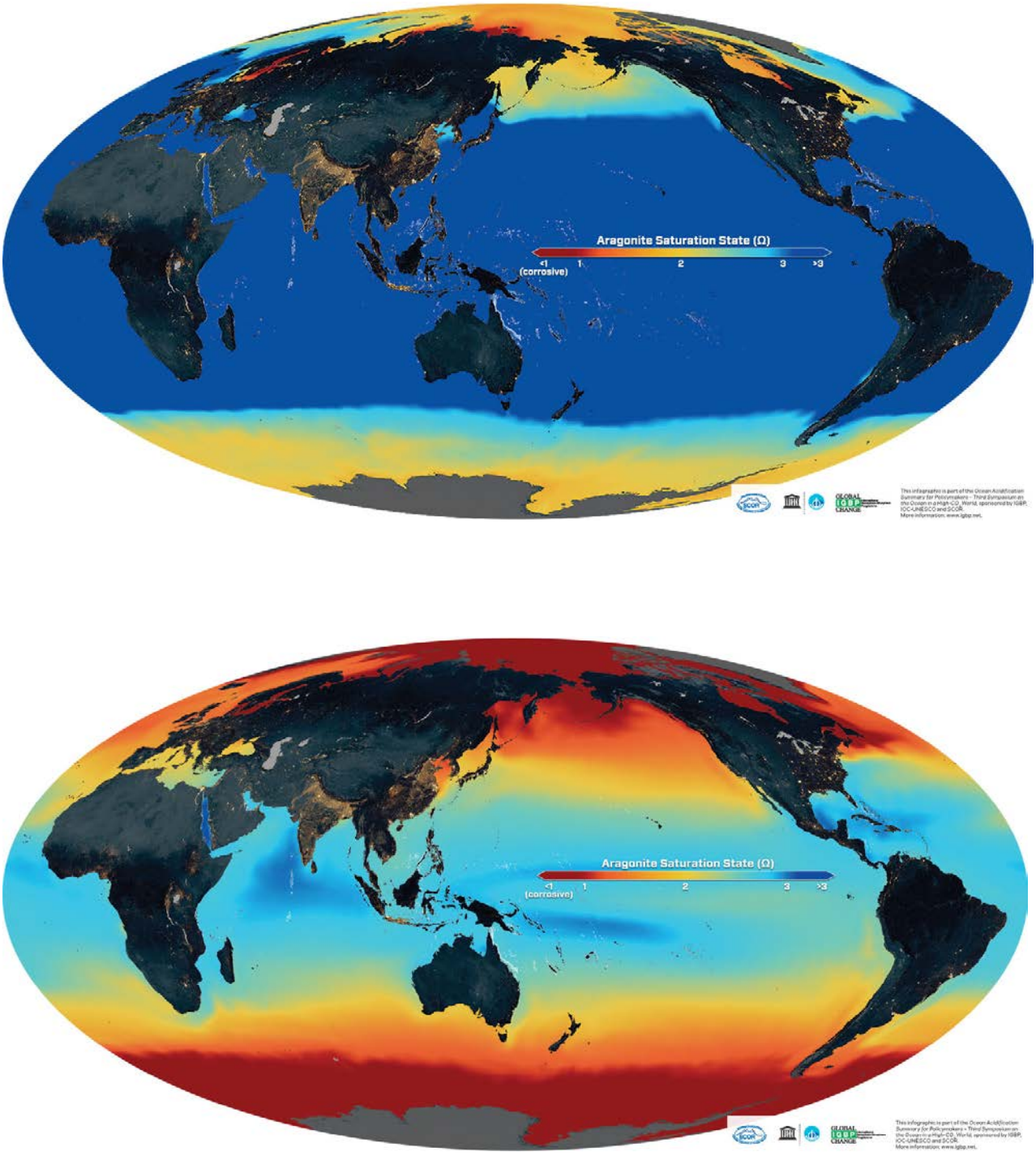

Figure 3. Aragonite saturation a) at the beginning of the industrial revolution 1850-1860, and b) as predicted in 2090-2100 (IPCC High CO_2 emissions RCP 8.5 scenario). Warmer colours denote lower aragonite saturation, with red indicating a Ω_A of 1 or below (IGBP/IOC/SCOR, 2013).

Monitoring the issue

Ocean pH has been undersampled spatially and temporally, mainly due to the vastness of the ocean, and that the majority of pH measurements are taken from vessels (Martz et al., 2010). Another issue is the instrument sensitivity required to accurately detect small changes in pH on a biologically relevant scale. Traditionally pH has been measured using potentiometric techniques using sensitive glass membrane electrodes (Jin et al., 2000), but calibration issues have resulted in the use of spectrophotometric methods for the vast majority of reliable ocean pH measurements (Friis et al., 2004; Nakano et al., 2006). In short, there is a pressing need to develop cost effective, stable and precise pH sensors for measuring global seawater, as demonstrated by the current Wendy Schmidt Ocean Health XPrize competition (http://oceanhealth.xprize.org/). However, there has been much debate concerning the use of pH as 'the' primary indicator of climate change on aquatic biological organisms. Recent ocean acidification research suggests that for some calcium carbonate-based organisms, such as molluscs, it is the aragonite saturation (the Ω_A) that is the crucial measurement to be made, as it provides an indication of whether the environment is conducive to survival and reproduction. In general, literature reports values below 1 as corrosive to shellfish, whereas others report that larval viability begins to be affected at values of 1.8 (Barton et al., 2012). Global predictions clearly show the drastic differences in aragonite saturation in a pre-industrial era compared to that expected in 2100 (Figures 3a and b), but local conditions may exacerbate impacts. For example in Prince William Sound in Alaska, conditions may arise where water salinity and pCO_2 concentrations are low and pH is high, but with corresponding aragonite saturation values below 1 (Evans et al., 2014), indicative of corrosive conditions for shellfish (Figure 4). Therefore in order to understand the biological impact of changing ocean conditions on calcium carbonate based organisms, it is important to carefully choose monitoring variables and to be cognisant of limitations (see Table 9 (Millero, 2007). Comprehensive ocean acidification monitoring equipment are commercially available, such as the Sunburst SuperCO_2 automated system developed by Hales et al (Evans et al., 2011; Hales et al., 2004), which can measure changing CO_2 levels every second providing highly accurate long-term data (www.sunburstsensors.com). These systems and subsequent improvements may not be cost effective for all applications, but nodes employing such equipment can be used to service local groups (e.g. industry, municipalities, researchers), due to its ability to sample discretely as well as continuously. Such equipment revolutions are likely to advance to cheaper more commercial products, enabling higher resolution monitoring on a larger spatial scale.

