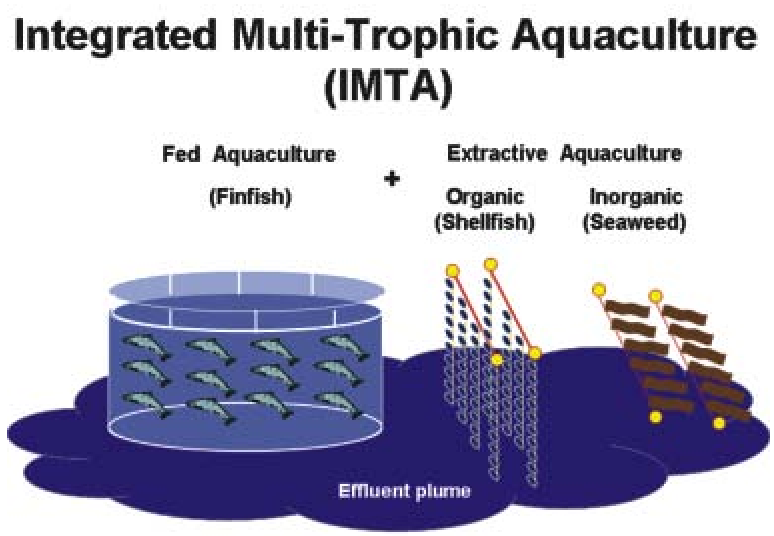
Contents

Proceedings of the Integrated Multi-Trophic Aquaculture Workshop held in Saint John, NB, 25-26 March 2004

Thierry Chopin and Shawn Robinson, guest editors



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Covers: Photomontage of different phases of integrated multi-trophic aquaculture (IMTA). Thierry Chopin and Bruce Moore harvesting kelps cultivated in proximity to salmon cages; Terralynn Lander measuring the growth of mussels; Terralynn Lander and Shawn Robinson ready for another day at the sites; Thierry Chopin harvesting kelps and Shawn Robinson measuring the weight of mussel socks in proximity to salmon cages. Courtesy of AquaNet and Innovative Video Solutions.

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Thierry Chopin

Defining the Appropriate Regulatory and Policy Framework for the Development of Integrated Multi-Trophic Aquaculture Practices: Introduction to the Workshop and Positioning of the Issues

Thierry Chopin and Shawn M.C. Robinson

The aquaculture industry in Canada is still at an early stage of development after almost three decades of expansion. It plans to continue to grow, but is debating how it can do so in a responsible, sustainable, and profitable way. This paper examines the different options (geographical expansion, intensification of existing sites, diversification) and recognizes that changes in attitudes are needed and innovative practices have to be developed for further advancement. One approach is integrated multi-trophic aquaculture (IMTA), which is being developed in the Bay of Fundy through an AquaNet project. To move from the "pilot" scale to the commercial "scale up" stage, the appropriate regulatory and policy framework, and the financial tools, have to be put in place or the industrial partners will have no incentive to develop IMTA. A workshop was held to identify the hurdles to IMTA and define the appropriate framework for addressing them in an efficient manner at the provincial, regional, and national levels. Most of the papers presented during the workshop are included in this issue of the *Bulletin of the Aquaculture Association of Canada.* A concluding paper summarizes what was accomplished during the workshop and what has been achieved since.

Introduction

The aquaculture industry in Canada is still at an early stage of development after almost three decades of expansion. It is still relatively small on a worldwide scale (Table 1), but significant on a local scale (Table 2). The finfish aquaculture sector

Table 1. Worldwide, Canadian, and New Brunswick marine aquaculture production (in millions of tonnes) in 2000 and 2002. Source: FAO[5] and DFO[3].

	2000			2002		
	World	Canada	New Brunswick	World	Canada	New Brunswick
Salmon, trouts, smelts	1.545	0.095	0.030	1.799	0.137	0.039
Shellfish	12.458	0.032	0.001	14.281	0.034	0.002
Seaweeds	10.1	a	–	11.6	a	–

[a] excludes confidential data

Table 2. Production and value of the main agro-food industries in New Brunswick between 2001 and 2003. Source: New Brunswick Department of Agriculture, Fisheries and Aquaculture.[8]

Agro-food Industry	Production (tonnes)			Value (CDN$ million)		
	2001	2002	2003	2001	2002	2003
Salmon aquaculture	33,900	38,900	33,100	180.010	194.500	179.000
Trout aquaculture	550	550	550	6.100	6.100	6.100
Oyster aquaculture	744	1,235	2,350	0.772	1.173	2.500
Mussel aquaculture	439	637	453	0.552	0.801	0.600
Total aquaculture	35,633	41,322	36,453	187.434	202.574	188.200
Fisheries	123,958	124,386	112,114	177.166	198.096	169.079
Potatoes	650,943	684,057	676,708	92.967	118.321	101.198

in New Brunswick plans to grow in production after leveling off in recent years (Fig. 1), but is currently debating how it can do so in a responsible, sustainable, and profitable way.

As the volume of production goes up, the cost of production usually goes down due to the implementation of automated technologies. In a commodity market, this results in lower prices to the consumer and lower margins for producers, due to competition from other producers. The result of this expansion is that more profits (to either owners or investors) can only be realized from the production side by increasing volume. In the fixed spatial area of a farm, this generally results in pushing the environmental carrying capacity to the limit. Maintaining sustainability, not only from an environmental perspective, but also from economic, social, and technical perspectives, has become a key issue. What are, then, the options for facing these challenges?

Geographical Expansion

Geographical expansion of aquaculture is still possible in some areas (e.g., Newfoundland and British Columbia), but for how long? In New Brunswick, site access and availability are already limited and public resistance is growing against further expansion of the current aquaculture model. Moving from sheltered nearshore sites to exposed nearshore sites and offshore sites has been contemplated, but technical and economic challenges remain, especially in regions where the coastal zone is already used by many stakeholders. Offshore development, proposed by some as the next frontier in aquaculture, is not necessarily the appropriate solution for all regions. It is obvious that, sooner or later, the scope for geographical expansion will be limited for existing monoculture technologies and practices.

Intensification of Existing Sites

If the expansion of finfish aquaculture is limited in spatial extent by biological and social factors, the only solution is to increase production from existing sites. This same issue faces human populations in urban ar-

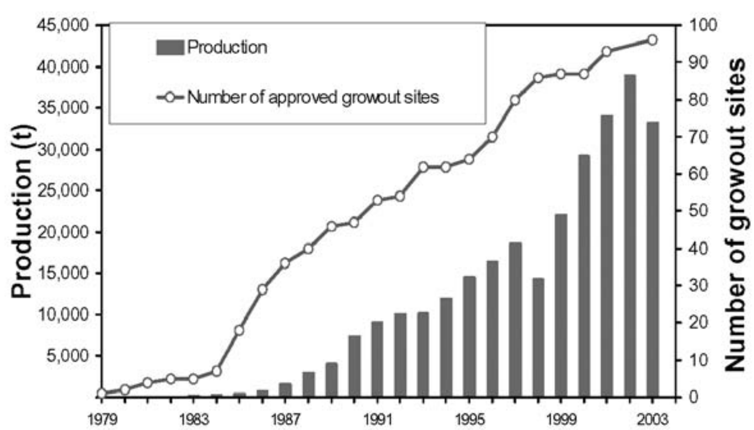


Figure 1
Salmon aquaculture production and number of approved growout sites in New Brunswick from 1979 to 2003.[8,9]

eas. The solution has been to increase the surface area of the ground by using buildings with multiple levels. When considering the seawater volume available at a lease site and the volume of water actually occupied by salmon cages, it is obvious that a cultivation unit is not optimized. The area of a lease site also has to accommodate the anchoring system, vessel access, water flow, etc. Advanced technology will thus be a prerequisite for intensification. As with concentrated housing for humans, there will have to be a high degree of surface area for organisms, and efficient systems for food delivery, waste treatment, and energy supply. Consequently, intensification will require: 1) innovative and environmentally-friendly technologies, 2) new and better management practices and codes, and 3) recognition of aquaculture within a broader integrated coastal management framework.

Diversification

It is amazing to realize that salmon aquaculture in Canada represents 68.2% of the tonnage of the aquaculture industry and 87.2% of the farmgate value.(1) In New Brunswick, it represents 95.5% of the tonnage and 98.9% of the farmgate value. Consequently, diversification of the industry is imperative to reduce the economic risk and maintain competitiveness.

The traditional view of diversification often involves producing a second product that is similar to the first and fits into the existing production and marketing systems. In finfish aquaculture, this has usually meant salmon, cod, haddock, or halibut. However, from an ecological point of view, these are all “shades of the same colour”. True ecological diversification means a change in trophic level (i.e., switching from finfish to another group of organisms, such as shellfish, seaweeds, worms, bacteria, etc.). Staying at the same ecological trophic level will not address environmental issues because the system will remain unbalanced.

Economic diversification should also mean looking at seafood from a different angle. Aquaculture products on the market today are similar to those obtained from the traditional fishery and thus are often in direct competition. While this may be part of the market forces at work, the opportunity exists to diversify from fish filets (or mussels and oysters), on a plate in a restaurant, to a large untapped array of bioactive compounds of marine origin (e.g., pharmaceuticals, nutraceuticals, functional foods, cosmeceuticals, botanicals, pigments, agrichemicals, biostimulants, etc.). Research and development on alternative species should no longer be considered as R&D on alternative finfish species, but rather on alternative marine products.

Moreover, diversification should be viewed as an investment portfolio, with short-term, long-term, high risk, and low-risk components, and with long-term growth and stability as the main objectives.

Changes in Attitudes are Needed

There is a paradoxical situation when looking at worldwide food production. In agriculture, 80% of the production is made up of plants and 20% of meat, while in aquaculture, 80% of the production is meat and 20% is plants. Regarding mariculture, production is made up of 46.2% mollusks, 44% seaweeds, 8.7% finfish, 1.0% crustaceans, and 0.1% various other animals.(4,5) In many parts of the world, aquaculture is not synonymous with finfish aquaculture, as many people in affluent western countries believe. We need to be aware of other food production systems in the rest of the world, if we want to understand our present system and correctly position it in perspective with other systems.

From the above numbers, one may be inclined to think that at the world level the two types of aquaculture—fed and extractive—are relatively balanced. However, because of the predominant monoculture approach, these types of production are often geographically disjunct and, consequently, rarely balance each other out at the regional scale. For example, fed salmon aquaculture is located in the Bay of Fundy in southern New Brunswick, while extractive mussel and oyster aquaculture is located in the Northumberland Strait and the southern Gulf of St. Lawrence along the coastlines of Prince Edward Island and northeastern New Brunswick. In Japan, aquaculture is mostly carried out in bays dedicated to either shellfish, seaweed, or finfish aquaculture.

It is also important to consider that while fish command a higher price per unit, sustainable ecosystems are not based on price for human return, but on a balance of biomass between organisms having complementary functions and a balance of energy flows.

Innovative Practices Need to be Developed

The challenge, then, is how to increase the production capacity of an existing site when the available options have shown their limitations. One of the possible answers is to increase the level of technology involved in the production of seafood so that food and waste handling systems are all actively considered in the growing operation from the start, and are modelled after natural ecosystems.

One of the innovative solutions being proposed for environmental sustainability, economic diversification, and social acceptability is integrated multi-trophic aquaculture (IMTA). This practice combines, in the right proportions, the cultivation of fed aquaculture species (e.g., finfish) with organic extractive aquaculture species (e.g., shellfish) and inorganic extractive aquaculture species (e.g., seaweed), for a balanced ecosystem management approach that takes into consideration site specificity, operational limits, and food safety guidelines and regulations. The aim is to increase long-term sustainability and profitability per cultivation unit (not per species in isolation, as is done in monoculture), as the wastes of one component (finfish) are captured and converted into fertilizer or food for the other components (seaweed and shellfish), which can in turn be sold on the market. In this way, all the cultivation components have economic value and each has a key role in the services and recycling processes of the system.

The paradox is that IMTA is not a new concept. Asian countries, which provide more than two-thirds of the world's aquaculture production, have been practicing IMTA—through trial and error and experimentation—for centuries.[2] Why, then, is it not more widely implemented, especially in the western world? The reasons generally center around social customs and practices that we are familiar with. Human society does not change quickly unless there are compelling reasons. The conservative nature of our marine food production industries is a good example of the relative slowness to adopt change.

Western countries are regularly reinventing the wheel. Research on integrated methods for treating wastes from modern mariculture systems was initiated in the 1970s.[11] After that period, scientific interest in IMTA stagnated, and it was not until the late 1980s and early 1990s that a renewed interest emerged, based on the common-sense approach that the solution to nutrification is not dilution but conversion within an ecosystem-based management perspective.[2,6,7,10] In recognition of this growing interest, the Aquaculture Europe 2003 conference in Trondheim, Norway chose the theme "Beyond Monoculture" and was the first large international meeting (389 participants from 41 countries) with IMTA as the main topic. The determination to develop IMTA systems will, however, only come about if there are visionary changes in political, social, and economic reasoning. This will be accomplished by seeking sustainability, long-term profitability, and responsible management of coastal waters. It will also necessitate a change in the attitude of consumers towards eating products cultured in the marine environment, in the same way that they accept eating products from recycling and organic production systems on land, for which they are willing to pay a higher price.

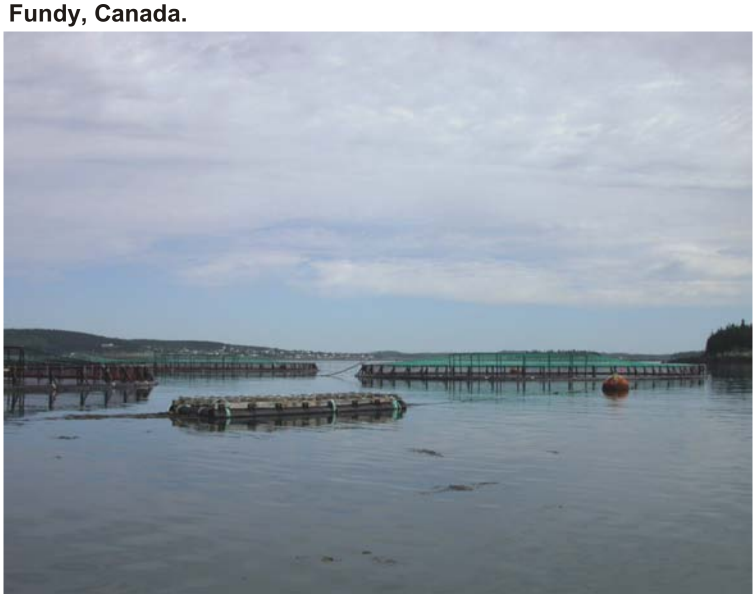
Figure 2
Harvesting of kelp (*Laminaria saccharina*) cultivated in proximity to Atlantic salmon (*Salmo salar*) at Charlie Cove, Bay of Fundy, Canada.
Photo: Manav Sawhney.

The AquaNet Project

An interdisciplinary team of scientists from the University of New Brunswick in Saint John and from the Department of Fisheries and Oceans in St. Andrews has been working on a salmon/mussel/kelp IMTA project in the Bay of Fundy since 2001 (Figs. 2, 3). The project is supported by AquaNet (the Canadian Network of Centres of Excellence for Aquaculture) and industrial and government partners (Heritage Salmon Ltd., Acadian Seaplants Limited, Ocean Nutrition Canada, Canadian Food Inspection Agency, Atlantic Canada Opportunities Agency, and New Brunswick Innovation Foundation). This project, like several others in the world (e.g., Chile, Israel, USA, South Africa, Australia), is on the verge of demonstrating the biological validity of the IMTA concept (e.g., significant increase in kelp and mussel production in proximity to salmon sites due to the more beneficial use/conversion of food and energy; advantages of environmental services through bioremediation and diversification of crops; and absence of transfer of therapeutants and chemicals used in salmon aquaculture to the kelps and mussels).

The next step is the scaling up of operations to demonstrate the biological validity at a commercial scale and to document the economic and social advantages of the concept, which will be key to convincing practitioners of monospecific aquacultrue to move towards IMTA practices.

Figure 3
Cultivation of blue mussel (*Mytilus edulis*) in proximity to Atlantic salmon (*Salmo salar*) at Charlie Cove, Bay of Fundy, Canada.



Defining the Appropriate Regulatory and Policy Framework, and Financial Tools, Conducive to the Development of Innovative Practices

As the IMTA concept evolves, it is important that all sectors of the industry be aware of the implications of the changes involved so that they can adapt in a timely and organized manner. To move research from the “pilot” scale to the “scale up” stage, some federal and provincial regulations and policies need to be changed or they will be impediments to industrial partners. For example, in its present version, the Canadian Shellfish Sanitation Program (CSSP) prevents the development of IMTA because of paragraph 12.2:

> "Shellfish and finfish should not be raised in close proximity as netpens have the potential to be point-sources of pollution due to human activity and poor husbandry practices. There should be a minimum of a 125 m prohibited area surrounding netpens. The size of this area will be dependent on the size of the finfish site and on the hydrography surrounding the site".

This paragraph needs to be reviewed and amended—based on the recent data and information provided by the AquaNet project and similar other projects—to allow IMTA practices to legally develop to a commercial scale.

It is also important to note that current aquaculture business models do not consider and recognize the economic value (goods and services) of bioremediation by biofilters, as there is no cost associated with aquaculture discharge/effluent in open seawater-based systems. Regulatory and financial incentives may therefore be required to clearly recognize the benefits of the extractive components of IMTA systems (shellfish and seaweed). A better estimate of the overall cost/benefits to nature and society of aquaculture waste and its mitigation would create powerful financial and regulatory incentives to governments and the industry to jointly invest in the IMTA approach.

At this stage of development of the AquaNet project, it was topical to hold a workshop to identify the specific hurdles and define the appropriate framework to address them in an efficient and timely manner at provincial, regional, and national levels. The 2-day workshop brought together 61 participants from Canada, the USA and Israel, representing federal and provincial/state agencies involved in aquaculture regulations and policies, researchers, industry, professional associations, and environmental NGOs. The objectives of the workshop were to:

- Introduce and transfer the knowledge gained thus far on IMTA from the research and development underway in Canada and other parts of the world.
- Review the regulatory and policy framework currently related to the development of the IMTA concept.
- Identify the origin(s) of this framework and discuss if it was designed with IMTA operations in mind, or if the implications for IMTA development have appropriate or inappropriate consequences.
- Identify any obstacles to the further development of IMTA.
- Devise solutions to those issues and produce a timeline for resolution and implementation by the regulatory agencies.

Working group sessions, held on the second day of the workshop, identified:

- What work is needed to allow the development of IMTA at the biological, economic, and social levels? How can the technologies be advanced? Who will do the work? What are the timelines?
- What regulations and policies need to be amended, and how? Who should effect the amendments? How do we initiate these amendments/changes? What are the timelines?

The workshop was a success due to the open and frank discussions among the participants and a rare willingness to seek and provide constructive, common-sense, and timely resolutions. What could have turned into another bureaucratic exercise in re-stating the positions of the various agencies, turned out to be an excellent and fruitful dialogue in which the participants seemed genuinely interested in the IMTA approach to aquaculture. Another reason for the success of this workshop was a "no escapee" clause! All participants attended the full two days, which allowed continuing multi-lateral discussions with all agencies and partners at the table, in contrast to earlier bilateral discussions which often resulted in limited and restricted progress, as the opinion or interpretation of one of the key players could not be sought immediately.

This issue of the *Bulletin of the Aquaculture Association of Canada* contains most of the papers presented during the workshop and finishes with a summary paper outlining what was accomplished during the workshop and indicating what has been since achieved at the provincial, regional and national levels in the remarkably short period of 14 months.

Acknowledgments

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The AquaNet Integrated Multi-Trophic Aquaculture Project: Rationale of the Project and Development of Kelp Cultivation as the Inorganic Extractive Component of the System

Thierry Chopin

Thierry Chopin, Shawn Robinson, Manav Sawhney, Susan Bastarache, Ellen Belyea, Ryan Shea, Wayne Armstrong, Ian Stewart, and Patrick Fitzgerald

The AquaNet project started from the realization that in regions where monospecific aquaculture activities are highly geographically concentrated, or located in suboptimal sites, nutrient enrichment may be locally significant. Contrary to common belief, the longterm solution to nutrification is not dilution—even in regions of exceptional tidal and apparent flushing regimes like the Bay of Fundy—but conversion by biological means. By integrating fed aquaculture of finfish with inorganic extractive aquaculture of seaweeds and organic extractive aquaculture of shellfish, integrated multi-trophic aquaculture (IMTA) allows the wastes of one resource user to become a resource (fertilizer or food) for the others. Food and energy are converted into other crops of commercial value, while biomitigation takes place. The interdisciplinary aspects of the AquaNet IMTA project are described in this paper, as well as the three phases of its development. The different steps in the cultivation of the kelp *Laminaria saccharina*, as the inorganic extractive component of an IMTA system, have been developed and improved. The production of kelp has been 46% greater at an IMTA site than at a reference site 1,250 m away that is not in proximity to any salmon aquaculture site. The future directions for the IMTA inorganic extractive component are discussed.