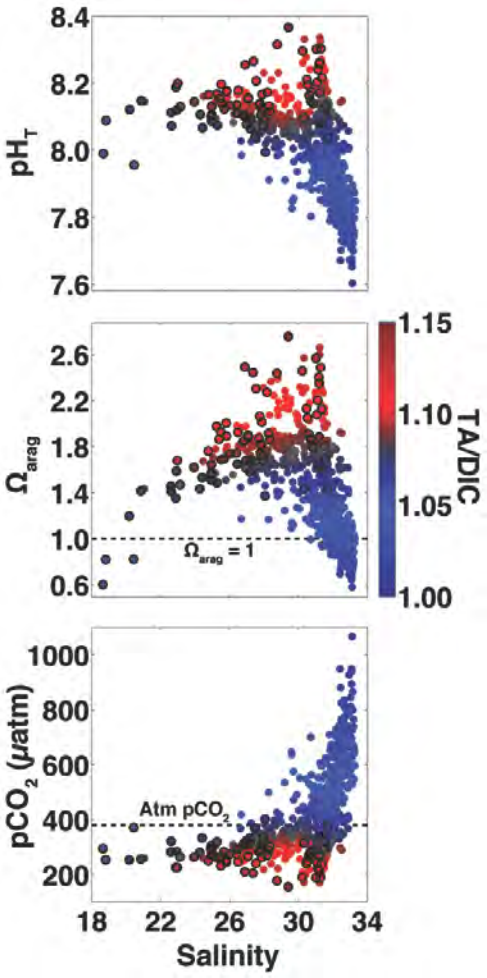

Figure 4. pHT (top), Ωarag (middle), and pCO2 (bottom; µatm) as a function of salinity and TA/ DIC ratio. The dashed horizontal line in the middle panel is the Ωarag = 1 level below which dissolution of aragonite will occur, and the dashed horizontal line in the lower panel is the September 2012 atmospheric pCO2 in PWS estimated following Evans and Mathis (2013; 380 µatm). Surface data (<9 m) are highlighted in each panel using bold circles (Evans et al., 2014; IGBP/IOC/SCOR, 2013).

Mitigation

In the Pacific Northwest there have been clear linkages between high pCO_2 concentrations and larval development and their associated impacts on shellfish aquaculture(Barton et al., 2012). Strategic multidisciplinary panels have made assessments identifying critical gaps in understanding, recommendations for future research and specific action plans for implementation (Kelly et al., 2014; Washington State Blue Ribbon Panel on Ocean Acidification, 2012) for major shellfish production States such as Washington and Oregon in the USA. Ecological resilience to climate change is a combination of resistance to increasingly frequent and severe disturbances, the capacity for recovery and self-organization, and the ability to adapt to new conditions (Bernhardt, Leslie, 2013). Currently ~100 different shellfish species (both marine and freshwater) are cultivated commercially (Gazeau et al., 2013), with a reported global value of US$ 13.1 billion in 2008 (DaSilva, Soto, 2009). Reductions in species numbers and populations due to climate change would restructure habitats and food webs, reduce associated

employment and sociological benefits (Newell, 2004). Detailed knowledge of local carbonate chemistry fluxes can be used to assist in the development of adaptive strategies for resource managers such as shellfish hatchery operators (Barton et al., 2012). Avoiding the use of low aragonite saturated waters when strong upwelling conditions may occur have enabled the significant restoration of oyster hatchery production (Barton et al., 2012), and seawater can be buffered to increase aragonite saturation. For infaunal species in detrimental sediment saturation states, sediment buffering using crushed shell may increase the alkalinity, pH and aragonite saturation states of the sediment and decrease shell dissolution and / or promote larval recruitment (Green et al., 2009). However if climatic shifts move further towards higher CO_2 conditions, there may be a point where adaptive strategies are no longer effective (Barton et al., 2012).

Addressing the causes and consequences of adaptive genetic differentiation among invertebrate populations promises to advance community ecology, climate change research, and the effective management of marine ecosystems (Sanford, Kelly, 2011). Selective breeding programs may be a solution for aquaculture operations to overcome future climate effects, as seen in significantly differing sensitivities to elevated pCO_2 conditions in wild and selectively bred populations of the Sydney rock oyster (Parker et al., 2011a). Hatchery operations in the USA have already seen differences in calcification rates in selective programs, thereby proving its usefulness as a breeding strategy (Waldbusser et al., 2010), although shifting baselines may encounter the limit of the species physiological threshold (Waldbusser et al., 2011), with periods of undersaturation likely to increase both in frequency and intensity (Harris et al., 2013). The determination and selective culturing of more resilient species may also help maintain mollusc harvests (Cooley et al., 2012), as there are adaptive differentiation to responses in marine invertebrates (Sanford, Kelly, 2011). Omics technologies may also assist in 'climate proofing' aquaculture enterprises through genomic resource development to select for genetic improvement within a species (Zhang et al., 2012), and proteomic studies identifying desirable protein signatures (Parker et al., 2011b). Insights from gene expression stress experiments are facilitating the development of biomarkers, which will be useful in determining physiological status of populations (Somero, 2012), helping to provide a molecular basis of the observed changes (Hüning et al., 2013).

Although not discussed in depth here, the interaction of pH and carbonate chemistry changes with other environmental stressors (e.g. increased temperature, changing salinity, species interactions, species acclimation potential) is not well understood (Gazeau et al., 2013). Resilience or ecosystem-based approaches can advance marine conservation and management, but must be balanced with social and economic costs and considerations (Bernhardt, Leslie, 2013). In order to fully elucidate the impacts of climate change on shellfish ecology, aquaculture and fisheries, it will be necessary to: perform multi-stressor experiments over large temporal and spatial scales; to examine specific species and genetic interactions; and to conduct metabolic studies to examine energy budget requirements so that the adaptive capacity, fitness and resilience of these ecosystems can be determined and appropriately managed.

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THE CHANGING CLIMATE OF THE ATLANTIC REGION OF CANADA

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Abstract

The leading authority on climate change, the Intergovernmental Panel on Climate Change (IPCC) has concluded that warming of the climate system is unequivocal, and will continue for centuries. A climate baseline can be developed for regions in Canada by locating climate stations in the study area using Canada's National Climate Data and Information (NCDI) Archive. For projections of future climate, global climate models (GCMs) are the most advanced science available. The Climate Research Lab at the University of Prince Edward Island has a dataset available to researchers, called the Climate, Ocean and Atmosphere Data Exchange (COADE), that provides easy access to the output from forty global climate models used in the deliberations of the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) including monthly global climate model projections of future climate change for a number of climate parameters including temperature and precipitation. Over the past 50 years, annual mean temperatures have increased at Fredericton, New Brunswick (0.4°C). Truro, Nova Scotia (0.5°C), Charlottetown, Prince Edward Island (0.5°C) and St. John's, Newfoundland and Labrador (0.3°C); while annual total precipitation has decreased at Fredericton, New Brunswick and Charlottetown, Prince Edward Island (-5%); and increased at Truro, Nova Scotia (+1%) and at St. John's, Newfoundland and Labrador (+3%). Applying the high greenhouse gas emission future (RCP8.5) on a base climate normal of 1981-2010 to an ensemble of forty global climate models used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) results in future temperature increases for the Atlantic Region of Canada ranging from 2.3 to 3.3 degrees Celsius, and in future precipitation increases ranging from 5.3 to 8.5 percent. These preliminary results should assist the aquaculture community in planning to adapt to changes in climate through increasing the understanding of how climate has impacted the region in the past, and how climate will impact in the future.

Introduction

The leading authority on climate change, the Intergovernmental Panel on Climate Change (IPCC) has concluded that warming of the climate system is unequivocal, and will continue for centuries. Global temperatures could rise by between 0.3°C to 4.8°C during the 21st century with predictions of more frequent warm spells, heat waves, and heavy rainfall, and an increase in droughts (IPCC, 2014). Recent studies of regional climate have shown that the climate of the Canadian province of Prince Edward Island in Canada's Atlantic Region is getting warmer and drier (Fenech, 2012), especially in the past 15 years; and the coastal waters off of Atlantic Canada have increased as much as 2°C over the past 30 years (Galbraith, 2012). Quantifying the risk (estimation of likelihood and consequence) of, and developing an adaptation plan for, climate change to the region's aquaculture industry is particularly important because of its inherent vulnerability. The aquatic environment is expected to respond to climate changes "in ways that are as equally significant as the responses of the terrestrial and atmospheric environments" (2WE Associates Consulting, 2000). The changes in the aquatic environment are expected to be more "creeping"

– sneaking up in a gradual and less apparent manner - than those taking place in the atmosphere due the ocean's ability to absorb and distribute heat. While fluctuations around the mean temperature will tend to be smaller than in the atmosphere, the aquatic ecology will nevertheless be less tolerant to wide temperature ranges than its terrestrial counterparts, and the rate at which natural habitat changes will challenge the adaptive capacity of aquatic species (Cochrane *et al.,* 2009). This short paper will provide some results from a preliminary baseline of climate observations and projections of future climate at individual stations in Canada's Atlantic Region to assist the aquaculture community in adapting to changes in climate through increasing the understanding of how climate has impacted the region in the past, and how climate will impact in the future.

Methods

A climate baseline can be developed for regions in Canada by: locating climate stations in the study area using Canada's National Climate Data and Information (NCDI) Archive (Environment Canada, 2014); downloading the full climate record for each of the climate stations in the region; conducting quality assurance and quality control (QA/QC) measures for daily temperature (maximum, minimum and mean) and precipitation (total) values including range, visual and missing data checks; and preparing summaries of daily climate data for each month, season and year.