Development and Rationale of the AquaNet Project

The AquaNet project started from the realization that in regions where monospecific aquaculture activities are highly geographically concentrated, or located in suboptimal sites, nutrient enrichment may be locally significant. In southwestern New Brunswick, the Atlantic salmon (*Salmo salar*) aquaculture industry has experienced considerable growth in the Fundy Isles region (50 km x 40 km) of the Bay of Fundy in less than three decades. The number of sites increased from two in 1980 to 96 in 2004 (Fig. 1). Annual salmon production increased

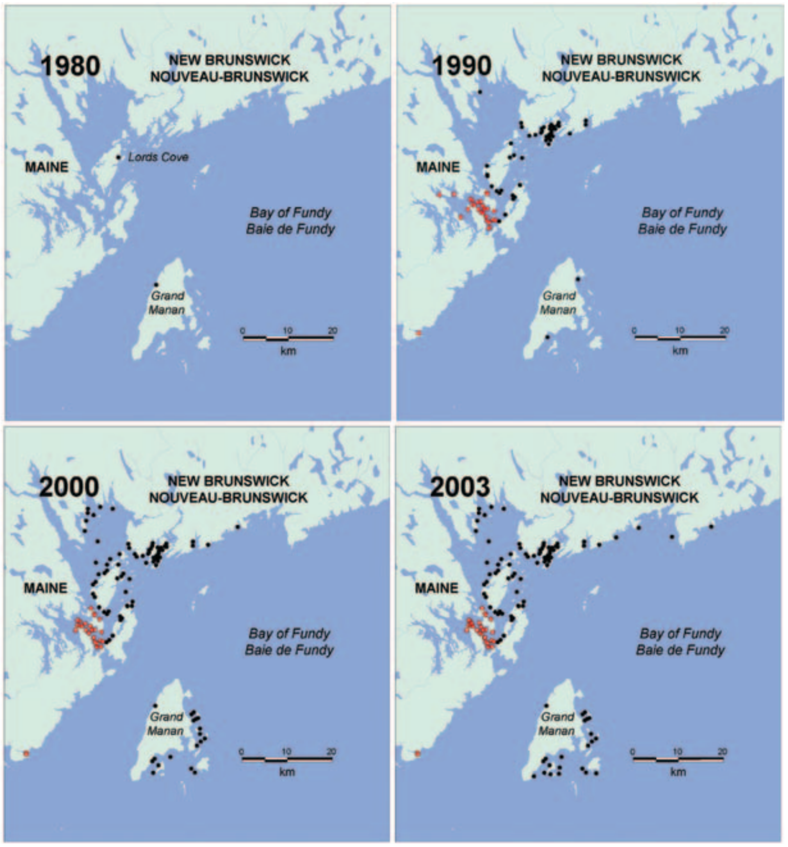

Figure 1
Evolution of the number and location of salmon aquaculture sites in the Fundy Isles region from 1980 (2 sites) to 2003 (96 sites) (courtesy of Blythe Chang, Department of Fisheries and Oceans).

from 635 tonnes in 1986 to 11,836 t in 1994, and appears to have levelled off at around 35,000 t (33,900 t in 2001, 38,900 t in 2002 and 33,100 t in 2003[4]). In 1994, with an annual production of 11,836 t, and nitrogen (N) and phosphorus (P) release rates of 78.0 and 9.5 kg per tonne of salmon per year,[1] the N and P input from aquaculture operations in the Fundy Isles region was 923 and 112 t per year, respectively. With improvements in feed composition, digestibility, and conversion efficiency, the N and P release rates were reduced to 35.0 and 7.0 kg per tonne of salmon per year in a matter of a few years.[3] However, salmon production increased by a factor of 2.9 in just 7 yr to reach 33,900 t in 2001. Consequently, the N input from aquaculture operations in the Fundy Isles region increased to 1,187 t per year, and the P input more than doubled to 237 t per year.

Contrary to common belief, the solution to nutrification is not dilution, even in regions of exceptional tidal and apparent flushing regimes like the Bay of Fundy, where water residency time can be locally prolonged.[7] Antoine

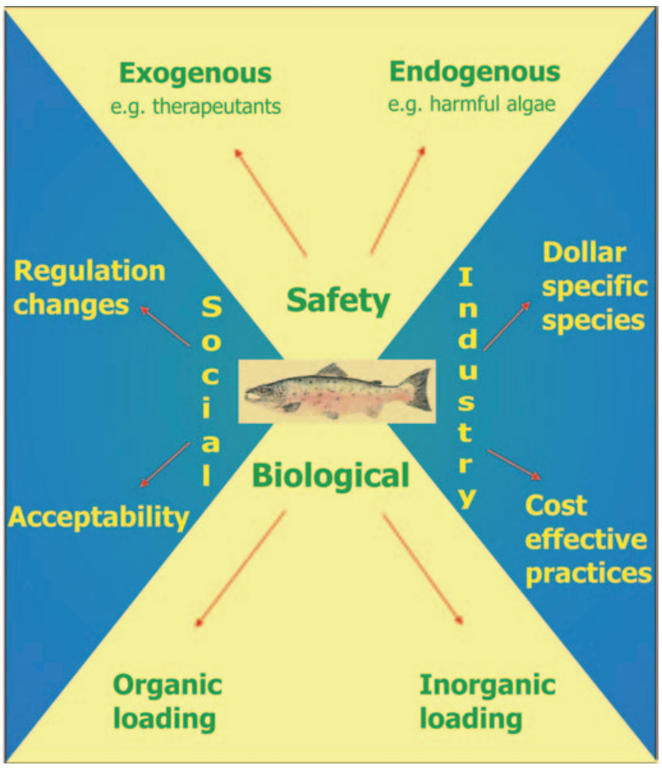

Figure 2
The interdisciplinary aspects covered by the AquaNet IMTA project: environmental sustainability (through nutrient organic and inorganic loading), economically viable diversification (through the choice of commercial second crops and cost-effective practices), food safety security (through the study of exogenous and endogenous sources), and social aspects (adapting regulations and policies for the development of acceptable practices).

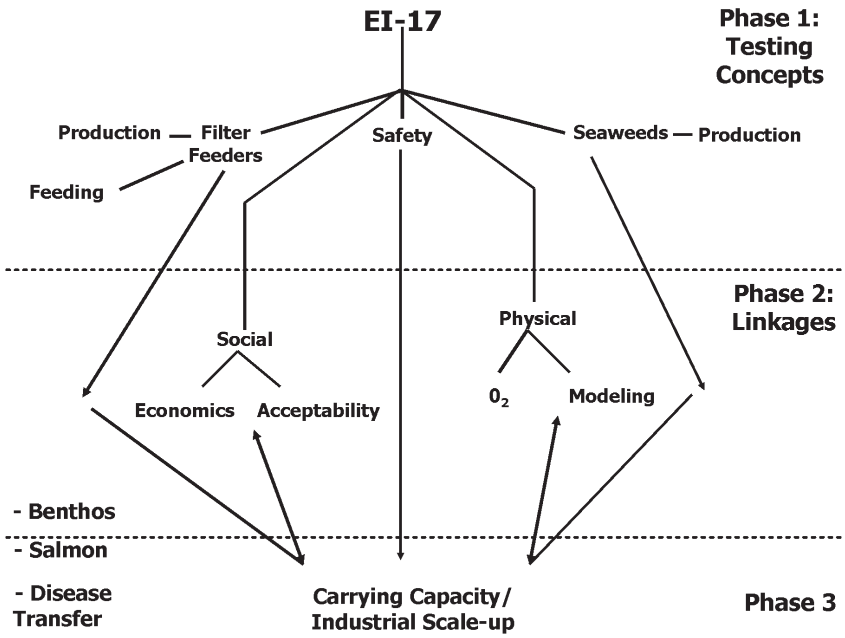

Figure 3
Development of the AquaNet IMTA project in three phases (see text for explanation of the different phases).

Laurent de Lavoisier, the well-known French chemist and physicist (but also a tax collector, which explains his premature death at age 51 under the Terror period of the French Revolution), summarized his work on the Laws of Thermodynamics by the famous sentence "Rien ne se perd, rien ne se crée, tout se transforme" ("Nothing is lost, nothing is created, everything is transformed"). Adapting this to our situation, we can say "the solution to nutrification is not dilution, but conversion". This is when the concept of integrated multi-trophic aquaculture (IMTA), becomes useful. By integrating the fed aquaculture of finfish with the inorganic extractive aquaculture of seaweeds and the organic extractive aquaculture of shellfish, the wastes of one resource user become a resource (fertilizer or food) for the others. Feed is one of the core operational costs of finfish aquaculture operations. Through IMTA, some of the food and energy considered lost in finfish monoculture are recaptured and converted into crops of commercial value, while biomitigation takes place.

The concept of IMTA is a common-sense solution used for centuries in Asian countries.(3) It has, however, experienced difficulties establishing itself as a viable aquaculture practice in Western countries. The first author started to promote the IMTA concept in Atlantic Canada around 1995,(2) without much success. It was only in 2000 that an adequate structure was found to develop the large interdisciplinary research effort necessary for IMTA to become a reality in Canada: AquaNet, the Canadian Network of Centres of Excellence for Aquaculture. AquaNet, being one of the 21 Networks of Centres of Excellence funded by three Canadian federal granting agencies—the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR) and the Social Sciences and Humanities Research Council of Canada (SSHRC)—and Industry Canada, was the ideal programme to address the key interdisciplinary aspects of the IMTA concept: environmental sustainability, economically viable diversification, food safety/security, and social acceptability (Fig. 2). The socio-economic aspects of the project are not addressed in these proceedings as the workshop focused on regulations and policies.


Laboratory Phase
On-site Phase
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Figure 4 (left). The different steps in the cultivation of the kelp *Laminaria saccharina:* a) Collection of reproductively mature (visible dark sori in the middle of the blade) sporophytes; b) Drying sori excised from vegetative blades; c) Sori releasing spores in beakers containing seawater; d) Spore solution; e) The spore solution is inoculated on small ropes spooled on PVC pipes in a culture tank; f) Spores germinate into female and male (slender) microscopic filamentous gametophytes on the spools; g) After male gametes have fertilized female gametophytes, each zygote develops into a microscopic sporophyte; h) Spools on PVC pipes covered with microscopic brown sporophytes; I) Young sporophytes, 0.5 to 1 mm in length, ready for transfer at the aquaculture sites; j) Triple line culture system, installed in November, between compensator buoys with larger ropes around which the small ropes, "seeded" with young sporophytes, have been unspooled; k) Ropes of adult sporophytes six months later (May); l and m) Harvesting of kelps in July.

A successful application to AquaNet allowed the development of Phase 1 of the project 'Environmental Integrity–17'(Fig. 3) between 2001 and 2004. This was a period of testing the IMTA concept and of trying various aquaculture sites having different oceanographic regimes in order to understand how three species (*Salmo salar*, *Laminaria saccharina* and *Mytilus edulis*), with different biological and physiological requirements, can be cultivated in proximity to each other. In addition, we examined what type of site was the best compromise to optimize an IMTA system. Phase 2 is on-going and includes:

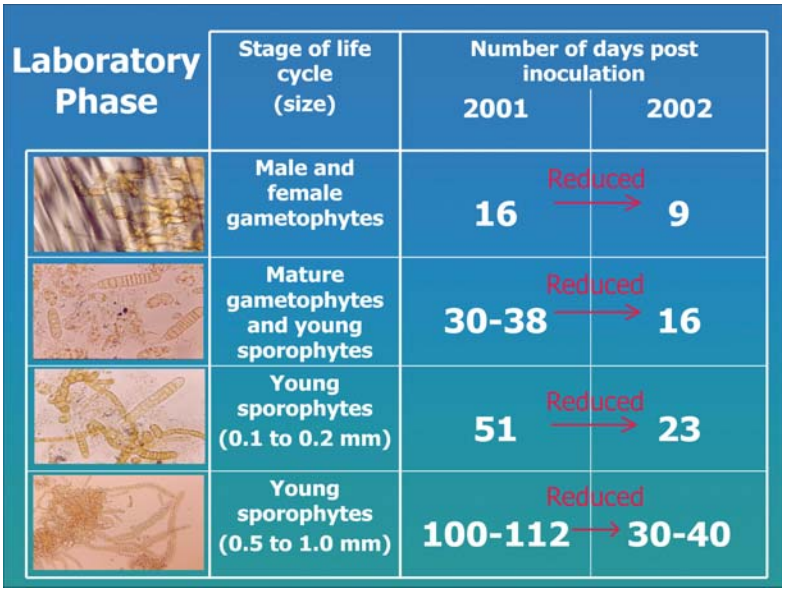
- investigating the linkages between the different species;
- addressing food safety concerns and using the results to help define the appropriate regulatory and policy framework for the development of IMTA in Canada;
- developing oxygen budget and economic models; and
- testing the social acceptability of the IMTA concept.

This will lead to Phase 3 in which operations will be scaled-up to a commercial level that will allow investigation into the impacts of IMTA on the carrying capacity of the coastal environment, water and benthos quality, potential for disease transfer, and animal and plant health.

Development of Kelp Cultivation as the Inorganic Extractive Component of an IMTA System

The first task was to succeed in cultivating *Laminaria saccharina* by controlling the different steps of its complex life cycle, both in the laboratory (the microscopic filamentous gametophytic and early sporophytic stages) and at the aquaculture sites (the macroscopic blade-like sporophytic stages; Fig. 4).

In the first year (2001-2002), it took 112 days to cultivate the microscopic phase from the time of spore collection to obtaining small sporophytes (0.5 to 1 mm in length) ready for deployment at the aquaculture sites (Fig. 5). Taking into consideration the time when kelps are naturally mature (obvious dark sori in the blade; Fig. 4a), the transfer to the sites occurred in February 2002, which was not optimal timing for either humans (the reality of winter in Canada!) or kelps (did not take full advantage of the winter growth period). By adjusting the photoperiod, the enrichment of the culture medium, and the spore density at the time of spool inoculation, the period of cultivation of the microscopic laboratory phase has been significantly reduced to 30 to 40 days in the subsequent three years. In terms of a commercial operation, this represents major savings in the cost of controlling light and temperature. This allowed transfer of the "seeded" ropes to the sites in



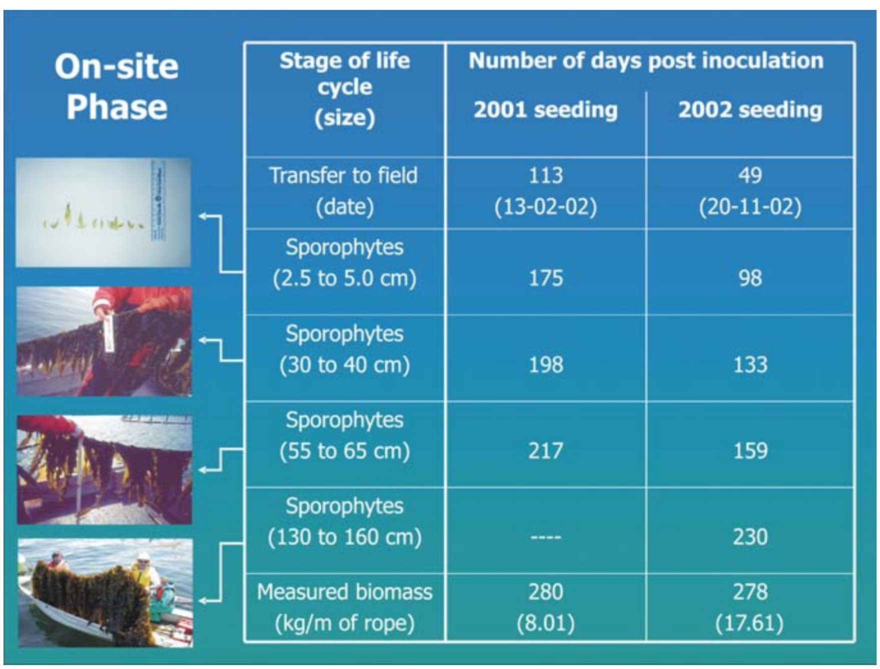
Laboratory Phase: Stage of life cycle (size)	Number of days post inoculation: 2001		2002
Male and female gametophytes	16	Reduced →	9
Mature gametophytes and young sporophytes	30-38	Reduced →	16
Young sporophytes (0.1 to 0.2 mm)	51	Reduced →	23
Young sporophytes (0.5 to 1.0 mm)	100-112	Reduced →	30-40

Figure 5
The different steps in the laboratory phase of the cultivation of the kelp *Laminaria saccharina* and time reduction obtained at each step.

November (Fig. 6), which greatly simplifies the deployment logistics and allows the harvesting of a much larger biomass after 7 to 9 months of cultivation. We have been able to increase the production from 8.01 kg/m of rope in 2002 to 17.61 and 20.67 kg/m of rope in 2003 and 2004, respectively.

The biomass production on ropes attached to the compensator buoys of the grid (15 to 20 m from the closest salmon cage) of an aquaculture site in Bocabec Bay (site 1 in the paper by Haya et al. in this issue), and on ropes attached to a smaller, circular aquaculture structure at a reference site 1,250 m away to the northeast in a location not in proximity to any aquaculture site, was measured in the spring of 2003 (Table 1). At the beginning of June 2003, production of kelp at the Bocabec Bay IMTA site was 46 % greater than at the reference site, illustrating the advantage of growing kelps in proximity to a salmon site, the source of enriched nutrient levels. In May 2003, the salmon at the aquaculture site were harvested. In July 2003, the kelp production at the aquaculture site was still higher than at the reference site; however, the difference had decreased to 24 % as the source of nutrients had been removed and kelps were exhausting their nutrient storage.[6]

Figure 6
The different steps in the cultivation of the kelp *Laminaria saccharina* at the aquaculture sites. Reduction of the time required for the laboratory phase allowed earlier transfer of the "seeded" ropes to the sites and harvesting of a larger biomass.



On-site Phase: Stage of life cycle (size)	Number of days post inoculation: 2001 seeding	2002 seeding
Transfer to field (date)	113 (13-02-02)	49 (20-11-02)
Sporophytes (2.5 to 5.0 cm)	175	98
Sporophytes (30 to 40 cm)	198	133
Sporophytes (55 to 65 cm)	217	159
Sporophytes (130 to 160 cm)	----	230
Measured biomass (kg/m of rope)	280 (8.01)	278 (17.61)

Future Directions for the Inorganic Extractive Component of the IMTA System

The on-site cultivation methods are evolving from an experimental system to a scaled-up commercial system. Initially, a system of mono-lines at different depths was deployed between the compensator

Table 1. Biomass production of *Laminaria saccharina* cultured at the Bocabec Bay IMTA site and at a reference site 1,250 m away, to the northeast, in a location not in proximity to any aquaculture site.

Date (day in culture)	Production at the IMTA Aquaculture Site (kg/m of rope)	Production at the Reference Site (kg/m of rope)	Increase in Production at the IMTA Aquaculture Site (%)
20 May 2003 (230)	15.68 ± 3.05	10.86 ± 1.12	44
11 June 2003 (252)	17.42 ± 3.65	11.96 ± 1.10	46
7 July 2003 (278)	17.61 ± 0.03	14.22 ± 1.59	24

buoys. Optimal depth and avoidance of self-shading oriented the design towards parallel double and triple-line systems between the compensator buoys. We are presently developing raft units, which can be placed near, but independent of the salmon grid structure, according to the nutrient plume and hydrodynamic conditions identified for each site. Harvesting methods will have to be mechanized, processing methods developed, and distribution networks established.

As biomass scaling-up takes place, on-site nutrient biomitigation by kelps will be measured and, associated with that of mussels, will be used to model biomass, nutrient and energy paths and budgets in IMTA versus monoculture settings. The shortening of the required laboratory phase and the earlier transfer to the sites allow contemplating the production of multiple crops per year and different harvesting times. This would increase the nutrient removal efficiency of the IMTA system (optimal biomass production and harvesting strategies for optimal nutrient removal). It will also allow for diversification of the type of seaweed products and market opportunities, based on their composition, quality, and properties obtained under IMTA conditions.

The project started with completing the life cycle of *Laminaria saccharina* and improving each step of the cultivation process. The development of the cultivation techniques for two other kelps, *Alaria esculenta* and *Laminaria digitata*, is currently being carried out. Species of seaweeds other than kelps could be considered, based on their nutrient removal capabilities and commercial values. Different species may have different site characteristic requirements and could be used in various combinations to optimize an IMTA system.

An economic analysis of seaweeds and their derived products and markets is being conducted. It will be an important contribution towards demonstrating the viability of seaweed cultivation and of the inorganic extractive component within an IMTA system. The initial recommendation is to develop the relatively small volume/high value-added niche market approach as the most appropriate strategy at this stage.

This economic analysis will then be inserted into the overall socio-economic model of the IMTA system as it gets closer to commercial scale and its economic impacts on coastal communities are better understood. It will then be possible to add profitability and economic impacts to the comparison of the environmental impacts between IMTA and monoculture settings. This will be sensitized for the most volatile parameters and explicit assumptions so as to develop a model for IMTA systems with built-in flexibility to be tailored to the environmental, eco-

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nomic, and social particulars of the regions where they will be installed. It could be modified to estimate the impact of organic and other eco-labellings, the value of biomitigation services, the savings due to multi-trophic conversion of feed and energy which would otherwise be lost, and the reduction of risks by crop diversification and increased social acceptability.