For projections of future climate, global climate models (GCMs) are the most advanced science available. Global climate models are strings of mathematical (differential) equations based on the basic atmospheric laws of physics, fluid motion and chemistry that, taken together with interactions with ocean, sea-ice and land components, describe the Earth's climate system. The largest supercomputers in the world are used to "run" the models by dividing the planet into a 3-dimensional grid (both horizontal and vertical), applying the mathematical equations, and evaluating the results. Results can vary widely between global climate models because of some fundamental differences between them such as the grid size used, the number of grids in the vertical, and the time period used between steps in the run. Some models do better than others at reproducing the historical climate in different regions (Fenech *et al*., 2012 provides a view of which models perform best where in Canada) especially in complex environments (coastal, mountainous, sea ice) where extra care is required for grid cell averaging and process parameterization. One must remember that no model perfectly reproduces the system being modeled. Such inherently imperfect models may nevertheless produce useful results. In this context, global climate models are capable of reproducing the general features of the observed global temperature over the past century (IPCC, 2007).

The largest uncertainties in the global climate models' future projections emerge from the greenhouse gas emission scenarios, or what human activities are anticipated in the future. Increases in the atmospheric concentrations of greenhouse gases (GHGs) (for example, carbon dioxide, methane, nitrous oxide and ozone) are what drive the climate warming. Future greenhouse gas emissions will be determined by three major factors: future human population growth; the strength of the future global integrated economy; and the future mix of energy sources (renewable versus non-renewable). These three factors will either influence the global climate in a major way (high emissions from all three),

moderately (medium emissions from all three) or in a minor way (low emissions from all three) – yet it is uncertain as to how.

Attempts have been made by the Intergovernmental Panel on Climate Change (IPCC) to provide a range of scenarios of future greenhouse emissions, based on varied futures of human activities, formerly known as the SRES Scenarios (for the IPCC AR3 and the IPCC AR4), and now (as of the IPCC AR5) known as the RCP Scenarios. SRES scenarios, from the IPCC's *Special Report on Emission Scenarios*, refer to six families of future greenhouse gas emission scenarios - A1FI (highest), A1B (mid), A1T (low), A2 (high), B1 (lowest), and B2 (low) – each having been used to project future atmospheric greenhouse gas concentrations, and thus the magnitude of increases in global temperatures. The IPCC AR5 now uses RCPs or Representative Concentration Pathways for future greenhouse gas scenarios. RCPs are greenhouse gas concentration (not emissions) driven; still span a large range of stabilization, mitigation and non-mitigation pathways; and are named after a possible range of radiative forcing (W/m2) values in the year 2100 - RCP2.6 (lowest), RCP4.5 (low), RCP6 (mid), and RCP8.5 (high). There is no immediate comparison between the SRES and RCP greenhouse gas emission scenarios, but they are similar.

Global climate model output from all models used in the deliberations of the IPCC assessments can be accessed through the IPCC Data Distribution Centre (see www.ipcc-data.org/) or more recently through the World Climate Research Program (WCRP) Coupled Model Intercomparison Program (CMIP) 5 (see cmip-pcmdi.llnl.gov/cmip5/guide_to_cmip5.html). These websites, however, require specialized knowledge in computer languages and the climate data itself as well as significant resources (primarily time) to download, convert, format, interpret, analyze and map the model output. This makes it less suitable for an individual researcher to have access to the data. Going to each global climate modelling centre individually can also be problematic. There can be many delays in gaining permission for data, requesting data, receiving data, cleaning data, getting answers to questions about data, among other things.

The Climate Research Lab at the University of Prince Edward Island has a dataset available to researchers that disseminates climate change scenarios and other climate change impact and adaptation information. The dataset, called the Climate, Ocean and Atmosphere Data Exchange (COADE), provides easy access to the output from forty global climate models used in the deliberations of the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) including monthly global climate model projections of future climate change for a number of climate parameters including temperature and precipitation. COADE was queried for temperature and precipitation changes for Canada's Atlantic Region using an ensemble (or average) of all forty IPCC AR5 global climate models. The *ensemble approach* has demonstrated in recent scientific literature to likely provide the best projected climate change future projection (see IPCC, 2010). This approach suggests that it is best to plan for the average climate change from all of the climate model projections by using a mean or median of all the models (or many models) to reduce the uncertainty associated with any individual model. In effect, the individual model biases seem to offset one another when considered together. Compared against historical observed gridded data, climate projections using the *ensemble approach* have been shown to come closest to replicating the historical climate.

Results

Results from climate baseline studies conducted at individual locations across the Atlantic Region are presented below. Climate normals, or averages, are used to summarize or describe the average climate conditions of a particular location. Climate normals are updated traditionally at the completion of each decade. Those offered below are based on the climate station observational data between 1961 and 2010. Annual mean temperatures have increased at Fredericton, New Brunswick (0.4°C). Truro, Nova Scotia (0.5°C), Charlottetown, Prince Edward Island (0.5°C) and St. John's, Newfoundland and Labrador (0.3°C) climate stations since 1961 (see Figure 1). Annual total precipitation has decreased at Fredericton, New Brunswick (-5%) and Charlottetown, Prince Edward Island (-5%); and increased at Truro, Nova Scotia (+1%) and St. John's, Newfoundland and Labrador (+3%) at climate stations since 1961 (see Figure 2).

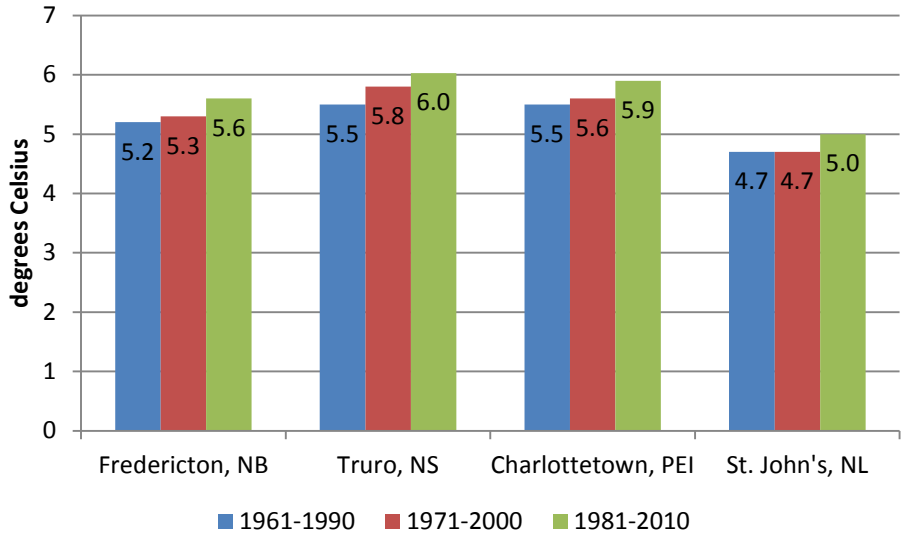

Figure 1. Annual Mean Temperature "Climate Normals" from 1961-2010 at Fredericton, New Brunswick, Canada; Truro, Nova Scotia, Canada; Charlottetown, Prince Edward Island, Canada; and St. John's, Newfoundland and Labrador, Canada.

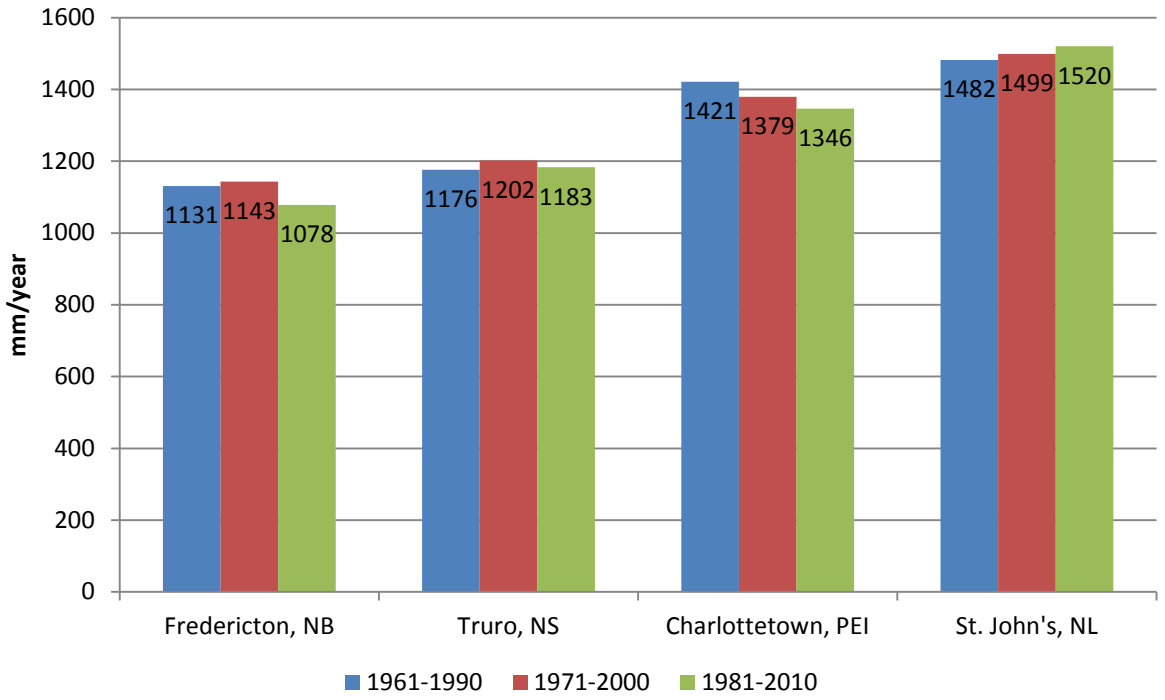

Figure 2. Annual Total Precipitation "Climate Normals" from 1961-2010 at Fredericton, New Brunswick, Canada; Truro, Nova Scotia, Canada; Charlottetown, Prince Edward Island, Canada; and St. John's, Newfoundland and Labrador, Canada.

Applying the high greenhouse gas emission future (RCP8.5) on a base climate normal of 1981-2010 to an ensemble of forty global climate models used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) results in future temperature increases for the Atlantic Region of Canada ranging from 2.3 to 3.3 degrees Celsius (see Figure 3), and in future precipitation increases ranging from 5.3 to 8.5 percent (see Figure 4). These preliminary results should assist the aquaculture community in adapting to changes in climate through increasing the understanding of how climate has impacted the region in the past, and how climate will impact in the future.