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We would like to acknowledge all the sponsors of the project. We extend our thanks to the whole AquaNet IMTA project team.

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Dynamics of the Blue Mussel as an Extractive Organism in an Integrated Multi-Trophic Aquaculture System

Terralynn Lander

Terralynn Lander, Kelly Barrington, Shawn Robinson, Bruce MacDonald, and Jim Martin

An integrated multi-trophic aquaculture (IMTA) project, incorporating the blue mussel (*Mytilus edulis*) and kelp (*Laminaria saccharina)* into existing Atlantic salmon *(Salmo salar)* aquaculture systems, has been ongoing in the Bay of Fundy since 2001. Our focus was to examine the possible feeding and growth benefits mussels may gain when co-cultured with salmon, compared to those grown outside of salmon influences. A 24-h seston series indicated that levels of particulate organic matter are elevated at salmon sites during periods of feeding. The increase was mainly in particles between 2 and 10 m, a range highly utilizable by suspension feeding mussels. *In situ* mussel feeding physiology (exhalant siphon area, clearance rates) indicated that mussels at the salmon site responded to the elevated food levels. The mussels at the site also reached a larger size (mean shell length) than the reference mussels. A taste test comparing site-grown and reference mussels showed no discernable difference between the two treatments.

IMTA systems represent a win-win situation in the Bay of Fundy. Product diversification leads to economic gains and culturing species that extract organic and inorganic system losses as a food source has the potential to lessen the impact of the aquaculture site on the environment.

Introduction

The greatest effect of fed, open-system, mono-specific cage aquaculture on an environment is the output of suspended solids and dissolved nutrients.[12] Salmonid farming, in particular, has experienced intense scrutiny due to the generation of large amounts of organic wastes, as uneaten food, faeces, and excretory products, which may cause localized hypernutrification that could lead to eutrophication.[1,3] In 1987, Gowen and Bradbury[4] estimated that up to 30% of fish feed (depending on the composition of the diet) goes uneaten by cultured fish. The data were collected primarily from freshwater trout in tanks and ponds, and wastage at salmon sea-cage farms (such as those in the Bay of Fundy) likely exceeds these values. However, with the advent of modern camera-based feeding systems and improved feed formulations (which improve feed conversion ratios), direct feed wastes can be tightly monitored and input to the surroundings minimized. Therefore, with current aquaculture practices, the value of 30% is possibly an over-estimation. However, feeding systems remain inefficient and waste feed, as well as organic and inorganic metabolites voided by the fish, are discharged into the surrounding water.

Research has demonstrated that levels of both chlorophyll a and particulate organic matter (POM) in the waters adjacent to salmon cages are enhanced due to such losses.[5,7] Although research has led to improved food conversion rates worldwide, salmon farming in the Fundy Isles region of the Bay of Fundy still produces an estimated discharge of 35 kg of nitrogen and 7 kg of phosphorus per tonne of salmon per year.[2] This represents a surplus of organic and inorganic energy that is not being incorporated into fish mass.

Integrated multi-trophic aquaculture (IMTA) methods, where “extractive” and “fed” species are grown simultaneously, have been proposed as a means of using this available energy. If waste material from fish cages is being broken down into finer particles, suspension feeding molluscs may be suitable for absorbing the organic particulate wastes,[6,9,14] and seaweeds could be suitable for absorbing the dissolved nutrients.[2,6,12] Such a bioremediative approach, utilizing lower trophic levels as nutrient recyclers, could reduce waste products and sedimentation, diversify products, and provide economic gains for growers.

It has been proposed by several authors,[9,11,14] that the blue mussel *Mytilus edulis* may be an excellent candidate for IMTA, as it is a generalist consumer, able to exploit organic matter from several sources (allochthonous or anthropogenic) as a function of its availability.[9] In an aquaculture environment, with higher concentrations of suspended organic and inorganic matter, mussels may gain a more reliable food supply, resulting in enhanced growth and reproduction. A reduction in the seasonal variability of food, compared to natural systems, may facilitate growth during nutrient-limited winters when many bivalve species are quiescent and enter a period of zero or negative growth,[15] and hence lessen time required to reach market size.

Figure 1
Collection of seawater samples for seston analysis.

The goal of this study was to characterize the level of nutritional enrichment available to mussels grown at Atlantic salmon aquaculture sites, and to quantify feeding and growth responses of the mussels to such enrichment.

Materials and Methods

1. Seawater analysis

Seston transects away from an aquaculture site

Two transects were carried out in June and July of 2002 at Atlantic Silver, Inc. (lat 48°08 18 N long W), an operational salmon aquaculture site, to quantify the intensity and dispersion of the suspended particulate nutrient cloud caused by anthropogenic feed input in and around a salmon site. Each sampling series was carried out midmorning during periods of fish feeding. Triplicate 1-L water samples were collected using a Niskin™ bottle (Fig.1) at a depth of 5 m at intervals of 0, 50, 100, 250, and 500 m along a transect line parallel to the direction of the dominant current for the area. Samples were kept on ice and transported to the laboratory. Organic and inorganic constitutents were quantified using techniques adapted from Strickland and Parsons.[10]

24-hour seston series

Five experiments were conducted to assess the daily seston cycle at aquaculture farms. In 2002, experiments were performed at two Atlantic salmon sites: Atlantic Silver, Inc., in Bocabec Bay (inner Passamaquoddy Bay) and J.D. Stewart, Inc. in Bliss Harbour (lat 45°02 long W; outer Passamaquoddy Bay). In 2003, experiments were performed at 3 sites, all owned and operated by Heritage Salmon Ltd., in Passamaquoddy Bay. Each site was sampled for 24 h on 3 consecutive days. The first site, Charlie Cove (lat 45°02 N, long 66°87 20 W), was sampled on 22-23 July 2003; the second site, Frye Island (lat 40 N, long 66°84 W), was sampled on 23-24 July 2003; and the third site, Fish Island (lat 45°00 47 N, long 66°92 24 W), was sampled on 24-25 July 2003. Each test site had a corresponding reference site 200 m away. Every hour for 24 h (every 2 h in the 2003 series), triplicate 1-L water samples were collected simultaneously at 5-m depth using a 4-L Niskin™ bottle from the aquaculture and reference sites. Water samples for seston analysis were filtered on board the research vessel and transported to the lab where the organic content was determined on all the samples using the Strickland and Parsons [10] method.

Particle concentration and size distribution

Concurrent with hourly seston sampling, triplicate 250- to 300-mL water samples (from 5 m) were collected, preserved, and transported to the lab. Particle size distribution and concentration were determined using a Coulter Multisizer IIe™. Each water sample was gently shaken and carefully poured through a 125- m sieve into a 200-mL beaker, placed into the multisizer chamber, and stirred continuously to maintain particle suspension via an automatic stir rod inside the unit. Water was pumped into a 100- m aperture for 30 s and the output program was set to provide size distribution and abundance of particles between 2 and 64 m in diameter.

Figure 2
Left: Mussels positioned for the feeding experiment with the exhalant siphon facing the video camera. Right: Camera set-up used in the feeding experiment.

2. Mussel feeding response

In situ mussel feeding response experiments were conducted at the three aquaculture sites sampled in 2003. The experiments were conducted concurrent with the water sampling procedures previously described. Seven days prior to experimentation, Velcro® was attached to each mussel (60 mm ± 0.5) with cyano-acrylate glue and the mussels were socked at a depth of 2 m at each site. One hour before sampling was scheduled to begin, 8 mussels were attached to a Velcro®-post frame and oriented so that the exhalant siphon faced the camera lens (Fig. 2). Underwater video cameras (Sony digital Handycams) were set to record images using a time-lapse interval of 2 s in each 30-s period. Mussel exhalant siphon area (ESA) was recorded at both test and reference sites simultaneously.

Images of mussel ESA were downloaded to the computer program Image J™, where the area (mm^2) of the exhalant siphon could be determined. Pictures were calibrated using a 10-mm mark on the frame posts. The mean of three images per hour (1 min before the hour, on the hour, and 1 min after the hour) were used to determine the ESA for each sample time. Sample times for ESA and all seston parameters were concurrent for comparison. Clearance rates (CR in L/h) were determined from the observed ESA. Under lab conditions, mussels were fed similar concentrations (mg/L) of food (*Isochrysis galbana* T-ISO) as those experienced by mussels *in situ.* Regression analysis of observed CR against observed ESA in the lab allowed for accurate prediction of CR from ESA *in situ*.(8)

Statistical analysis

Statistical analyses of seston parameters were done using analysis of variance (ANOVA). Statistical analysis of mussel ESA and CR were done using repeated measures analysis of variance (rmANOVA). Statistics were done using the software SPSS 11.5 for Windows.

Figure 3
Left: Socked mussel spat deployed in February 2002.
Right: Experimental mussel socks in January 2003.

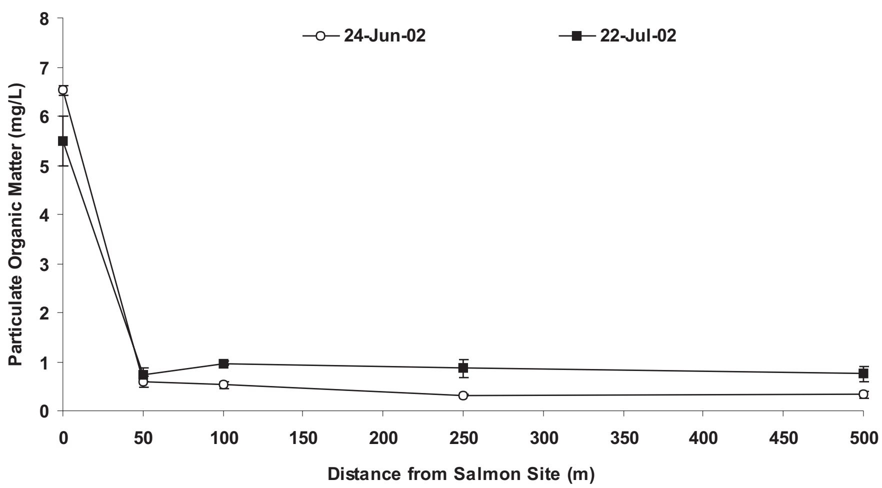


Figure 4
Particulate organic matter in seawater samples taken from intervals along a transect away from the Atlantic Silver, Inc. site. Error bars represent one standard error.

3. Mussel growth response

Mussel spat (mean shell length 16 mm), socked (Fig. 3) in 1-m sock units hung inside predator-proof cages, were deployed at two salmon sites and at a reference site, and grown from February 2002 to January 2003. At each salmon site, one sock/cage unit was tied directly to three randomly chosen salmon cages, with three units being bottom-moored at the reference site. Replicate cages measured intra-station variability and provided back-up in the event of a lost unit. At monthly intervals, 20 mussels were randomly selected from each sock and transported to the lab where various growth parameters were examined. Length, width and height of each mussel were measured (to 0.01 mm) with digital calipers. As well, the open whole weight and open drained weight were recorded. Shell and tissue were separated and dried to constant weight at 80 ºC . Wet and dry meat, as well as the dry shells were weighed to the nearest 0.01 g.

Statistical analysis

Condition index, used to relate amount of shell to living tissue (indicating market quality and resource allocation), was assessed as [dry tissue weight X dry shell

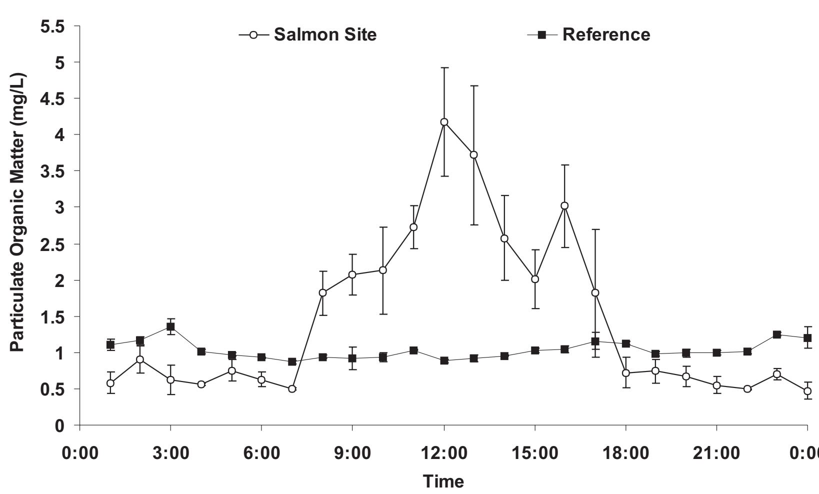
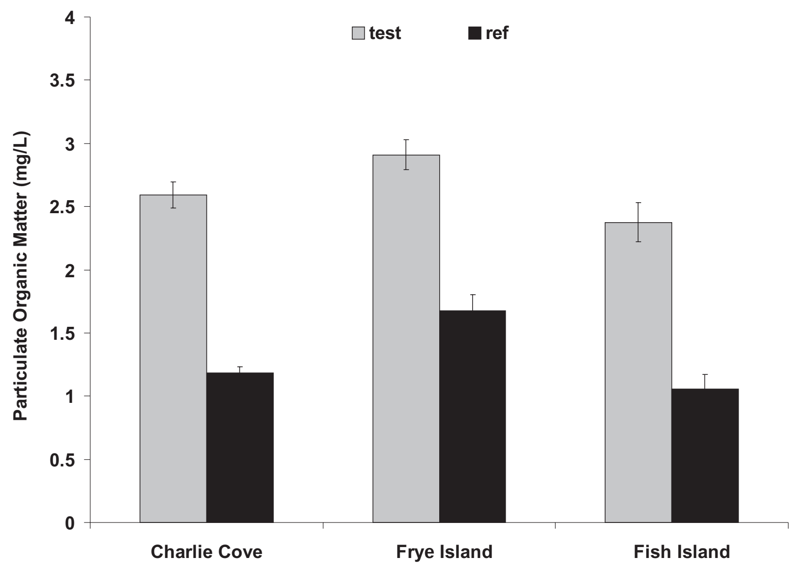


Figure 5
Particulate organic matter in seawater samples at 1-h intervals over a 24-h sampling period at the Atlantic Silver, Inc. salmon site and at a reference site 1.25 km away in August 2002. Error bars represent one standard error.

Figure 6
Total particulate organic matter for experimental salmon (test) sites and reference sites during the 2003 24-hour sampling series.



weight $^{-1}$ x 100%],[12] for all mussels from each sample. Wet and dry meat yields, as well as percent water content, were calculated for each mussel. Means were calculated for each treatment (n = 60) and plotted over time. Nested, repeated measures ANOVA were used to ascertain differences in growth parameters.

4. Mussel taste test

A taste test was conducted upon termination of the experiment to assess whether there was a discernable difference between cage and reference grown mussels. Mussels were steamed in separate pots of seawater with no additives that could affect the taste of the mussels. A triangle test was used whereby tasters were given three mussels, two from the same location (i.e., cage or reference), and one from the remaining location. Twelve testers took part in 5 to 8 trials each, and were asked to taste each mussel and to identify the 'different' mussel of the three, and finally, to grade the taste of each mussel as either 1 (poor), 3 (fair), or 5 (good).

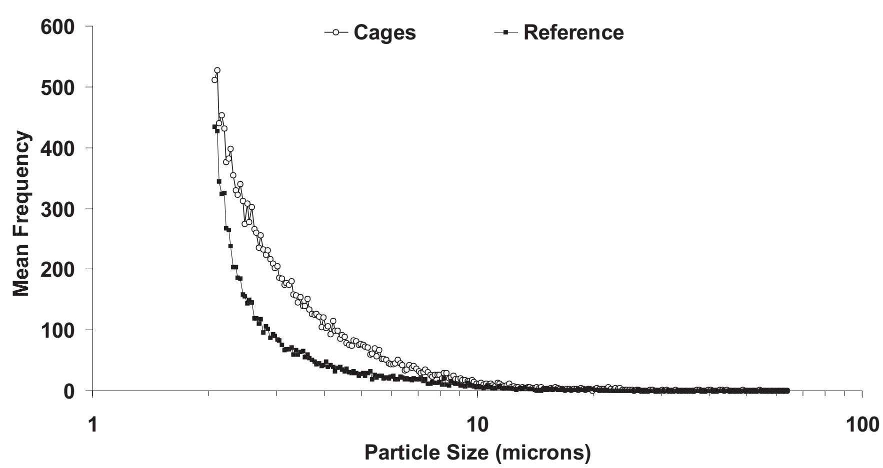


Figure 7
Particle size comparison from a seawater sample collected during salmon feeding at an experimental salmon site and at a reference site.

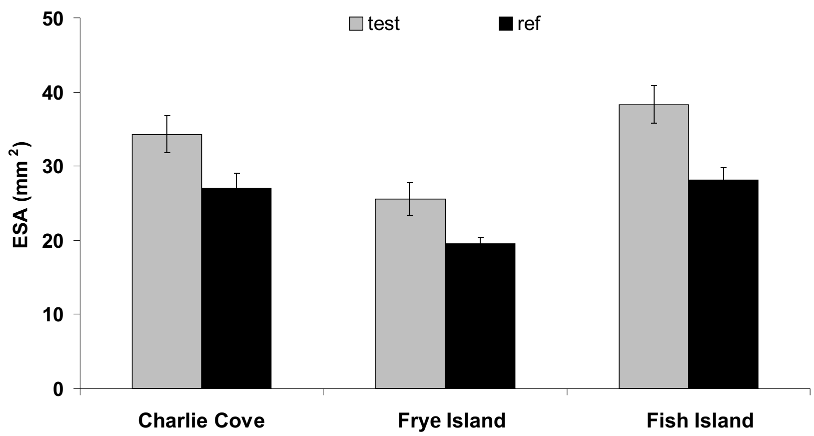


Figure 8
Mean exhalant siphon area (ESA) for mussels videotaped at experimental salmon (test) and reference sites during the 2003 24-h sampling series.

Results

1. Seawater analysis

Transects indicated elevated levels (5.49 to 6.52 mg/L) of particulate organic matter at salmon sites (Fig. 4), which dropped off at 50 m and remained at low levels (< 1 mg/L) in all subsequent samples. Daily organic matter measurements indicated an elevation (to a maximum of 4.18 mg/L) in particulate organic loads during the salmon feeding cycle at Atlantic Silver, Inc. in 2002 (Fig. 5), which dropped to pre-feeding levels (0.47 to 0.95 mg/L) upon termination of feeding. The reference site, 1.25 km away, had no comparable increase in daily particulate organic matter and remained stable throughout the study period. Total particulate organic loads were also significantly higher over 24-h cycles at all sites studied during 2003 (ANOVA, $p < 0.0001$, Fig. 6). Figure 7 represents a sample plot of water particle sizes found in reference and cage samples collected during 2002. During the salmon feeding period there was a large increase in particles in the 2 to 10 m range.

2. Mussel feeding response

Mussels suspended at all three salmon sites in 2003 showed significantly greater ESA and CR than mussels at reference sites (Figs. 8, 9). Repeated measures

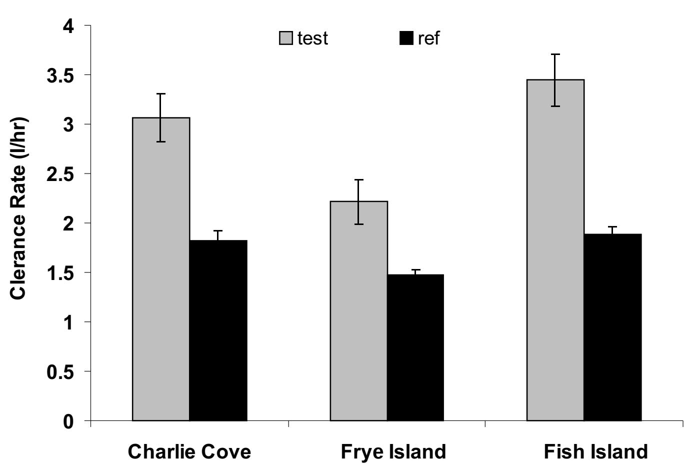
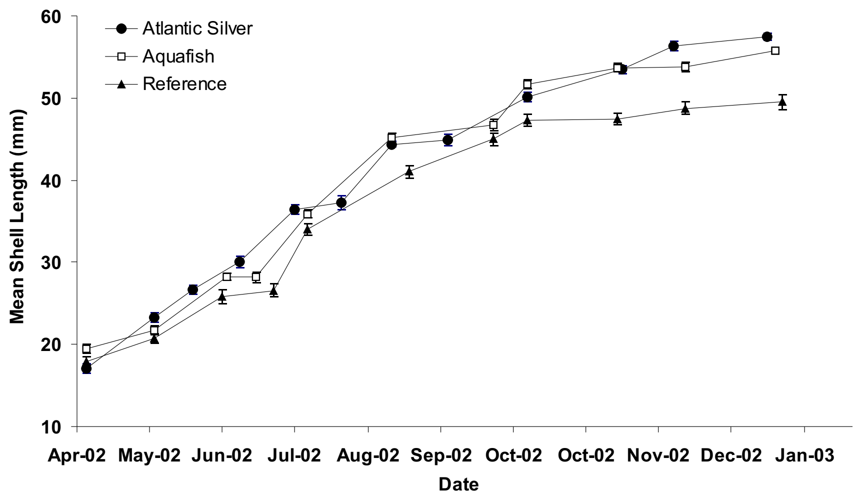


Figure 9
Clearance rates (CR) calculated for mussels videotaped at experimental salmon (test) and reference sites during the 2003 24-hour sampling series.

Figure 10
Mean shell length of mussels (n = 60) grown adjacent to salmon cages at two commercial sites (Atlantic Silver, Inc. and Aqua Fish Farms) and at a reference site. Measurements taken at monthly intervals from April 2002 to January 2003. Error bars represent one standard error.



ANOVA revealed that ESA and CR for mussels at the Charlie Cove and Frye Island sites were significantly higher at the $p < 0.0001$ level than mussels at their respective reference sites, while the mussels at the Fish Island site were significantly higher at the $p < 0.01$ level than mussels at its reference site.

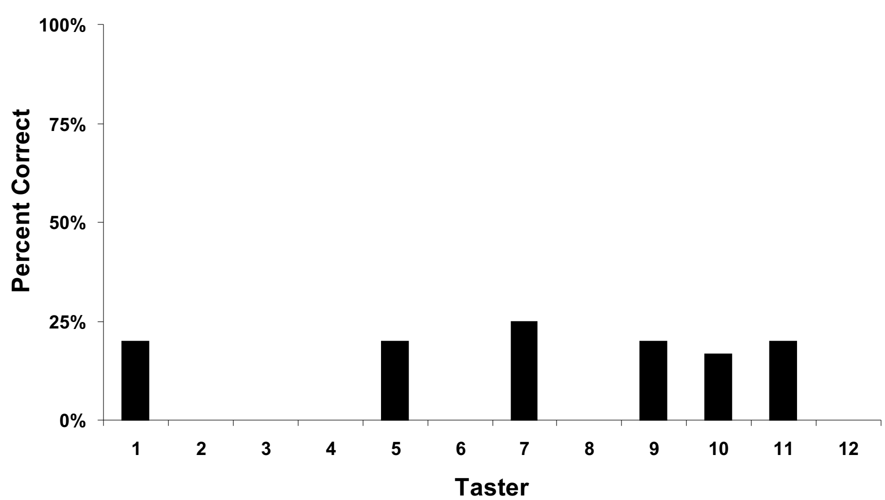
3. Mussel growth response

Figure 10 shows the mean shell length of experimental mussels (n = 60 for each sampling) from two salmon sites and a reference site over the duration of the experiment. Final sizes for the mussels grown at Atlantic Silver, Inc. and Aqua Fish Farms were 57.5 and 55.7 mm, respectively. Final size of the reference mussels was 49.5 mm. When comparing the growth patterns from all three sites, repeated measures ANOVA revealed significant overall differences ($p < 0.05$) in shell length between the salmon site grown and reference mussels.

4. Mussel taste test

Six of the 12 tasters were unable to select the 'different' mussel in any of the trials. The remaining tasters chose correctly between 20 and 25% of the time, less than the expected value of 33% correct due to guess alone (Fig. 11). All tasters

Figure 11
Percent of times mussel taste-testers in a triangle test correctly chose the 'different' mussel based on culture location (i.e. tasting one salmon cage mussel and two reference mussels or one reference mussel and two salmon cage mussels).



rated the mussel taste quality from fair to good (Fig. 12).

Discussion

Our studies demonstrated that salmon aquaculture sites provide a nutrient enhanced environment for the blue mussel, via exogenous input of a highly organic food source with particles within the utilizable size range for this species (2 to 110 m). Such particles were a direct consequence of fish feeding activities, as chlorophyll a concentrations at the salmon and reference sites did not show significant differences during the study periods (Lander, unpublished data). Thus, an increase in phytoplankton was eliminated as cause for the increased organic particulate. Via *in situ* video time series it was determined that mussels were exhibiting physiological responses to the elevated food levels by increasing their ESA to maximize particle capture, as well as water filtration and CR to maximize food intake.

Integrating blue mussel culture into existing Atlantic salmon aquaculture sites provides synergistic benefits for the mussel lines. Salmon sites offer a year-round food supply to the mussels, promoting growth during nutrient-limited periods (i.e. winter).[15] This is supported by the growth data presented here, where the most marked growth difference in site and reference grown mussels was found in the winter (November 2002 to January 2003); most likely a result of the exogenous food supply available at the sites. Such enhanced growth lessens the time to produce a commercial crop, thus permitting higher turnovers, and greater revenue.

In addition, removal of excess particulates by lower trophic levels (i.e. mussels) at salmon sites lessens the overall organic losses in the system, permitting recovery of lost energy in the form of an added marketable product with no discernable difference in taste compared to mussels grown away from the sites. Thus, IMTA systems represent a win-win situation whereby salmon growers gain from product diversification and subsequent economic gains, while making their sites 'greener' in the process.

To date, studies addressing the relative success of IMTA systems involving culture of both *Mytilus edulis* and salmonids have yielded conflicting results.[9,11,14] However, results of this study have demonstrated that mussels are responding both physiologically and morphologically to co-culture with salmon in the southwestern Bay of Fundy and therefore represents a feasible and profitable next step in the evolution of aquaculture systems in the region.

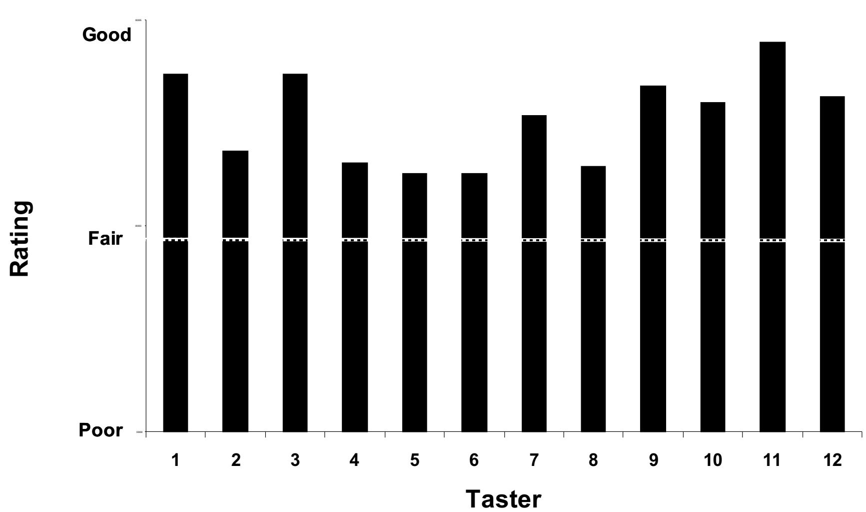


Figure 12
Average overall rating of all mussels consumed by taste-testers in a blind triangle test using mussels grown adjacent to salmon farms and at reference sites.

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Monitoring of Therapeutants and Phycotoxins in Kelps and Mussels Co-cultured with Atlantic Salmon in an Integrated Multi-Trophic Aquaculture System

Katsuji Haya

Katsuji Haya, Dawn Sephton, Jennifer Martin, and Thierry Chopin

There has been concern in integrated aquaculture with the potential transfer and accumulation of therapeutants used in the treatment of diseases in cultured salmon, as well as the concern that kelps and mussels grown adjacent to salmon cages can accumulate phycotoxins produced by harmful algae. Kelps and mussels were sampled periodically in 2001 and 2002 from an experimental integrated aquaculture site in Passamaquoddy Bay and analyzed for eight therapeutants and two phycotoxins (paralytic shellfish poisoning (PSP) toxins and domoic acid (DA)). None of the therapeutants or domoic acid was detected in kelp and mussel tissues. *Alexandrium fundyense* cells (responsible for producing PSP toxins) were detected in water samples from May to October in 2001 and 2002. Peak abundances (up to 1400 cells/L) occurred in mid June to late July and levels of PSP toxins in mussels peaked in late June, lagging the peak of *A. fundyense* abundance by 3 to 8 days. PSP toxins in mussels exceeded the regulatory limit (RL) of 80 µg STX equiv./100 g tissue wet weight from late May to early July 2001 and in late June 2002. PSP toxin concentrations decreased as the blooms of *A. fundyense* diminished. Results indicate that mussels and kelps grown in an integrated aquaculture operation with salmon in the Fundy Isles region could be harvested for human consumption using appropriate management and monitoring regimes.

Introduction

A study on the economic, environmental, and social feasibility of integrated multi-trophic aquaculture (IMTA) for salmon (*Salmo salar*), kelp (*Laminaria saccharina*), and blue mussel (*Mytilus edulis*) in the Fundy Isles region of New Brunswick, Canada, is in progress. In this case, salmon forms the "fed" component, while the mussels and kelps form the "extractive" component of the integrated system. One objective of IMTA is to mitigate the adverse ecological effects of wastes from one species by having the other species use the wastes as nutrients or fertilizers. However, the properties of mussels and kelps that make them suitable for the extractive function raise issues related to their safe harvest for human consumption.

The major source of the additional nutrients for the extractive components is from excess feed and metabolic excretion from the fish. However, the mussels and kelps may also accumulate other wastes from salmon aquaculture operations. Of concern are contaminants in feed, therapeutants, chemicals and preservatives in construction materials, and pathogenic bacteria.[2,17] *Alexandrium fundyense* and *Pseudo-nitzschia pseudodelicatissima* are organisms responsible for producing paralytic shellfish toxins and domoic acid, respectively. Both organisms occur annually in the Bay of Fundy,[12,14,15] and shellfish can accumulate these toxins to concentrations that are toxic to vertebrate consumers.

Another objective of the project is to determine whether mussels and kelps co-cultured with salmon can be harvested as food for humans. An overview of our studies on the accumulation of contaminants from feed, therapeutants, and phycotoxins by mussels and kelps is presented. Current information suggests that with timely monitoring and effective management practices mussels and kelps can be harvested.

Methods

In 2001, multi-year-class wild blue mussels (40 to 80 mm in length) were collected at IMTA site in Passamaquoddy Bay (#1, Fig. 1). In 2002, one-year-old mussels (25 to 60 mm in length) were socked in 1- to 2- m long polyvinyl mesh socks (14-mm mesh) at a density of 300 to 400 mussels/m and suspended at 5-m depth in Passamaquoddy Bay. Kelp cultures were initiated under laboratory conditions and attached to long-lines at the IMTA sites in the fall. Surface water, mussels, and kelp samples were collected periodically from April to November in 2001 and 2002. In 2003, the study was extended to three other sites in the Bay of Fundy (#2, 3, and 4; Fig. 1).

Surface water samples were collected by bucket and immediately preserved with formalin:acetic acid (1:1) for determination of *A. fundyense* and *P. pseudodelicatissima* cell densities using settling chambers and an inverted microscope.[13] Mussels and kelps were stored frozen and analyzed by the Canadian Food Inspection Agency (CFIA) for PSP toxins and domoic acid, heavy metals (Hg, Al, Cr, Mg, Fe, Ni, Cu, Zn, Se, Cd, Pb), therapeutants (antibiotics and antiparasitics), and persistent organic pollutants (PCBs and organochlorine pesticides).

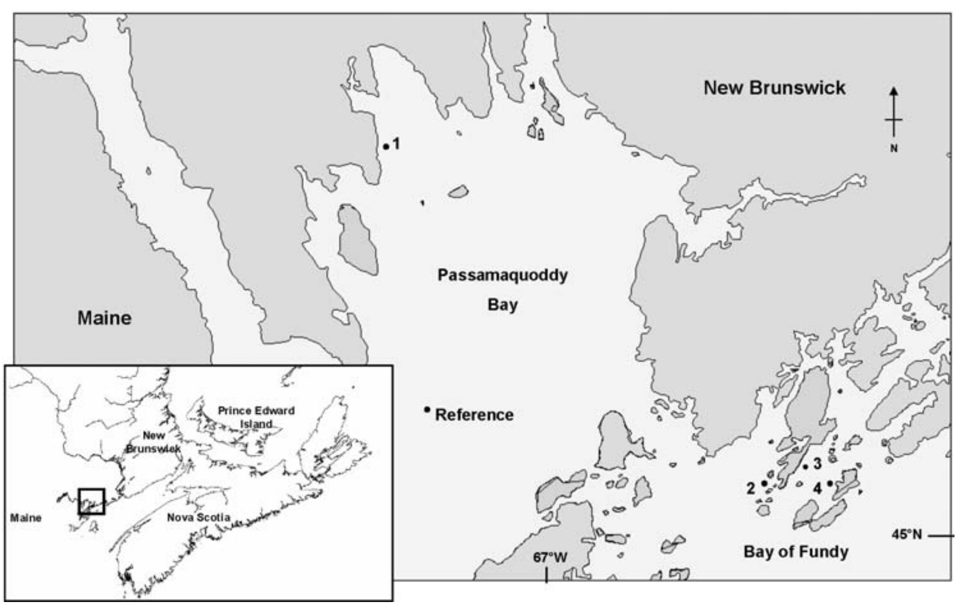


Figure 1
The four integrated multi-trophic aquaculture (IMTA) sites in the Fundy Isles region of New Brunswick, Canada.

Results and Discussion

Many chemicals are used in salmon aquaculture, both intentionally and unintentionally. In Canada, these chemicals include feed additives, chemotherapeutants, disinfectants, pesticides, herbicides, and anti-fouling agents.[2,17] Contaminants in feed ingredients and therapeutants added to feed as a means of administration can be accumulated by mussels and kelps. Significant concentrations of heavy metals (Zn, Cu, and Fe) have been found in salmon feed and concentrations of these metals were higher in sediments and sea urchins near salmon farms than from reference sites.[4,5] However, for the cultured mussels sampled from the IMTA sites, the concentrations of Hg, Al, Cr, Mg, Fe, Ni, Cu, Zn, Se, Cd, and Pb were not different from those at 22 monitoring (reference) sites that are part of the Gulf of Maine/Bay of Fundy Mussel Watch Program.[10] Some persistent organic contaminants (PCBs, DDTs) have also been found in feed and sediments near aquaculture sites,[8] and were found in higher concentrations in cultured salmon than in wild salmon.[9] But concentrations of PCBs, DDTs and other organochlorine pesticides were below quantifiable concentrations in mussels and kelps sampled from the IMTA sites in Passamaquoddy Bay and the Bay of Fundy.

Oxytetracycline has been found to be persistent in sediments and has been detected up to 30 m away from salmon aquaculture sites.[1,3] Antibiotic resistant bacteria in sediments have been correlated with salmon aquaculture in the Bay of Fundy.[6] Emamectin benzoate has not been detected in sediments following treatments for sea lice infestations of cultured salmon.[7] During the summers of 2001 and 2002, salmon cultured at the cage site in Passamaquoddy Bay (Fig. 1) received treatment with emamectin benzoate for sea lice infestations and oxytetracycline for bacterial infections. However, neither of these therapeutants was found in the co-cultured mussels and kelps sampled within a week of treatments. Other therapeutants used by the salmon aquaculture industry in the Bay of Fundy (cypermethrin, ivermectin, chlorotetracycline, tetracycline, sulphadimethoxine, and sulphadiazine) were not detected in mussels or kelps sampled from any of the integrated aquaculture sites in Passamaquoddy Bay during 2001 and 2002 and the Bay of Fundy in 2003 (Fig. 1). These studies indicate that mussels and kelps co-cultured with salmon in the southwestern Bay of Fundy do not accumulate contaminants and therapeutants in salmon feed.

"These studies indicate that mussels and kelps co-cultured with salmon in the southwestern Bay of Fundy do not accumulate contaminants and therapeutants in salmon feed."

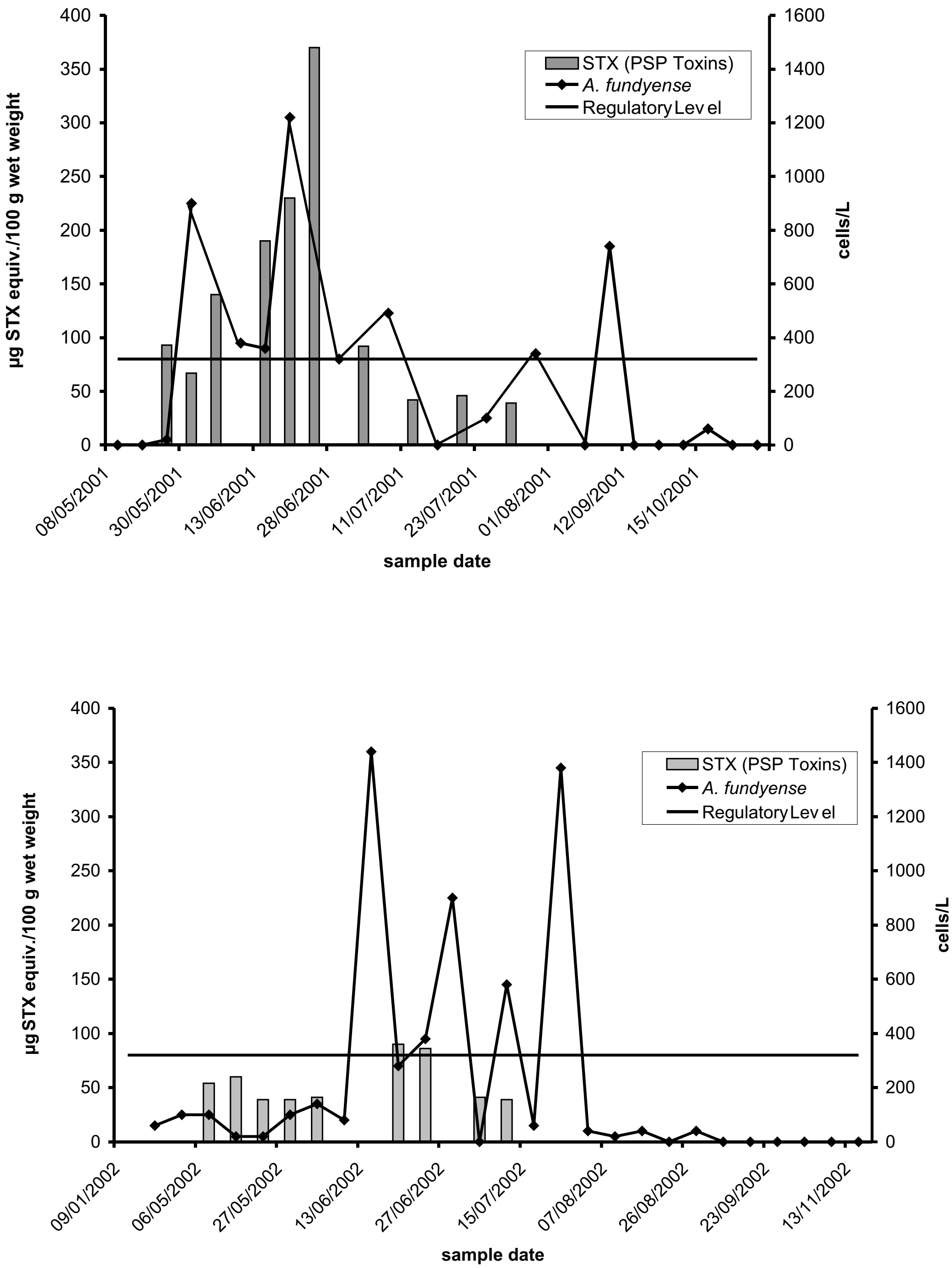
Harmful algal blooms of concern to the shellfish industries in the Bay of Fundy are *A. fundyense* and *P. pseudodelicatissima*. *Alexandrium fundyense* produces a series of toxins that cause paralytic shellfish poisoning (PSP) and *P. pseudodelicatissima* produces domoic acid (DA), which causes amnesic shellfish poisoning (ASP) in human consumers. Closures to harvesting of mussels and clams in the Fundy Isles region due to the accumulation of toxic concentrations of PSP toxins have occurred annually since 1940 and to DA in 1988 and 1995.

Pseudo-nitzschia pseudodelicatissima was discovered as the producer of DA in the Bay of Fundy when concentrations greater than one million cells/L were observed from late July through September 1988 in Passamaquoddy Bay.[11] For DA to exceed the regulatory limit, there must be greater than one million cells/L in water samples. Such high concentrations have only been observed in the years 1988 and 1995 in the Bay of Fundy. The 1995 closures occurred in exposed areas of the Bay of Fundy; there were no closures in Passamaquoddy Bay. With the high concentrations required to exceed the regulatory limit, it has been possible through regular phytoplankton sampling to provide ample warning (often up to three weeks) to regulatory agencies for DA toxins in shellfish. The highest concentrations observed in 2001 and 2002 at the IMTA site occurred in mid July 2002, when 20,000 cells/L were found. DA was not detected in mussels and kelps sampled from the site in Passamaquoddy Bay in these years.