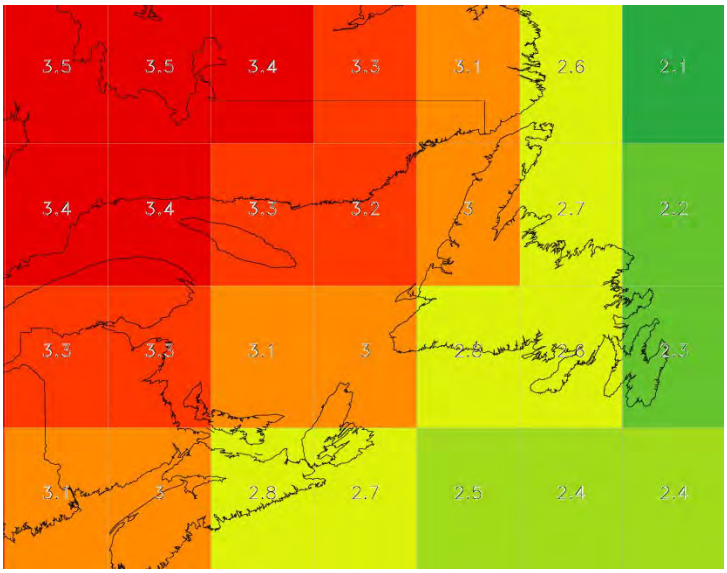

Figure 3. Changes in Annual Mean Temperature "Climate Normal" for the 2050s (2041-2070) at Atlantic Region of Canada in degrees Celsius (©UPEI Climate Research Lab).

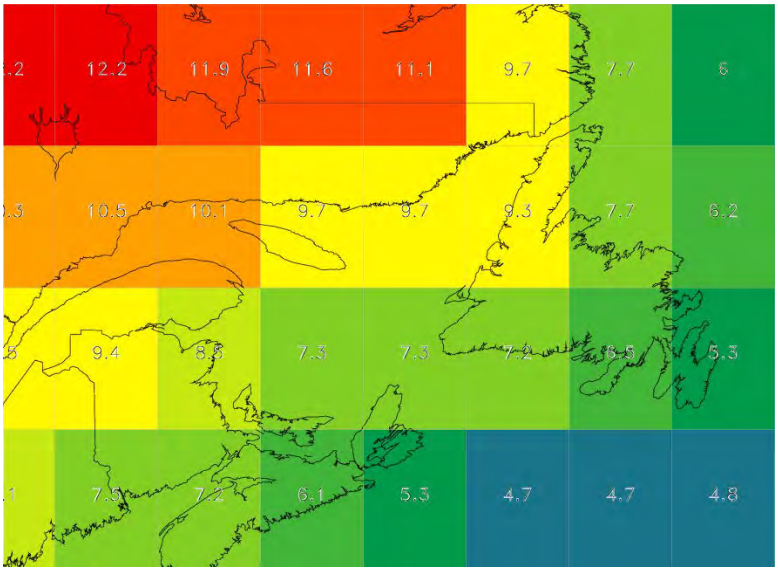

Figure 4. Changes in Annual Total Precipitation "Climate Normal" for the 2050s (2041-2070) at Atlantic Region of Canada in percentage change (©UPEI Climate Research Lab).

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REVISITING TEMPERATURE EFFECTS ON AQUACULTURE IN LIGHT OF PENDING CLIMATE CHANGE

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Abstract

Temperature change is one of the most consequential effects of climate change on aquaculture. Assuming dietary needs are met, temperature is the next major growth driver of poikilothermic ('cold-blooded') aquatic animals. Temperature is a necessary input for several aquaculture growth models. However, simply adjusting model temperature values while ignoring other climate related factors is unlikely to accurately predict climate change effects on growth rate, time to market and thereby economic return. Not only will temperature drive growth rates of poikilotherms, it can also influence immune functionality, life cycle of pathogens, reproductive cues, larval survival, diet digestibility, gene expression, metabolic rate, enzyme functionality and behavior. Multiple temperature driven effects will occur in consort. Due consideration is needed to understand and anticipate these outcomes. This proceeding briefly examines some of the pathways that climate driven temperature changes may affect how aquaculture is practiced.

Introduction

Climate driven temperature change is now occurring, and ongoing changes are likely to affect how most aquaculture is practiced. Assuming dietary needs are met, temperature is the next major growth driver. It is a necessary input for several growth models, such as the Thermal Growth Coefficient (TGC) in von Bertalanffy variants or the Arrhenius temperature function in Dynamic Energy Budget (DEB) modelling. Not only will temperature drive growth rates of poikilotherms, it can also influence physiology, metabolism, heath, behavior and external stressors. A reassessment of temperature on aquaculture is warranted in light of multiple effects and accompanying positive or negative synergies. The latest Working Report (WP5) by the Intergovernmental Panel on Climate Change projects, that pending any major volcanic eruptions, an average increase of approximately 1 degree over the ocean surface will occur by 2060 (Rhein et al., 2013). This is an average however and does not communicate regional differences. Additionally, there is uncertainty with regards to projections of short-term extreme temperature events at near-shore areas where aquaculture is practiced.

Will warmer waters increase aquaculture production?

Small changes in average temperature may have significant effect on growth rates. If all other confounding effects of temperature are ignored, response of growth rate to temperature can be theoretically modeled. A Thermal Growth Coefficient (TGC) for a particular stock of fish is a mathematical value calculated with growth (final – initial body weight) over a defined period of temperature days (average temperature * number of days) (Cho and Bureau, 1998). The equation can be rearranged to predict the final body weight if the historical TGC value is known and temperature can be adjusted to estimate effects to growth rate. If Atlantic salmon are sold between 5.5 and 6.0 kg, an average increase in 1°C, over the production cycle will decrease time to market by approximately 2 months (fig. 1). If diet is not a factor, shellfish also grow faster. Applying a Dynamic Energy Budget (DEB) model (Rosland et al., 2008) to the blue mussel, an average increase of 1°C will increase dry tissue weight by approximately 5.5% in 5 months, from spring to fall (fig. 2). It may seem that small increases in average temperature will benefit aquaculture production. However, how realistic is it to project potential growth changes while ignoring compounding temperature effects or other environmental stressors associated with climate change?