Blooms of *A. fundyense* occur annually between May and September in the Bay of Fundy.[14,15] The blooms are seeded in the offshore and tend to be advected to

Figure 2

Concentrations (cells/L) of *Alexandrium fundyense* (surface) and PSP toxins (µg of saxitoxin equiv./100 g tissue wet weight) in mussels, *Mytilus edulis,* whole body homogenates from the IMTA site in Passamaquoddy Bay, during 2001 and 2002 (regulatory limit indicated at 80 µg of STX equiv./100 g wet weight).



the inshore. Passamaquoddy Bay is less exposed and therefore less prone to high cell densities, so shellfish do not accumulate high levels of toxins. If an area is closed as a result of unsafe PSP toxin levels, it is generally not for long. In some years, some of the shellfish harvesting areas in Passamaquoddy Bay have not closed to harvesting at all. The concentrations of *A. fundyense* observed in surface water samples from Passamaquoddy Bay during 2001 and 2002 were relatively low (1,400 cells/L; Fig. 2). PSP toxins above the regulatory limit (RL) of 80 μg STX equiv./100g tissue wet weight were detected from mid May to late June in both years. Peak concentrations of PSP toxins in mussels lagged the peak concentrations of *A. fundyense* in the surface water by a few days. Similarly, as the intensity of the *A. fundyense* blooms diminished, the concentrations of PSP toxins in the mussels decreased. PSP toxins were not detected in kelps sampled from the site in Passamaquoddy Bay.

These results suggest that cultured mussels can accumulate concentrations of PSP toxins above the regulatory limit. DA was not detected in mussels during the study period, but it is important to note that the only DA closure in Passamaquoddy Bay occurred in 1988. PSP closures tend to occur during the summer months, but this is a busy period for salmon aquaculture operations, and mussel meat quality is not prime at this time due to reproduction, so harvesting the mussels from fall to early spring is preferred. Although harvesting of wild mussels throughout the Bay of Fundy has been closed since 1944, the CFIA has monitored mussels on an irregular basis. The CFIA has a regular monitoring program for clams and, in spite of annual closures to harvesting due to PSP toxins, there is an active and thriving wild clam industry in the Bay of Fundy. This is a common management protocol in most shellfish harvesting countries in Europe and Asia. Thus, in conjunction with appropriate monitoring protocols,[16] such as regular phytoplankton monitoring and regular as well as immediate pre-harvest toxicity testing, it is possible that marketing of mussels as a safe seafood for consumption would be feasible through much of the year in Passamaquoddy Bay.

Summary

Accumulations of therapeutants in mussels and kelps were not detected. Therefore, there is low risk with use of medicated feed. Levels of heavy metals and organic contaminant concentrations in sediment, mussels, and kelps were not different from those found in natural populations, and were below regulatory limits. *Alexandrium fundyense* was present from May to September. PSP toxin concentrations in mussel tissues in Passamaquoddy Bay exceeded the regulatory limit for only short periods of time (late May to early July). Field and laboratory data indicate that PSP toxins are readily accumulated and depurated by *M. edulis*. PSP toxins were not detected in kelps. *Pseudo-nitzschia pseudodelicatissima* cells were present at low levels from April to September, but no DA was detected in mussel and kelp tissues. The culture and safe harvesting of blue mussels and kelps are feasible in the Passamaquoddy Bay region.

Acknowledgments

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An Introduction to the Oceanographic Aspects of Integrated Multi-Trophic Aquaculture

Fred Page

Fred Page, Jeffrey Piercey, Blythe Chang, Bruce MacDonald, and David Greenberg

A research project on integrated multi-trophic aquaculture (IMTA) of salmon, mussels, and kelps is being conducted in southwestern New Brunswick. The study area is spatially and temporally complex. The oceanography component of this project has just started and will be studying water circulation patterns and dissolved oxygen dynamics, including the roles of salmon, mussels, and kelps on the oxygen budget of an IMTA site. We will be collecting field data on water movements and dissolved oxygen levels, and will be using a computer circulation and particle tracking model. We will also look at the issue of scale when dealing with the management of aquaculture: site-specific versus bay-wide management and regulation. This information will help determine where best to locate IMTA operations in the area.

Introduction

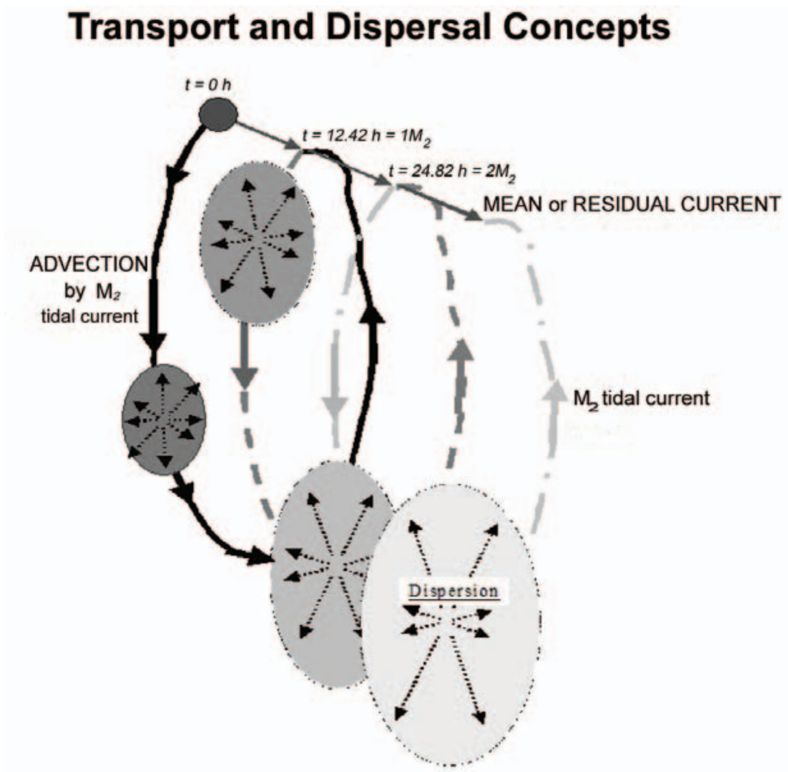
Integrated multi-trophic aquaculture (IMTA) takes place in the coastal marine environment and if it is to be acceptable and successful it must accommodate the environmental situation and the coastal zone management objectives for the area. Our general interest is in developing an understanding of the influences of the environment on IMTA and the influences of IMTA on the environment of the caged fish and other components of the IMTA complement, as well as on the environment as a whole. We are also interested in the issue of how an IMTA operation should be spatially and temporally structured on a range of spatial scales to best achieve the production and environmental objectives. Our focus to date has been on investigating the dynamics of the dissolved oxygen concentration at fish farms and the influence of IMTA on these dynamics.

In the following we highlight some of the oceanographic features that may influence the way we think about and develop IMTA in a tidal environment and introduce some specifics pertaining to dissolved oxygen concentrations in the environment and in fish cages that may be considered as candidates for IMTA operations. Unlike some of the other research components of the southwestern New Brunswick (SWNB) IMTA project, our component has just started and hence to some extent we are still developing our concepts.

Some Oceanographic Background

Southwestern New Brunswick is a tidally-dominated area and hence the development of IMTA should take some of the characteristics of a macro-tidal environment into consideration. A fundamental component of IMTA is the transfer of

Figure 1
Illustration showing the conceptual framework for how a patch of particles or a dissolved substance disperses over time in a tidally-dominated flow field that has little spatial structure. The arrows indicate how the patch is advected (i.e., translated) by the principal lunar semi-diurnal (M_2) tide. The net displacement of the patch over an even multiple of the M_2 tidal period (12.42 h) is referred to as the residual or mean displacement or motion. The spreading and dilution of the patch as it is advected is illustrated by the increasing size of the ellipses and the decreasing intensity of the ellipse grey shading.



effluents (e.g., fish feces, excess feed, nutrients) from fish cages to other organisms such as mussels and kelps. The motion of the water within the farms and bays mediates this transfer. The basic concepts underlying the transport and dispersal of dissolved and particulate substances in water are shown in Figure 1. The motions are modified by the specifics of how the substances interact with the water and the organisms and chemicals within it. To gain some understanding of how this conceptual framework operates in the SWNB area, we have collected field data on water currents and developed a 3-dimensional finite element circulation and particle tracking model of the area.[2,3]

Our empirical data on transport pathways and dispersal rates were gathered using CAST (convertible accurate surface tracker) drifters. These drifters record GPS (global positioning system) positions at time intervals of approximately 10 to 12 minutes and were configured to drift with the currents in the surface 1 m of the water column. The drifters were often released in clusters and were generally tracked for 5 to 6 h, but in some cases, recovery did not occur until the day after release. Some examples of drifter tracks from the southern Grand Manan area of southwestern New Brunswick are shown in Figure 2. In general our drifter experiments have indicated that water moves away from the fish farm site and does not return on tidal time scales, water from one farm may pass through another farm, and estimated rates of horizontal dispersion are consistent with the theoretical and empirical relationships of Okubo.[4]

More extensive estimates of the transport and dispersal patterns around farms have been made using the circulation and particle transport model mentioned above. The circulation model is fully non-linear, includes intertidal drying, has 21 sigma depth levels (reduced in water shallower than 10 m), and has variable horizontal resolution with a minimum resolution in some areas of approximately 50 m). The model is formulated to include tides, winds, and baroclinicity, but to date

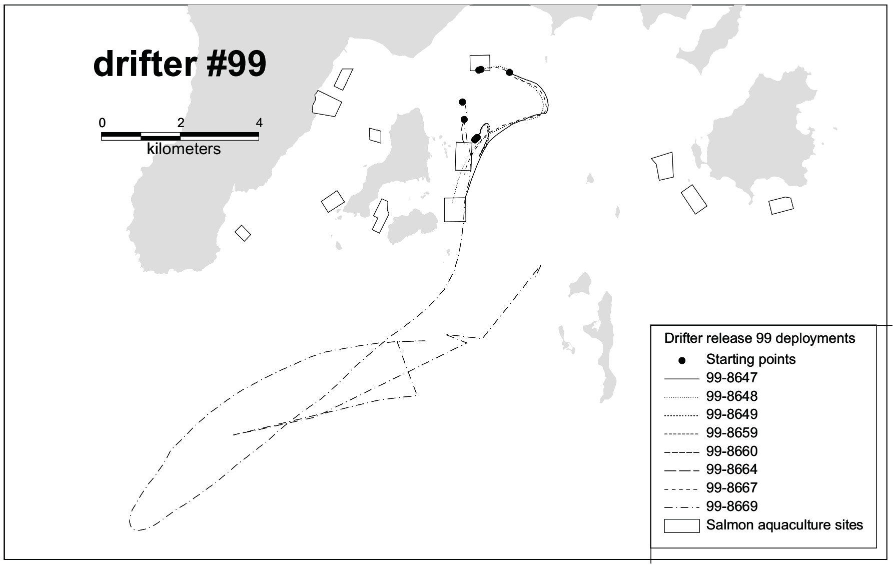


Figure 2
Example of CAST drifter tracks from the southern Grand Manan areas on 10 July 2002. The white polygons are the site boundaries for salmon farms.

we have only explored the effects of the M_2 (semi-diurnal principle lunar) tide and considered the influence of some steady winds. An example of the output from the model for the southern Grand Manan area is shown in Figure 3. The output shows that water currents vary in magnitude and direction on small spatial scales (10s to 100s of meters). An example of the model-generated particle tracks for one salmon farm in southern Grand Manan is shown in Figure 4. The output illustrates how the rate, direction, and pathway of the advective flux of suspended and dissolved material from a farm is not constant in a tidal environment: it changes with the phase of the tide and the transport pathway can be spatially complex.

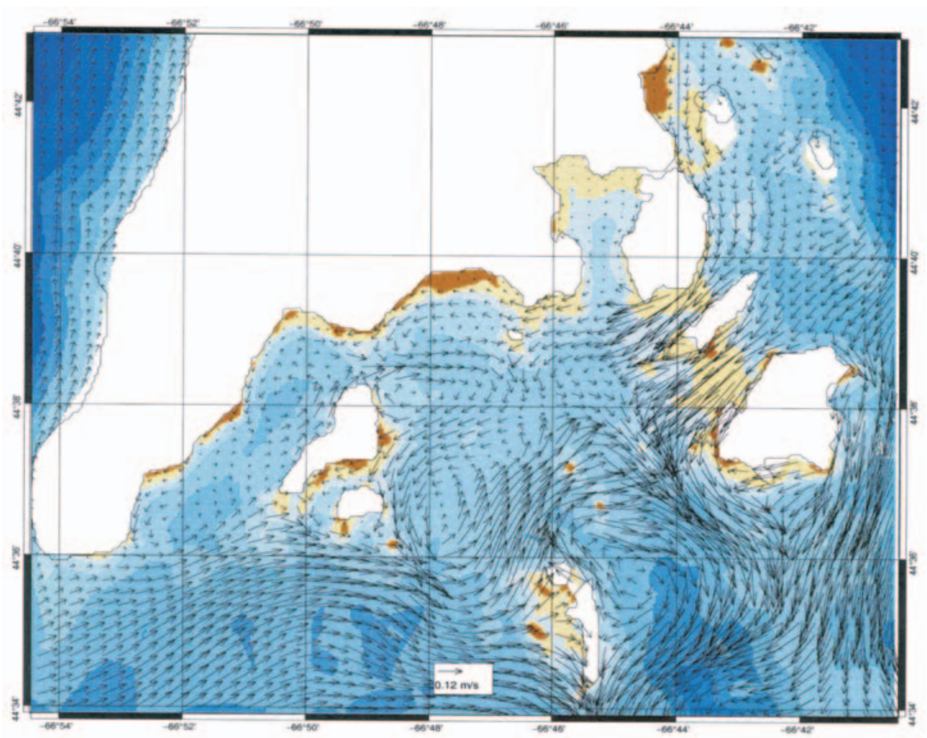


Figure 3
Example of circulation model output for southern Grand Manan.

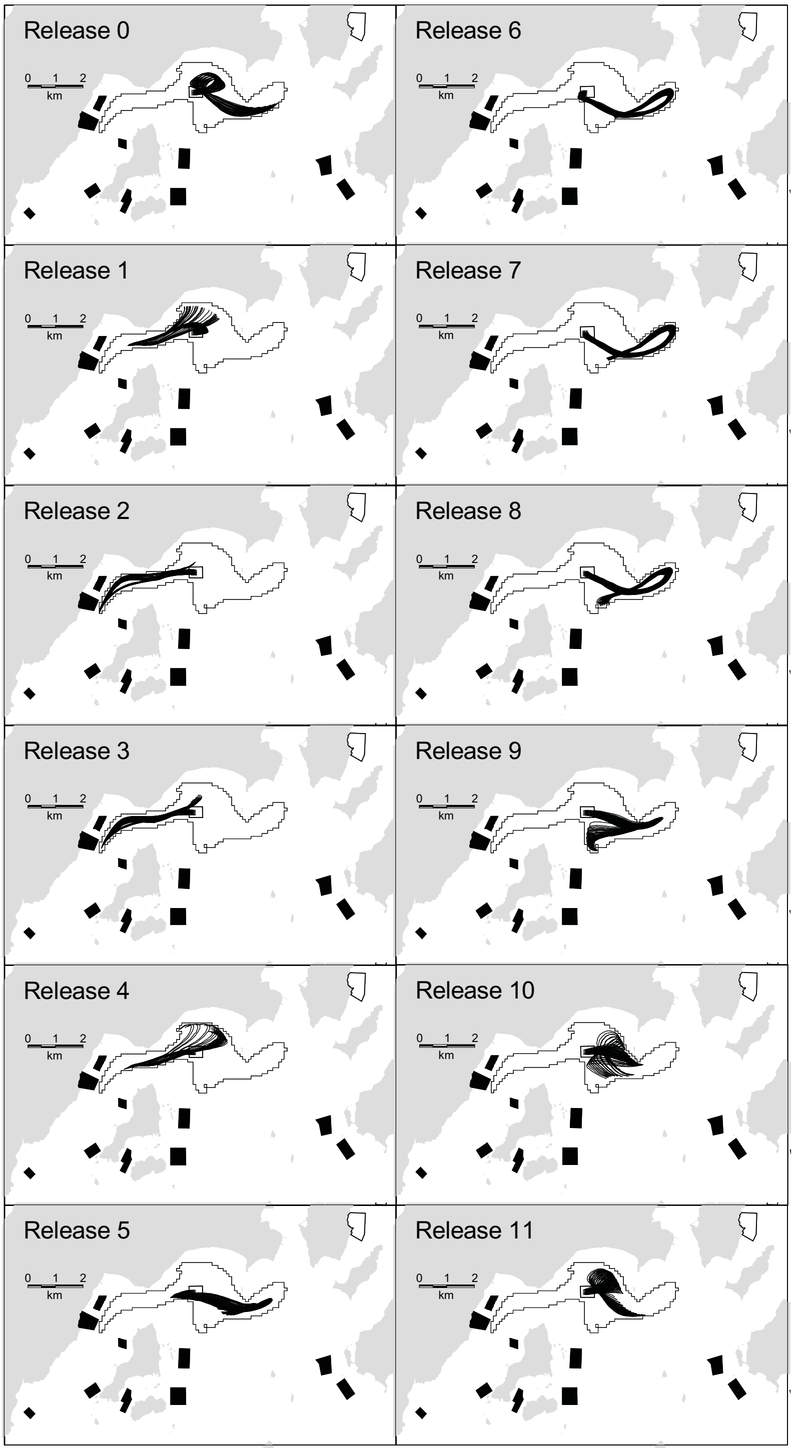


Figure 4
Model particle tracks for each of 12 hourly releases from a salmon farm in the southern Grand Manan area. Each release consists of 36 particle tracks, released from points equidistantly spaced in a 200 m by 200 m grid centered around the site centroid, and tracked for one tidal cycle (12.4 h). The outline of the combined tidal excursion areas is also shown. The smaller black or white polygons are salmon farms.

The Integrated Multi-Trophic Aquaculture Concept in Southwestern New Brunswick

The IMTA concept being explored in SWNB consists of the concurrent culture of finfish, shellfish, and seaweed (algae) on a single salmon farm site. A hypothetical farm configuration is illustrated in Figure 5. Near-bottom culture is being considered but is not being actively pursued at the moment and has not been included in

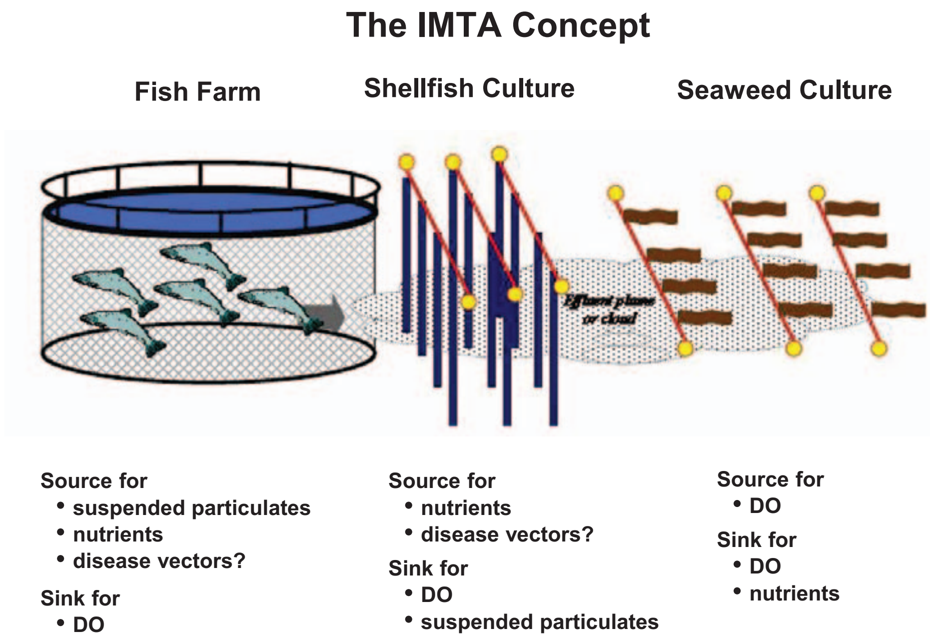


Figure 5
Conceptual diagram of an integrated multi-trophic aquaculture (IMTA) operation including fish, shellfish, and seaweed.

the diagram. For a spatially-fixed farm structure, such as that used by most salmon farming operations, the suspended and dissolved substances, nutrients, and gases such as dissolved oxygen (DO) are carried away from the fish cage toward the shellfish and seaweed during some phases of the tide. During other phases of the tide the materials carried away from the fish cage do not flow through the shellfish and seaweed components of the operation. Hence, the mussels and seaweeds do not consistently benefit from the farm effluents and they do not consistently remediate the effluents. IMTA operations that are moored so that all aspects of the farm can swing with the currents might ensure a more consistent flux of substances between the fish cages and the other components.

Although the signal from a fish cage will flow through other cages and IMTA components within the farm during at least some phases of the tide, a diluted and potentially mediated effluent signal may be transported to other farms and components of a bay. This may trigger some development and regulatory considerations regarding the scale of focus. For example, what scales of IMTA interactions are of primary interest—the farm scale, bay scale or some other scale? Do we want site-specific performance thresholds and monitoring, and/or bay-scale performance-based standards?

Dissolved Oxygen Dynamics

Background data concerning the annual cycle of dissolved oxygen in SWNB (monitored at sites located away from salmon farms) show that maximum dissolved oxygen concentrations occur in June and July and minimum concentrations occur from September to December (Fig. 6). The ambient concentrations appear to be always greater than 7 mg L^{-1} (and greater than 80% saturation). At these concentrations, caged salmon should not experience low oxygen stress.[(1)]

Although the ambient concentrations of DO are relatively high, the concentration of DO within salmon cages may sometimes be below ambient concentrations. For example, a time series of the concentration of DO obtained from a salmon cage shows evidence of regular episodes of reduced concentrations of DO (Fig.

7). In this particular case, the DO concentration dropped below 6 mg L^{-1}, indicating a potential for low oxygen stress. Filtering the data with a running average indicates a low frequency fluctuation in DO concentration that has a period of about 8 to 9 d and a high frequency fluctuation with a period of about 12.4 h—the period of the dominant M_2 tidal motion (Fig. 7). These high frequency variations often result in relatively low concentrations of DO persisting for about 3 h every tidal cycle. These periodic fluctuations are not detected by a sampling approach that takes a single DO measurement at a consistent time of day (Fig. 8). Sampling the DO concentration in such a limited way would largely miss the periods of low oxygen.

As mentioned in the introduction, our work within the IMTA umbrella has focused on developing an understanding of the dynamics of DO at the farm and bay scales. This focus was chosen for various reasons, including:

- Some salmon farms in the SWNB area have experienced production losses that might be associated with low concentrations of DO.
- Mass balance calculations have suggested that the respiration rate of the salmon biomass in cages is sometimes sufficient to reduce the concentration of DO in some cages and in some Bay Management Areas.[5-7]
- Point observations of the concentration of DO in the SWNB region have indicated that concentrations can get low in some areas. Time series of the DO concentration within some cages have shown periodic reductions of DO to relatively low concentrations (< 5 mg L^{-1}; ambient concentrations are generally above 7 mg L^{-1}).
- The culture of shellfish and seaweeds on a fish farm adds additional sources and sinks for DO that may significantly influence the oxygen budget for a farm and bay.

Figure 6
Dissolved oxygen (DO) levels at reference sites (located away from fish farms) in southwestern New Brunswick. Top graph shows dissolved oxygen in mg L^{-1} and the lower graph in percent saturation. Maximum levels occur in June-July and minimum levels in September-December. DO levels remain above 7 mg L^{-1} and above 80% saturation (dotted lines).

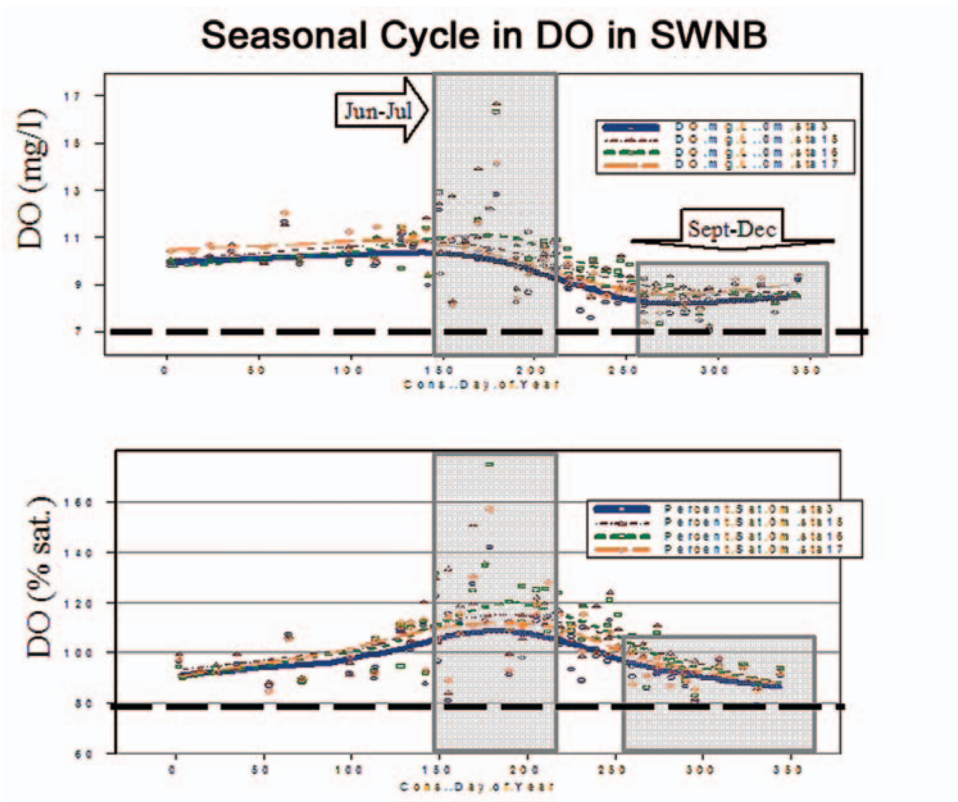
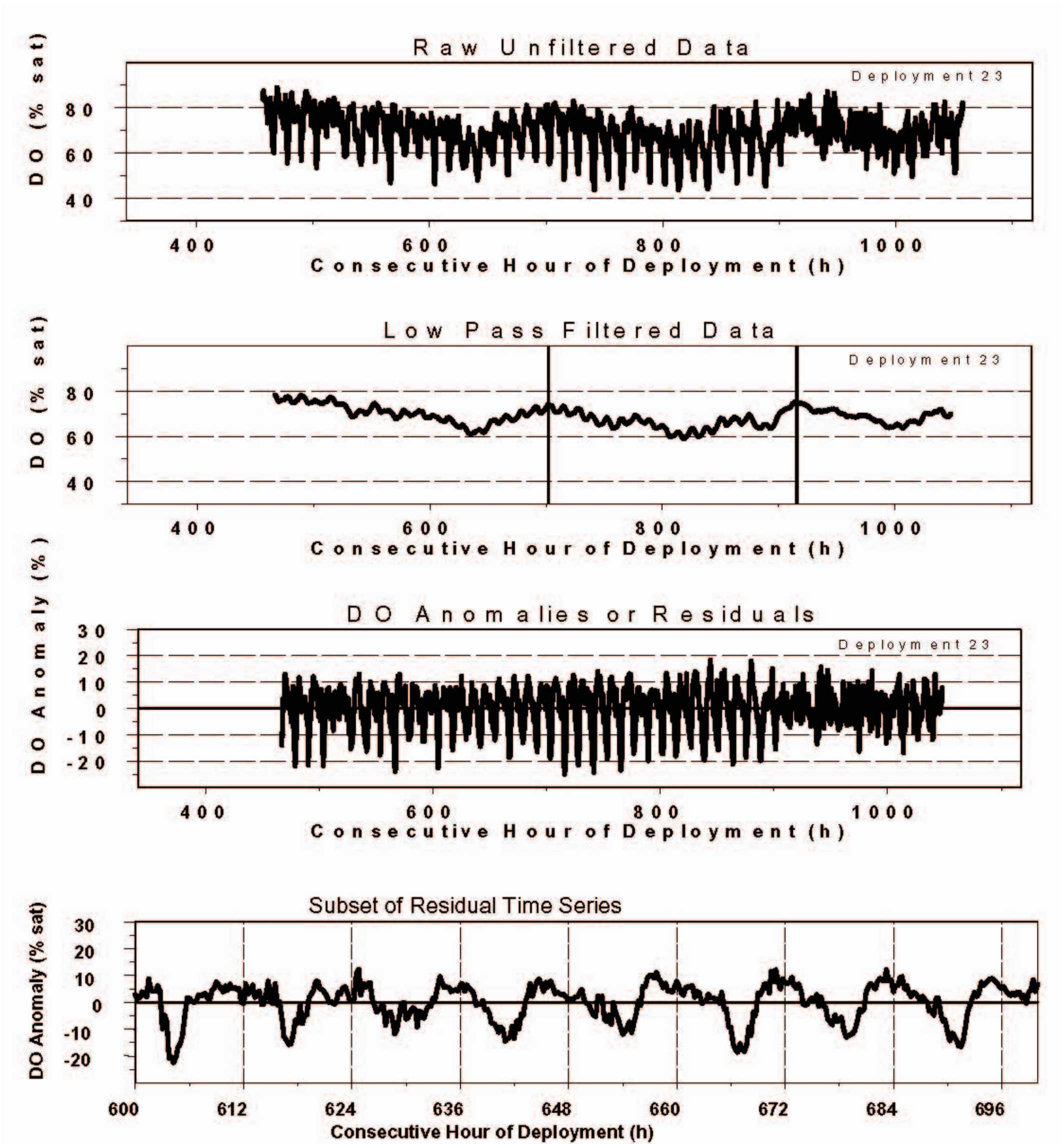


Figure 7
Dissolved oxygen (DO) levels at salmon farm in southwestern New Brunswick. Top graph shows actual continuously recorded data. The next graph shows the same data, filtered using a running average: the data indicate a cycle of about 8 to 9 days (indicated by the vertical lines). The next graph shows the differences between the top two graphs. The bottom graph is an enlarged subset of the third graph, showing regular low oxygen periods of about 3 hours every tidal cycle (12.4 hours, indicated by dotted vertical lines).



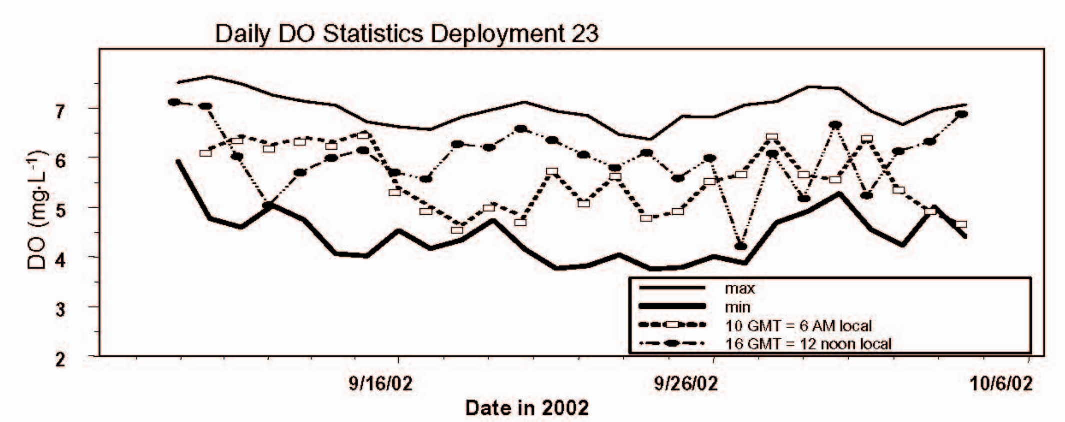


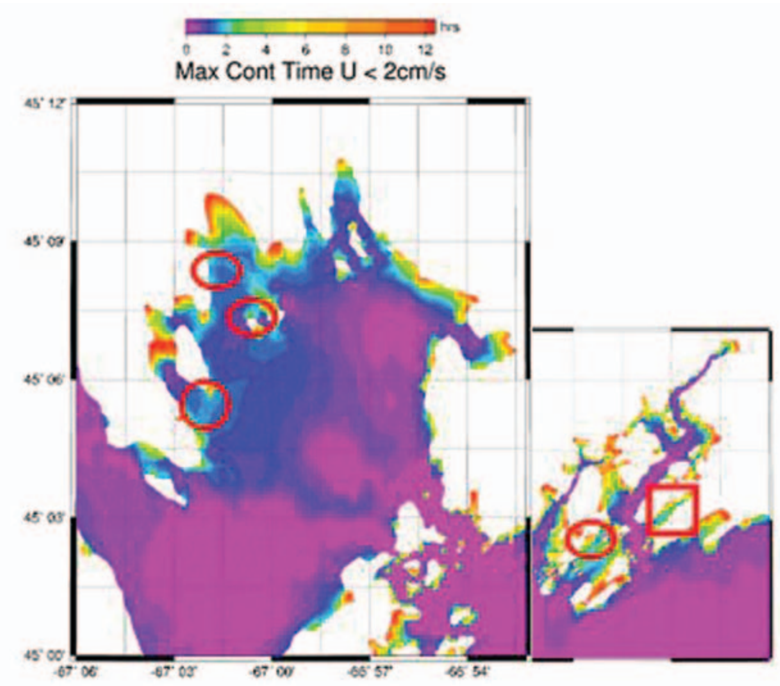
Figure 8
Daily maximum and minimum dissolved oxygen (DO) levels, compared to values recorded at the same times every day (0600 h and noon) from a salmon farm in southwestern New Brunswick. The data show that single daily readings will not give an accurate record of low oxygen occurrences at a farm.

- Some regulators and industry members have indicated an interest in more knowledge of DO dynamics in aquaculture.

The specific objectives of our work include:

- Measurement of respiration rates of some of the major components of the SWNB IMTA project, including a determination of the rate and role of mussel (*Mytilus* spp.) line, biofouling, and kelp (*Laminaria saccharina*) respiration on the oxygen budget of the site.
- Estimation of the spatial and temporal variations in DO at some salmon aquaculture sites and in some Bay Management Areas, and development of simple models of the DO dynamics in an IMTA site. The model being considered is an extension of the simple box model used by Page et al.,[6] which estimated the concentration of DO as a function of advective fluxes of oxygen into and out of the cage or farm and the removal of oxygen by the fish. The ex-

Figure 9
Areas predicted to be susceptible to low dissolved oxygen (DO), based on the duration of weak (< 2 cm s^{-1}) current speeds (U) as estimated from a circulation model. Areas with longer durations of weak currents are more susceptible to low oxygen conditions. The figure also shows examples of locations that have experienced low DO: ovals are fish farming areas and the rectangle is an industrial site.



tended model would include respiration by fish, mussels, and biofouling, and the addition of oxygen by sources such as kelps.

- We may also use a regional circulation model to help estimate areas within SWNB where fish farming and IMTA may have the potential to generate localized reductions in the concentration of DO under specific farming configurations. For example, spatially mapped contours of the duration of time within a tidal cycle in which model-predicted tidal currents are less than 2 cm s^{-1} may be indicative of locations susceptible to generating localized reductions in the concentration of DO (Fig. 9).

Summary

IMTA takes place in a spatially and temporally complex and variable environment. This complexity and variability needs to be considered in the design of IMTA operations and regulatory objectives. We have begun to obtain some baseline measurements and develop some simple models to help develop an integrated understanding of the dynamics of IMTA at the farm and bay scales. This information will help us predict the best areas for siting IMTA operations, both for minimizing impacts on the environment, as well as for optimizing production of the cultured organisms.

Acknowledgments

This work has been funded in large part by Fisheries and Oceans Canada and AquaNet, the Network of Centres of Excellence for Aquaculture. The principal participants are Fisheries and Oceans Canada (St. Andrews Biological Station), the University of New Brunswick at Saint John (Department of Biology), Heritage Salmon Ltd., Acadian Seaplants Limited, and Ocean Nutrition Canada.

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Finfish-Shellfish Integrated Aquaculture: Water Quality Interactions and the Implication for Integrated Multi-Trophic Aquaculture Policy Development

Stephen F. Cross

The sensitivity of shellfish to waterborne materials (e.g., metals, complex organic compounds, bacteria) makes them ideal candidates in the assessment of the water quality impacts of salmon net-cage operations. The use of shellfish as biomonitors also has important implications with respect to seafood safety, given their value in the commercial and recreational harvest/aquaculture sectors. A 2-yr research program was designed to determine the extent to which water-borne materials are dispersed through the water column from a salmon farm and to establish where these materials become bioavailable to shellfish *(Patinopecten yessoensis, Crassostrea gigas)* located within this distribution pathway. The results indicate that the "zone of influence" of such material is dependent on the hydrodynamic properties of the site. Farm sites with high currents rapidly dilute and disperse waterborne contaminants, so that accumulation within the tissues of shellfish cannot be detected despite long-term exposure. Sites with reduced tidal flows result in a localized persistence of low-level waterborne contaminants. However, the bioaccumulation effects are temporal in nature and associated only with the contaminant pulses that occur within a production cycle (e.g., antibiotic treatment). Shellfish quickly depurate post-treatment and remain well within safe limits for human consumption.

Product diversification from the finfish aquaculture sector's perspective makes integrated finfish-shellfish aquaculture a viable economic consideration, particularly in remote coastal regions and considering the opportunity for capitalizing on the use of existing infrastructure.

Introduction

Environmental studies of salmon farm impacts (e.g., Gowan and Bradbury[1] and Rosenthal[2]) have indicated that waste material dispersion and accumulation occurs primarily within a 50-m area immediately around the farm structures. However, given that these studies focused on the benthic impacts and thus examined the distribution of heavier organic materials (excess feed, fish feces) the additional possibility of a lighter waterborne waste material component (seston, dissolved), with a slightly greater distribution pattern, may have the potential to impact shellfish and other non-target resources located in the immediate vicinity of the farm operation.

The sensitivity of shellfish to all types of waterborne materials (e.g., metals, complex organic compounds, bacteria) makes them appropriate candidates in the assessment of potential water quality impacts associated with salmon netcage operations. The use of shellfish as biomonitors not only permits a test of the spatial influence of these substances in the marine environment, but also has important implications with respect to seafood safety given their respective value in commercial (wild harvest, aquaculture), recreational, and traditional First Nation uses.

If the water quality issues related to marine netcage culture are quantified as minimal or, ideally, non-existent, then a unique opportunity for shellfish-finfish integrated aquaculture (a component of an integrated multi-trophic aquaculture (IMTA) system) becomes available to the aquaculture industry. Product diversification from the finfish aquaculture sector's perspective, and regional expansion to remote areas from that of the shellfish sector, may make such a venture a viable economic consideration, particularly given the opportunity of capitalizing on the use of existing infrastructure (transportation, anchoring, vessels, personnel, marketing, etc.).

Considering the environmental and seafood safety concerns that have been expressed about the effect of salmon farming practices on adjacent shellfish resources, scientific data on the fate and effects of farm-derived materials with respect to adjacent shellfish resources are critically important in a discussion of the potential of integrated multi-trophic aquaculture. This research project was designed to demonstrate the extent to which waterborne materials are dispersed through the water column, and more importantly to determine if these materials are bioavailable to shellfish located within the distribution pathways. Results of this study will permit an accurate estimation of the "zone of influence" for the dispersion of such materials, and thus the physical information necessary to determine if finfish-shellfish integrated aquaculture is a feasible option for British Columbia, and Canada, from a seafood safety perspective.

The objective of this 2-yr study was to quantitatively document the culture performance of two commercially-important deepwater shellfish species, the Pacific oyster (*Crassostrea gigas*) and the Japanese scallop (*Patinopecten yessoensis*) incorporated adjacent to marine finfish culture operations, and to determine (from a seafood safety perspective) whether finfish-shellfish integrated aquaculture is a viable option for the Canadian aquaculture industry.

The specific objectives of the study, which took advantage of a design and infra-structural framework that explored the potential for waterborne contaminant dispersion and persistence, were to:

- quantify the growth rates and survival of the shellstock deployed at various distances from two marine netcage culture sites (one Atlantic salmon, one Pacific salmon);
- monitor, over an 18-month growth period for the animals, the body-burden levels of selected chemical, therapeutant, and bacteriological contaminants considered of concern and potentially originating from adjacent marine finfish culture operations;
- implement blind organoleptic testing of the project shellstock to document (in comparison with other remote shellfish production sites) the quality and possible "tainting" of shellfish grown adjacent to salmon farms; and to
- assess the results of these project data in terms of product safety, and the technical and economic feasibility of integrated finfish-shellfish aquaculture in coastal British Columbia.

This paper, which was presented at the 2004 IMTA Workshop in Saint John, New Brunswick, provides a summary of this 2-yr research initiative, with a focus on the implications for commercializing integrated aquaculture and the associated needs for policy and regulatory reform that would facilitate such development.