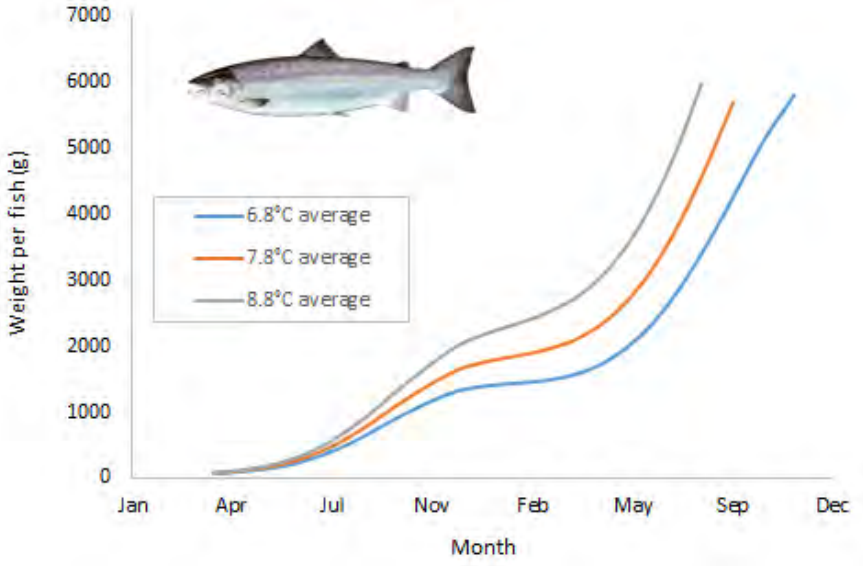

Figure 1. Estimated growth change of Atlantic salmon in response to increased water temperature, ignoring all other temperature effects. The simulation assumed smolts entered the water at 60 g in April, a Thermal Growth Coefficient of 0.300, and an initial mean annual temperature of 6.8°C.

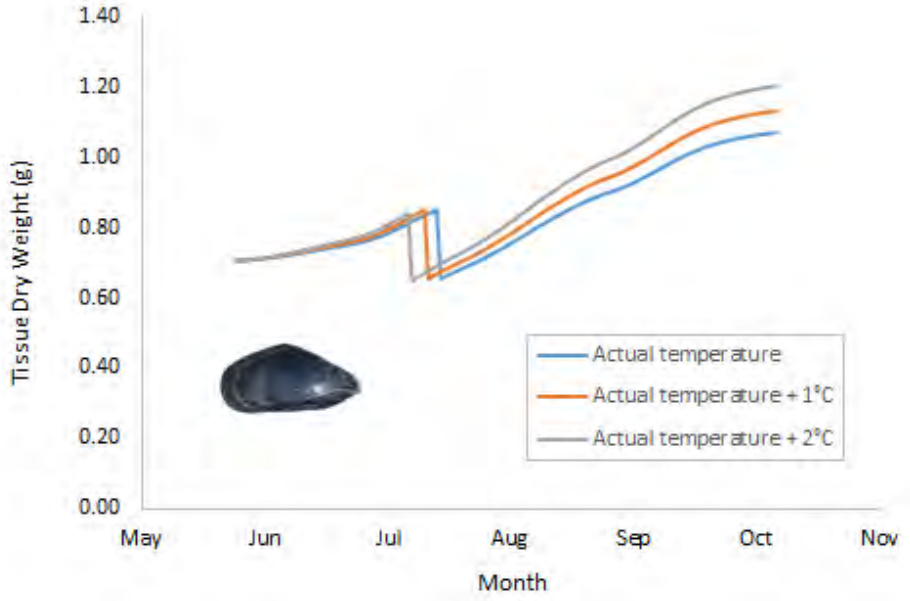

Figure 2. Estimated growth response of the blue mussel to a 2° mean temperature increase under consistent food density. The lower and upper thermal tolerance of approximately 2 and 25 °C, respectively, with DEB model reference temperature of 20°C. The drop in summer tissue weight is a function of spawning.

Other temperature effects

Marine animals have a temperature range of optimal aerobic fitness. As the edge of this range is approached, fitness measures such as growth, health and behaviour are detrimentally effected. Environmental and biotic stressors, such as those expected to accompany climate change, will reduce the temperature range of aerobic performance (Denman et al., 2011). As such, there exists a two-fold threat, where animals operating near their upper thermal limit are susceptible to small increases in temperature while other potential external stressors (e.g. pH, oxygen saturation) are likely to reduce the overall range of this optimal aerobic fitness.

There is limited literature on the effects of climate change on water borne pathogens and immune response to temperature seems to vary between related species or even populations within the same species. There have been some reports of increased infection potential from the sea-lice, *Lepeophtheirus salmonis* (Stien et al., 2005); furunculosis, *Aeromonas salmonicida*, infection of lake fish (Tam et al., 2011) and *vibro* infection of the Pacific oyster, *Crassostrea gigasoysters* (Wendling and Wegner, 2013). In some instances the anticipated increase of infection with temperature, such as tape worm infection of juvenile sockeye salmon, has not occurred (Bentley and Burgner, 2011). Species variation of immune response to temperature is prominent in the literature. The haemocyte count (phagocytic cells in invertebrates) of the clam, *Chamelea gallina*, is sensitive to temperature increases (decreased count), but not the mussel, *Mytilus galloprovincialis* (Matozzo et al., 2012). The sea urchin, *Lytechinus variegatus*, responded with a

significant decrease in the phagocytic indices (cell adhesion and spreading) from 25 to 30 °C, but not in the urchin, *Echinometra lucunter* (Branco et al., 2013).