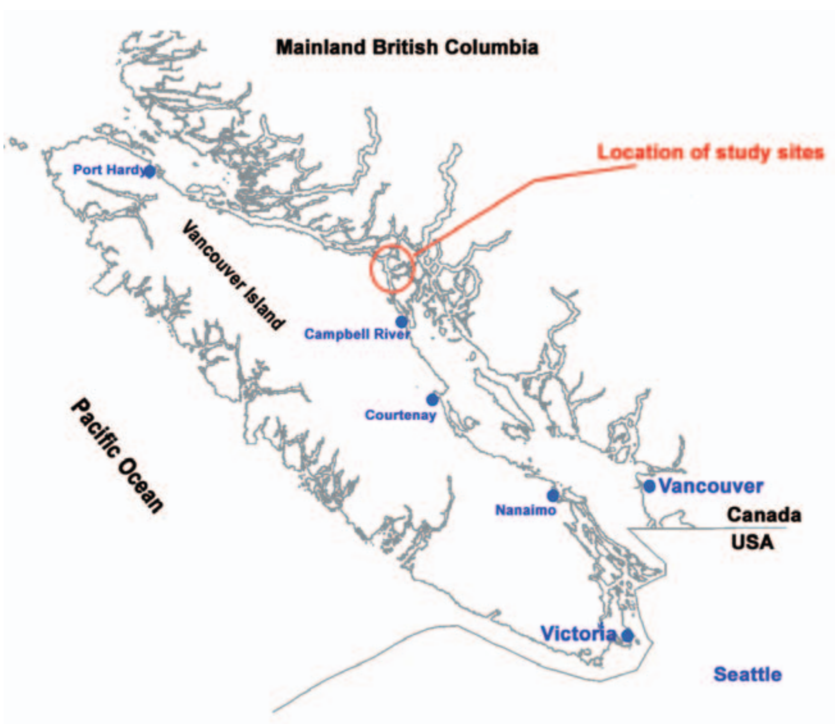
Methods and Materials

This research was conducted at two salmon farms. The criteria used to select these sites included an effort to have sites that:

- would be represented by both an Atlantic salmon (*Salmo salar*) and Pacific salmon (*Oncorhynchus tshawytscha*) production facility, ensuring that unique aspects of the operations that could reflect contaminant loading differences would be assessed (e.g., chemotherapeutant usage, organic waste loading associated with FCR characteristics, etc.);
- had comparable levels of production, ensuring similar waste material loading and potential level of environmental effects;
- were represented by significantly different physical oceanographic properties, allowing an evaluation of waterborne contaminant dispersion and environmental persistence under varying physical conditions;
- displayed biophysical attributes that would suggest the sites were good candidates for shellfish aquaculture; and
- were a reasonable distance from a coastal community center to ensure that sample acquisition and transport to laboratories occurred in a timely manner.

The two sites selected for the study, Young Passage and Venture Point, satisfied each of the above criteria, as well as being in relatively close proximity to further support survey/sampling logistics. The two study sites are situated north of Campbell River, in coastal British Columbia, Canada (Fig. 1).

Figure 1
General area of finfish aquaculture study sites with respect to coastal population centers of southwestern British Columbia, Canada.



The species of shellfish used for this assessment were *Crassostrea gigas*, the Pacific oyster, and *Patinopecten yessoensis*, the Japanese scallop. Both species are commercially important suspended (off-bottom) aquaculture species, ensuring that results of this research could be applicable from a commercialization perspective (i.e., development of integrated finfish and suspended shellfish aquaculture employing these species). These species also provided inherent biological differences that further supported the objectives of the study (e.g., differential filtration rates, contaminant retention periods, etc.). As various tissue components of the scallop are used as seafood products (e.g., meats, roe-on meat, whole animal), this species permitted a tissue partitioning component of the research to be conducted, allowing evaluation of possible water quality effects on potential harvest constraints, management requirements, and/or seafood processing options.

Sampling equipment and test bivalve molluscs were suspended in the water column from a shellfish longline (3-cm diameter polysteel rope), supported horizontally (1.0 m below the sea surface) by regularly-spaced polyethylene floats (41-cm diameter). The longline system was aligned in the downstream direction from the finfish production facility (determined through tidal current measurements), attached to the steel cage system at one end and anchored in place with a 2-tonne cement block at the other (Figure 2 illustrates the visible features of this infrastructure). The entire floating portion of this structure was 250 m in length.

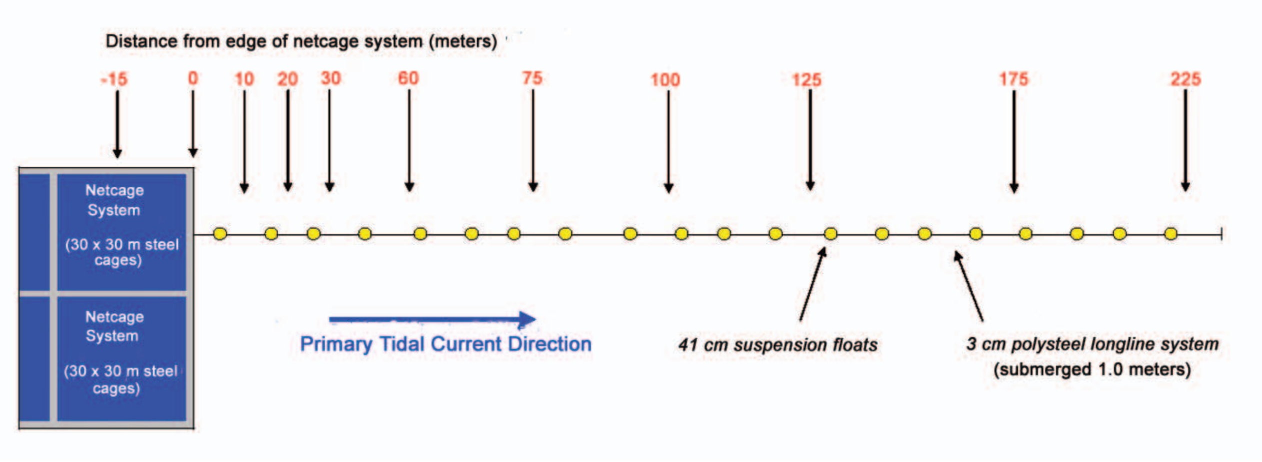
Figure 2
Shellfish longline extending downstream of salmon netcage system. S. Cross shown in foreground sampling Japanese scallops *(Patinopecten yessoensis)* from the perimeter station (adjacent to net).

Figure 3 provides a diagrammatic representation of this infrastructure showing the plan-view and side-view configuration of sampling infrastructure in relation to the sea surface, sea bottom, and the adjacent netcage system. The upper portion illustrates the position of the sampling stations that were established along the shellfish longline. A total of ten stations were deployed along the line at each of the two study sites. Sampling stations were concentrated in the near-field region of the netcage where waste material and waterborne contaminant effects were presumed to be the greatest. These stations were established at the netcage perimeter (0 m), and then downstream at 10, 20, 30, 50, 75, 100, 125, 175, and 225 m from the edge of the netcage system.

An eleventh sampling station was deployed within the nearest netcage at each of the sites. This station was considered a positive control to the study as all of its constituent sampling apparatus would be in direct contact with the materials entering the farm system (i.e.,

Figure 3
Configuration of research infrastructure showing shellfish longline system in relation to netcage aquaculture facility. A) Horizontal distribution of sampling infrastructure; B) Vertical distribution of sampling infrastructure in relation to farm structures.

A. Plan-view diagram of netcage system in relation to experimental longline and sampling stations



B. Side-view diagram of netcage system in relation to closest sampling infrastructure

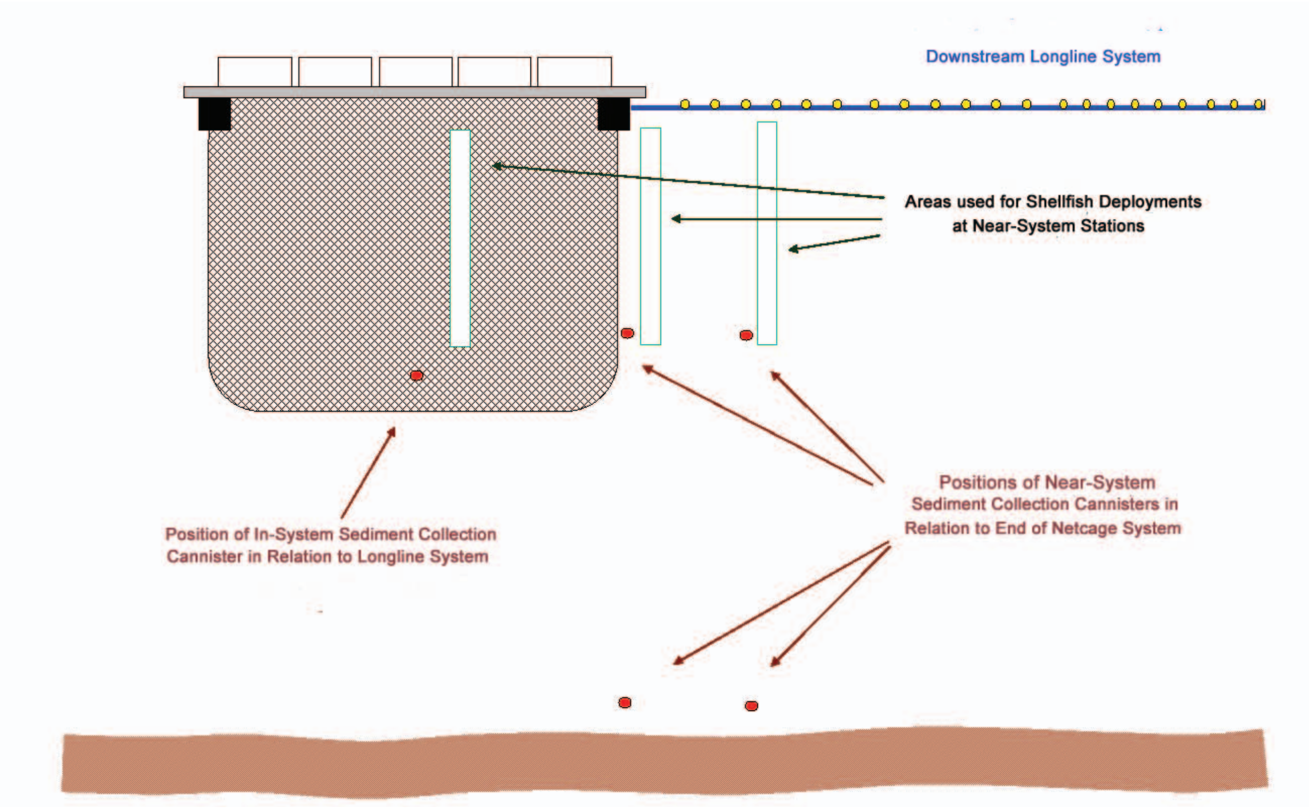
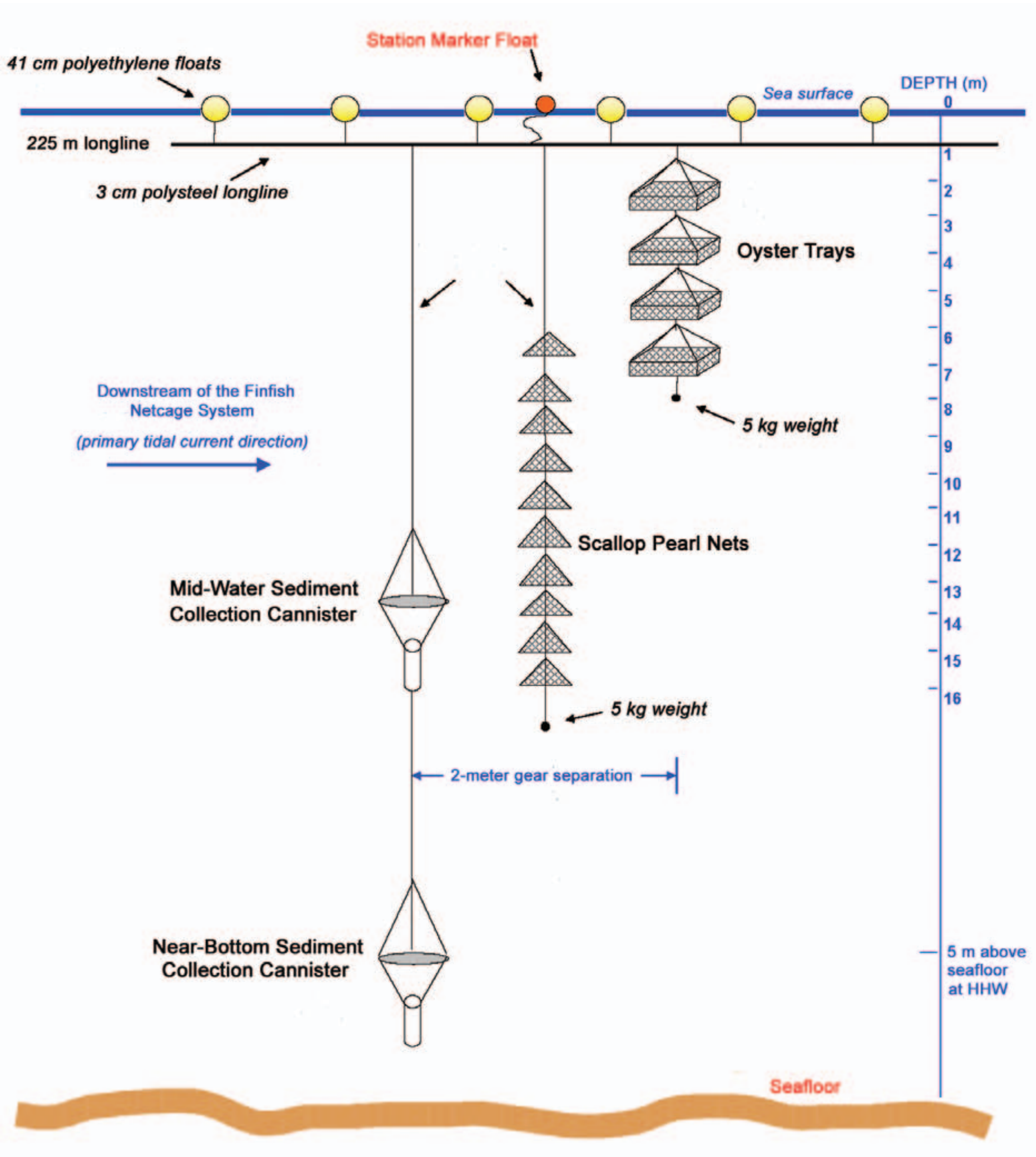


Figure 4
Research infrastructure configuration showing arrangement of shellfish and sediment canister equipment at each sampling station.



feed, fecal material (and its leachates), trace metals from surrounding treated nets, etc.).

The marine netcage systems at the study sites were steel cages that measured 30 x 30 m, with a depth of approximately 22 m. Figure 4 provides a cross-sectional view of the netcage system in relation to the established shellfish longline infrastructure. The vertical area occupied by the sampling gear at each of the first three stations (in-cage, perimeter, and at 10 m) is delimited with the rectangular box (vertical axis elongated). This is the area in which the shellfish were suspended from the longline at these stations; a similar configuration was used for each of the downstream stations not shown in the figure.

Data acquisition, over a complete finfish production cycle, included: (i) detailed oceanographic evaluations of water movement through the netcage system and downstream through the shellfish culture component of the integrated aquaculture system; (ii) routine sampling of shellstock to assess culture performance; (iii) regular sampling of shellfish tissues to document body-burden levels of trace metals; (iv) opportunistic sampling of shellfish tissues to determine levels of chemotherapeutant residues released from the finfish system post-treatment; and (v) measurement of organic waste loading, dispersion, and chemical composition.

Results

A few examples from the research program have been extracted from the pro-

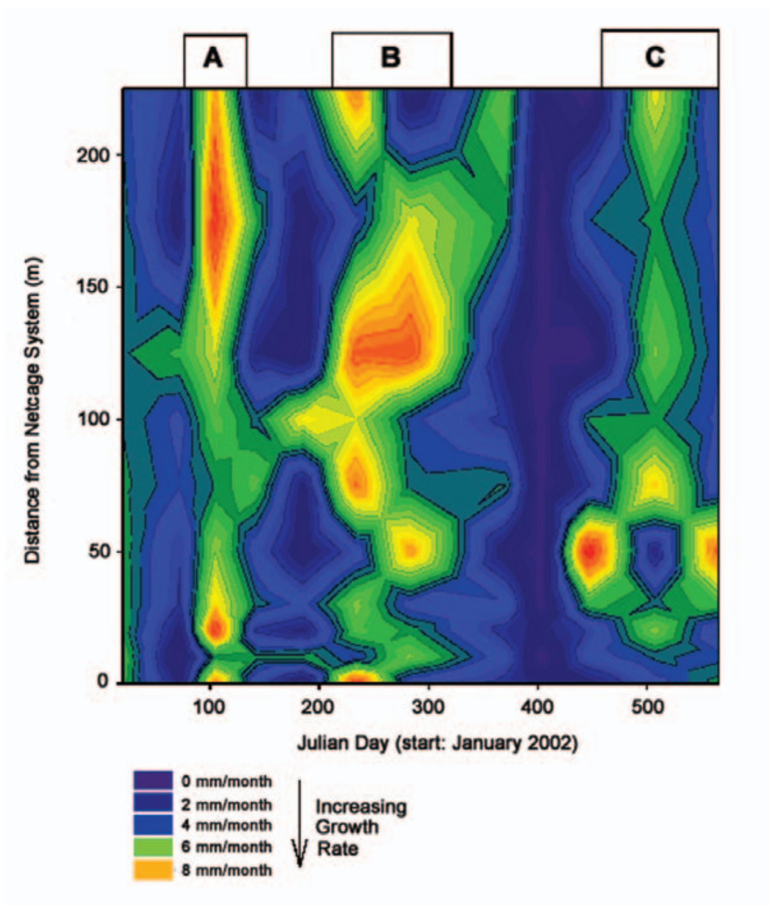


Figure 5
Contour plot of *Patinopecten yessoensis* growth performance at Young Passage study site as a function of the distance from the netcage system (Y axis). Growth data standardized as average shell height (n = 10; mm/month) across each of the 12 survey periods (X axis: Julian day starting at January 2002) for each of the 10 longline stations. A: April-May 2002. B: August-October 2002. C: April-May 2003.

gram database to illustrate the effects that have bearing on Canadian IMTA development from a policy and regulatory perspective.

Shellfish performance

Shellfish were sampled every 30 to 45 d over an entire production cycle. Shell height and mortality were used as measures of culture performance, with the resulting data used to assess spatial (distance downstream of netcage system) and temporal (seasonal, production-related) differences. Figure 5 illustrates the change in growth rates for the Young Passage scallops over the 2-yr period (x-axis) with respect to distance from the netcage system (y-axis). This contour plot shows seasonal increases in growth (spring and late summer, early fall) associated with typical phytoplankton fluctuations. Winter growth is significantly reduced.

There does not appear to be any positive or negative effects on growth associated with proximity of the test shellfish to the finfish component of the integrated system. This held true for both study sites and for each of the shellfish species examined. It is speculated that natural seston levels are sufficiently high as to mask the contribution of that of the finfish farm; given a maximum uptake (filtration rate) in these bivalve species, the resulting growth associated with the farm component of these suspended organics cannot be detected. This does not, however, suggest that these farm-derived organic constituents (and any associated contaminants) are not bioavailable to these shellfish, but rather that they do not have a cumulative effect that can be seen in the growth of the shellstock. On the east coast,

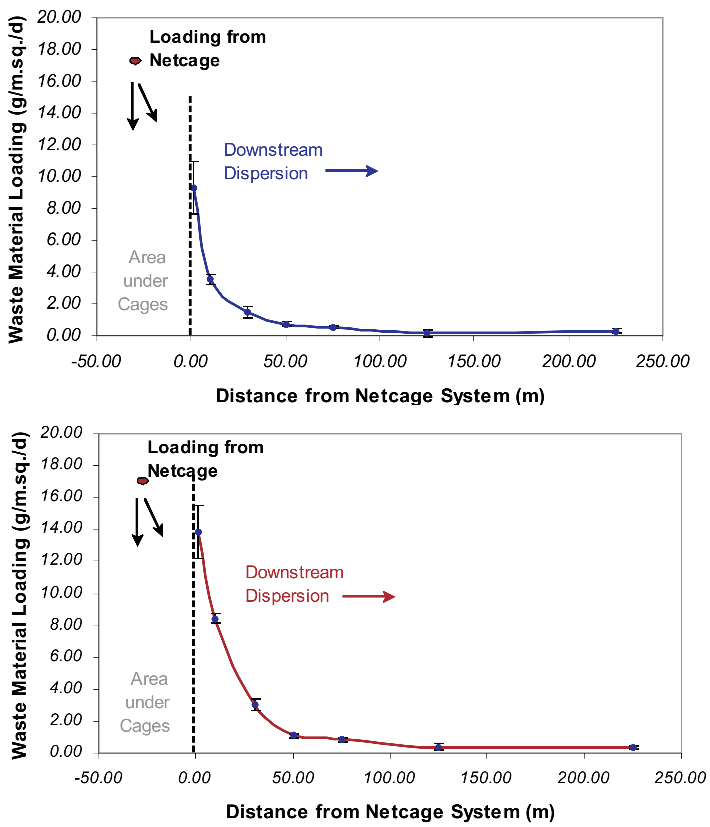


Figure 6
Dispersion of organic wastes downstream of the Young Passage finfish aquaculture facility. Upper graph shows retention of organics in the mid-water sediment collection canisters while the lower graph shows the accumulation just above the seafloor at each downstream station. Data are standardized to g/m^2/day.

enhanced growth has been shown in a variety of such evaluations (e.g., Nortug et al.[4]), but with mussels.

In terms of survival, all shellfish grown in close proximity to the farm performed similarly to that of a typical shellfish aquaculture facility. Overall production mortality (seed to harvest) was consistently between 2 and 4%, with no apparent relationship with distance from the netcage system.