It is well known that temperature can influence reproductive cues in poikilotherms, but contextualizing these effects as positives or negative for aquaculture may vary. If Atlantic salmon, *Salmo salar*, are exposed to elevated temperature during gametogenesis, both gonadal steroid synthesis and hepatic vitellogenin production are impaired, altering hepatic oestrogen receptor dynamics, thereby reducing maternal investment and gamete viability (Pankhurst and King, 2010). However, temperature increases can induce oocyte maturation and ovulation in cultured Japanese conger, *Conger myriaster*, without the need for exogenous hormone treatment (Utoh et al., 2013).

Given the extent temperature influences metabolic rate of poikilotherms, it is not unreasonable to expect some degree of thermal influence on nutrition. Feed conversion ratio of the green sea urchin, *Strongylocentrotus droebachiensis*, (Siikavuopio et al., 2012), Australasian sea cucumber, *Australostichopus mollis* (Zamora and Jeffs, 2012), and the digestibility of saturated fatty acids in salmonids (Hua and Bureau, 2009), are reported to be influenced by temperature.

Confounding effects

As with the other climate influenced parameters, temperature change will not occur in isolation. This could result in either positive, negative or combined outcomes, and examples are already appearing in the literature. While increased Patagonia reservoir temperature has resulted in reduced ovulation, spawning and larval survival of cultured trout, the growth rate increased substantially (Baez et al., 2011). Recent summer surface temperatures in Lake Huron, have been sub-optimal for trout culture, but at least one farm has reported that the overall mean annual temperature increase still resulted in improved harvest weight by 10-20% (Anonymous, 2013). In other instances, problems with projected summer temperatures are expected to outweigh growth-rate benefits of warmer winter temperatures. Increased winter water temperatures are projected to accelerate growth rate of four abalone species in southern Australia, but the projected summer temperatures are expected to cause a 10-fold increase in juvenile mortality (Russell et al., 2012). A dual effect can result from increased temperature with regards to lower oxygen limits. Warmer temperatures decreases oxygen saturation while accelerating metabolic rate and oxygen consumption, resulting in increased need for oxygen with decreased availability. In post-smolt Atlantic salmon the % air saturation of hypoxic tolerance threshold increases exponentially with metabolic rate (Remen et al., 2013). Multiple effects of increased temperature appears to compound development issues of European seabass. A thermal increase in early life stage of European seabass, *Dicentrarchus labrax,* decreases female sex ratio (78 ± 2% females at 15 °C vs. 29 ± 2% females at 20 °C), and therefore growth performance, while also increasing haemal lordosis and the lack of swim bladder inflation which leads to spinal deformation (Sfakianakis et al., 2013).

Adaptation and mitigation potential

There are a number of uncertainties at present which make outcome prediction of warming waters very difficult. The potential for short-term adaptation or epigenetic expression is arguably one of the biggest uncertainties. Fish are highly ‘plastic’ and some examples of early life-stage developmental adaptation

have been identified in the common sole (Zambonino-Infante et al., 2013) and salmonids (Anttila et al., 2013, Benjamin et al., 2013, Siikavuopio et al., 2013). Some cultured sea urchins are reported to gradually maximize their food intake, to adjust to changes in ambient temperature (Watts et al., 2011). While there appears to be some potential for short term adaptation, perhaps the larger question is: can longer term evolutionary type responses manifest at the same rate as climate change? The number of species extinctions over the last few centuries suggests we should not rely too heavily on Mother Nature's ability to adapt to rapid, human-expedited, environmental change.

There seems to be little similarity of response to increasing temperature by related species or even between populations of the same species. Response is likely to be a function of culture temperature and the relative location of this temperature on a population's aerobic performance curve. Are culture temperatures well within the range of optimal performance or are temperatures approaching the upper thermal tolerance limit? An appropriate mitigation strategy would need to account for this. Nevertheless, the most immediate mitigation solutions to for rising temperatures in the short-term, are likely to focus on, diet, environmental control, predictive capacity, selective breeding and relocation. Several species have demonstrated better survival and conditioning from heat shock and thermal stress, with appropriate diet, such as the California mussel, *Mytilus californianus*, (Fitzgerald-Dehoog et al., 2012), juvenile abalone, *Haliotis midae,* (Vosloo et al., 2013), juvenile sea urchins (acidification), *Paracentrotus lividus*, (Asnaghi et al., 2014) and juvenile mirror carp, *Cyprinus carpio* (Huang et al., 2014). 'Plastic responses' suggest greater environmental control during early rearing may help direct epigenetic response. Hatcheries are already well positioned to do this. As more unknowns become quantified, predictive modelling will eventually have the potential to assess performance response to climate induced temperature change. Early warning mechanisms may also assist greatly in preparedness, such as the Predictive Ocean Atmosphere Model for Australia (POAMA), which warns salmon famers of adverse temperature conditions on the order of months (Spillman and Hobday, 2014). Aforementioned differences in tolerance within species suggest selective breeding has the potential to select for heat tolerance properties (e.g. Quinn et al., 2011; Arctic charr, *Salvelinus alpinus*). Finally, there is also the obvious, but perhaps the most challenging option, and that is to relocate to cooler waters.

Conclusions

Given species or population specific responses, uncertainty of confounding effects, and unknowns around adaptation capacity, research must progress accordingly. Relevant research must consider multiple stressors in consort, ensure due statistical consideration of interaction, and re-examine the potential of epigenetic and evolutionary adaption. For meaningful research to occur on climate change and aquaculture, sober thought and meaningful reflection are crucial in order to guide research efforts in an age of finite resources.

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