Waste Dispersion and Characteristics

Sediment canisters were used to document the dispersion pattern of organic waste material originating from each of the two finfish aquaculture facilities. The dispersion of settleable solids was clearly related to tidal dynamics. The faster flows associated with the Venture Point farm site revealed a greater distribution field for these wastes, with the loading (per square meter) substantially reduced across the 10 downstream sampling stations. At the site with much lower tidal activity, the dispersion was confined to below and immediately adjacent to the netcage system. In both cases, a much smaller fraction was available within the mid-water capture, suggesting that the majority of the material is confined to the near-field region of the facility.

Figure 6 compares the upper and lower sediment canister results for the Young Passage farm site. The downstream dispersion of this settleable material appears to be concentrated below and immediately adjacent to the netcages, with a maximum dispersive range of approximately 100 m. Waste loading estimated from within-cage indicates that approximately 17 to 18 g/m^2/day is discharged from the cage, with this value reduced to less than 1.0 g/m^2/day at the seafloor some 75 m downstream.

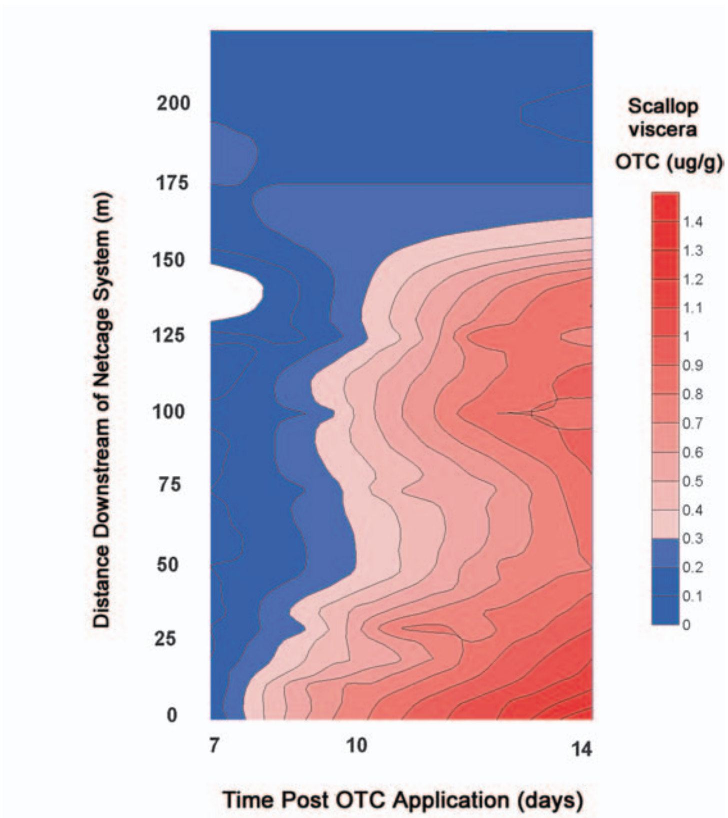


Figure 7
Levels of oxytetracycline (OTC) found in scallop viscera (adductor muscle excluded) post-treatment at Young Passage salmon farm site.

Water quality effects

The potential for contamination of shellfish tissue grown in close proximity to a commercial finfish aquaculture facility was tested over the entire production cycle at each of the two test sites. Tissues were analyzed for a suite of trace metals, with a focus on potential candidates that could be attributed to micronutrient feed additives or to leachates from the operational infrastructure (e.g., antifoulant-treated nets, galvanized system components, etc.).

Although there was some indication of near-field uptake by the adjacent shellstock, the concentrations remained low and their persistence dependent upon tidal conditions, duration of exposure, and clearance rates for the species in question. Figure 7 provides an example of shellfish tissue levels resulting from an in-feed treatment of oxytetracycline (OTC) at the study farm site applied over a 10-d period. The shellstock grown downstream of the farm did not show increased tissue level response (above analytical detection) until 7 d post-OTC treatment initiation, and from that point revealed an ongoing accumulation to a maximum at approximately 12 d following the start of the OTC treatment. The scallop viscera (adductor excluded: did not show any accumulation of OTC) achieved levels of 1.4 g/g (adjacent and within the netcages), with a downstream measurable effect to approximately 175 m, at which distance levels were at the acceptable Canadian Food Inspection Agency (CFIA) harvest level for finfish tissue (0.2 g/g). All of these values, however, fell well below the acceptable level for human consumption as permitted by the US Department of Agriculture (USDA) (2.0 g/g). Shellfish tissue clearance also occurred in these shellfish, with levels returning to below detection within approximately 3 weeks of treatment.

The persistence of OTC residues in the water column will determine the bioavailability to adjacent shellfish, and thus the ultimate tissue levels that will define seafood safety concerns for any product cultured for production purposes. The levels noted in Figure 7 were found only at the farm site with minimal tidal exchange, suggesting a localized persistence that resulted in the above situation. In contrast, at the high-energy farm site, samples revealed that no chemotherepeutant residues were found above that of the limit of analytical detection. It is hypothesized, given these contradictory results, that in areas where the dilution process is sufficient, bioavailable concentrations (even at the closest station) are extremely low and thus will not lead to any measurable increase in the shellfish tissue.

Discussion and Conclusions

This west coast research program has demonstrated that finfish-shellfish integrated aquaculture, one possible component of a more complex IMTA system (e.g., Neori et al. [3]), is a feasible aquaculture development for Canada and likely for other temperate coastal regions. Data acquired through production-cycle monitoring have shown some localized water quality impacts on the shellfish component, although these effects are considered largely site-specific (related to oceanographic and physiographic characteristics) and manageable given their temporal nature.

Research implications on IMTA policy development

This research initiative has indicated that water quality interactive effects are site-specific, with the occurrence and magnitude of these effects determined (in part) by the hydrographic characteristics of the IMTA farm site. The intermittent nature of these impacts on IMTA product quality may require implementation of a farm-based management (monitoring) system to ensure harvest timing avoids periods of tissue contamination (albeit at low concentrations). This may not be any more cumbersome than some regional industry-government management programs associated with bacteriological and/or biotoxin monitoring. Such initiatives might require the development of HACCP protocols including farm operational records for chemotherepeutant usage, projected clearance periods (fish, shellfish), sample collection (tissues; lot testing), harvest approvals, etc.

Research implications for industry development of IMTA

Although the limitation of expansion space can be a primary factor for exploring the feasibility of IMTA, the aquaculture development potential in western Canada is limited not by spatial constraint but rather by a combination of social and technical limitations. With aquaculture currently concentrated within the southern reaches of the coast (Fig. 8), the central and northern regions remain virtually untouched.

Expansion of the finfish sector to the central and north coast remains hindered by social uncertainty. Environmental issues continue to serve as a deterrent for

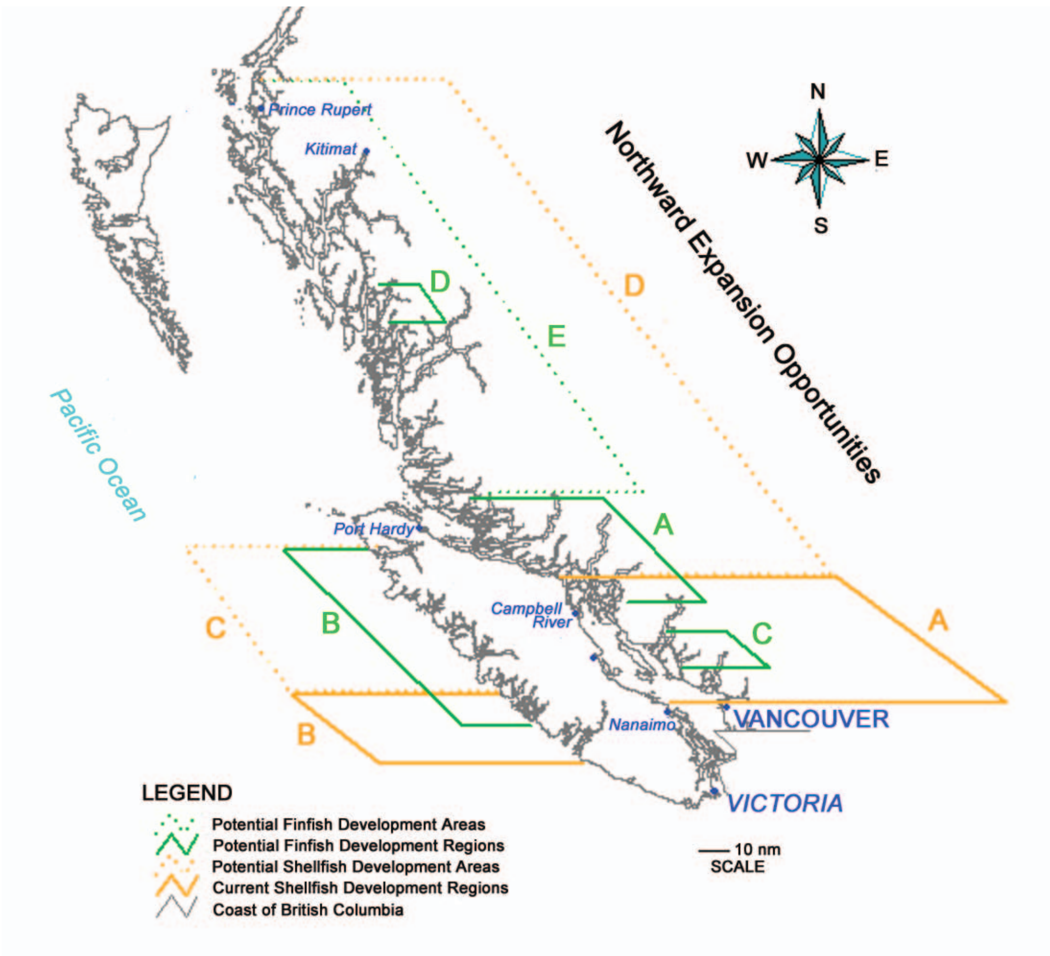


Figure 8
Shellfish and finfish aquaculture expansion potential in coastal British Columbia. Current and potential development regions in relation to coastal urban centers.

new sites and coastal First Nations remain divided as to the risks of this sector as it relates to traditional coastal resources (e.g., wild salmon, shellfish beds, kelps, abalone). However, these perceptions are not focused on the shellfish aquaculture sector, which remains of interest to First Nations as an alternative to declining fisheries and wild harvest opportunities.

While the finfish aquaculture sector maintains the infrastructure for remote operations, and thus the capacity for developing the very remote areas of the central and north coasts, the shellfish industry sector is presently operating in areas with direct access to upland infrastructure, including transportation, processing, seed supply, labour pool (and accommodation), etc. The development of remote areas, although technically feasible, would require consideration of such logistics and the significant capital and operational costs.

In consideration of these aquaculture development constraints, the introduction of IMTA to the west coast of Canada may serve as a conduit for development of both the finfish and the shellfish aquaculture sectors in these remote areas. The benefits of introducing this new approach includes opportunities for shared: i) infrastructure, including on-site accommodation facilities and transportation logistics; ii) farm personnel; and iii) processing and marketing.

The development of a shellfish (or other IMTA) component may not necessarily be desirable to a finfish company, but collaborative agreements to develop joint operations may prove valuable from a social perspective (First Nations, coastal community revitalization, etc.).

IMTA has the potential to provide considerable social and economic opportunities for coastal communities. IMTA could also add measurable environmental benefits to existing aquaculture systems, setting the stage for future production efficiencies.

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Integrated Multi-trophic Aquaculture: Variations on the Theme of Biofiltration

Dror Angel

Aquaculture effluents and the environmental impacts associated with them are a major concern of the finfish farming industry, regulatory authorities, and many other coastal stakeholders. Integrated multi-trophic aquaculture (IMTA) is a multi-pronged approach that addresses both environmental concerns and socioeconomic issues related to intensive cage aquaculture by cultivating biofiltering organisms in conjunction with finfish. Two modes of biofiltration are discussed: *extensive biofiltration*, which entails providing hard substrates that enable a natural biofouling community to become established around the fish farm, and *intensive biofiltration,* which includes the deployment of commercially-viable species of invertebrates and algae around the fish cages. Neither of these modes of biofiltration are currently employed in conjunction with European aquaculture, but there is hope that this will change in the near future.

Interactions between aquaculture and the marine environment have been intensively studied over the past two decades.(1-5) Key papers that emerged from these studies focused on the geochemical impacts associated with organic enrichment of the sea floor under fish cages and on the changes observed in the faunal communities underlying the fish farms.(6-8) Aquaculture impacts on the water quality of the receiving waters (water column effects) in most areas were practically immeasurable(9-11) and therefore generally ignored. Biogeochemical effects on the sea floor were much more evident and were eventually adopted as indicators of the degree of negative impact a certain farm had on its surroundings.(12-15) Since environmental regulations stipulate that a fish farm may not exceed a given benthic impact, it became necessary for fish farmers to reduce their organic loading.

To reduce organic loads below fish farms, several workers considered the feasibility of capturing falling particles(16) and/or removing organically-enriched sediments from the sea floor by mechanical means.(17,18) While these are good ideas, they are not "sustainable" solutions because they: a) may create new environmental problems (e.g., nutrient enrichment as a result of resuspension of organically-enriched sediments), b) may increase the impacted area, c) are inefficient at nutrient removal, and d) are very costly and therefore would not be employed by fish farmers.

A sustainable alternative to the "mechanical solutions" is a biological approach to aquaculture waste management. The biological capture of effluents, also known as biofiltration, is where a variety of animals, plants, and microbes are used to either mineralize or package the particulate and dissolved aquaculture nutrients into biomass. Biofilters are one of the essential elements of successful and economical land-based recirculating aquaculture systems since they remove excess nutrients, maintain good water quality, and enable the water to be re-used.(19) In many systems, biofiltration is performed primarily by nitrifying bacteria, whereas in others, the biofilter biomass (algal or invertebrate) may be harvested (see below), thereby serving as a bonus to the fish farmer.

In net-cage aquaculture, biofilters may help maintain environmental integrity by capturing effluents that would otherwise enter coastal waters, leading to eutrophication or other effects. I'd like to discuss two types of biofiltration systems that may be employed around net-cage fish farms: extensive and intensive biofilters. *Extensive biofilters* are communities of naturally-occurring organisms that develop on artificial structures deployed near fish farms with the intention of capturing and then either mineralizing or harvesting as much of the aquaculture effluents as possible. One of the early designs of this sort of biofilter was constructed by Chojnacki and Ceronik[20,21] to stimulate removal of excess nutrients from the highly eutrophic Polish coast of the Baltic Sea. This idea was extended to the removal of aquaculture effluents around Finnish fish farms in the northern part of the Baltic Sea,[22] as a means to make finfish cage aquaculture more sustainable.

In early 1998 two benthic artificial reefs were deployed near a commercial fish farm in the Gulf of Aqaba, Red Sea (Fig. 1), and monitored to assess whether they could capture substantial amounts of aquaculture effluents and also provide improvement to the impacted benthos below the fish cages.[23,24] The structures were rapidly colonized by rich and diverse communities of invertebrates and fish (Fig. 2), which removed substantial quantities of chlorophyll a from the seston. A more elaborate system of benthic biofilters was constructed and deployed on the sea floor around fish culture zones in Hong Kong, to examine whether the reefs lead to changes in sediment and water quality (www.artificial-reef. net). Preliminary data indicate there is improvement in both the quality of the water overlying the sediments and in the sediments themselves.[25]

The success of the benthic artificial reefs under the Red Sea fish farms led to a larger project, BIOFAQs (www.sams.ac.uk/biofaqs/) which focused on the deployment of artificial settlement substrates in the water column (Fig. 3) adjacent to the fish cages.[26] This project, conducted at fish farms in four countries (Scotland, Slovenia, Greece, Israel), demonstrated the potential to capture and harvest fish farm effluents in the form of biofouling biomass. The advantage of extensive biofilter systems is that they are relatively inexpensive to construct, deploy, and maintain, but they generally do not produce a high-value crop. More-

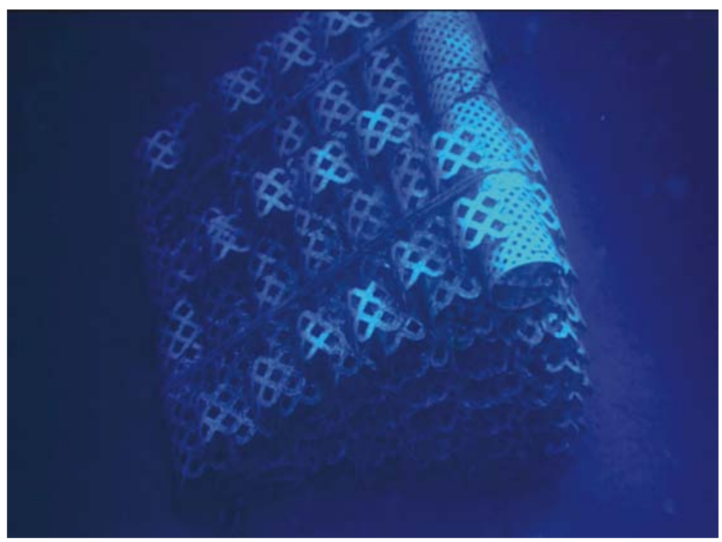

Figure 1
Benthic biofilter (plastic structure—2.8 m x 2.4 m x 2.4 m, WxLxH) located at 23 m depth, adjacent to the Ardag fish farm in the northern Gulf of Aqaba, Red Sea, just after deployment in March 1999 **(photograph, Stephen Breitstein).**

Figure 2
Close-up of one of the benthic biofilter cylinders showing a diverse community of fouling organisms, epifauna and fish, Gulf of Aqaba, Red Sea, in July 1999, four months after deployment **(photograph, Noa Eden).**

over, the efficiency of biofiltration in a "mixed-community" is unknown since we do not control the composition of the attached community. The alternative to the extensive biofilter model is the intensive biofilter.

Intensive biofilters are "planned" communities of sessile or motile animals and/or macroalgae that have commercial value. There is a large initial investment in seeding the lines or biofilter surfaces with specific invertebrates and algae, as well as an investment in maintenance of the biofilter communities to ensure optimal survival and growth rates. However, the filtration rates of these biofilters are a lot more predictable than the extensive systems since the biofiltering organisms are generally ones that have been studied. Moreover, the economic benefit from the biofilter "crop" is a bonus to the farmers since one of the criteria in selecting the species is their commercial value. Although the focus of this discussion is biofiltration as it applies to net-cage mariculture, there are many examples of intensive, land-based (e.g., ponds or tanks) integrated aquaculture that employ the same principles. Buschmann et al.,[27] Chopin et al.,[28] Troell et al.,[29] and Neori et al.[30] described systems that focus on the integration of finfish and seaweed aquaculture, while Shpigel et al.[31] and Neori et al.[32] described slightly more complex systems for land-based co-production of finfish, macroalgae and molluscs.

With regard to "open" net-cage mariculture, Kautsky and Folke,[33] and Folke and Kautsky,[34] proposed one of the early conceptual models for sustainable salmon aquaculture that involved bivalve and macroalgal production on fish cage effluents. Subsequently, Hirata,[35] Troell et al.,[36] and Chopin et al.[37] provided some evidence that co-culture of macroalgae around net-cage fish farms is a feasible means to trap dissolved inorganic farm effluents. Several other studies [38-40] indicated that shellfish co-cultured with finfish might be very useful for taking up particulate organic effluents generated by the fish farms. Some of the most recent and promising work on both seaweed and shellfish aquaculture in conjunction with salmon farms has emerged from the Canadian AQUANET project (www.aquanet.ca). This project has demonstrated the biological feasibility of co-cultivation of different "trophic levels", and has addressed food safety, socio-economic, and other concerns related to such integrated multi-trophic aquaculture (IMTA).[41-43]

Additional work on IMTA has focused on the cultivation of various other animals on aquaculture effluents, serving both environmental and commercial interests.

Figure 3
An array of 8 cylindrical plastic biofilters (each 25 cm diameter, 50 cm height) deployed at 8 m depth, 15 m west of the Ardag fish cages in the northern Gulf of Aqaba, Red Sea, October 2001 (photograph, Stephen Breitstein).

Ahlgren[44] studied co-cultivation of sea cucumbers and salmon, Porter et al.[45] and Katz et al.[46] examined co-cultivation of sea bream and grey mullets (Fig. 4), and Kelly et al.[47] and Cook et al.[48] investigated sea urchin and salmon co-cultivation. These, and other ongoing studies, indicate there are numerous creative and profitable ways in which we may sustainably harness the energy and nutrients released from intensive net-cage aquaculture.

Although several of the IMTA pioneers were Europeans (e.g., Troell, Folke, and Kautsky), integrated aquaculture has not yet been adopted in open aquaculture systems in the European Union. The real, and perceived, environmental impacts of aquaculture are one of the main concerns that have inhibited the growth of this industry in Europe. Whereas there have been a number of large multi-national programs (ICES, MARAQUA, OAERRE) focusing on the establishment and adoption of best environmental practices for aquaculture, European policy regarding aquaculture is still in a fragmented state[49] and this has inhibited developments in the field of impact mitigation. As a result, though many acknowledge the need for practical IMTA in Europe (http://www. easonline.org/agenda/en/AquaEuro 2003), at the time of this writing there are still several hurdles regarding conventional aquaculture that must be overcome before IMTA can be addressed.

Acknowledgments

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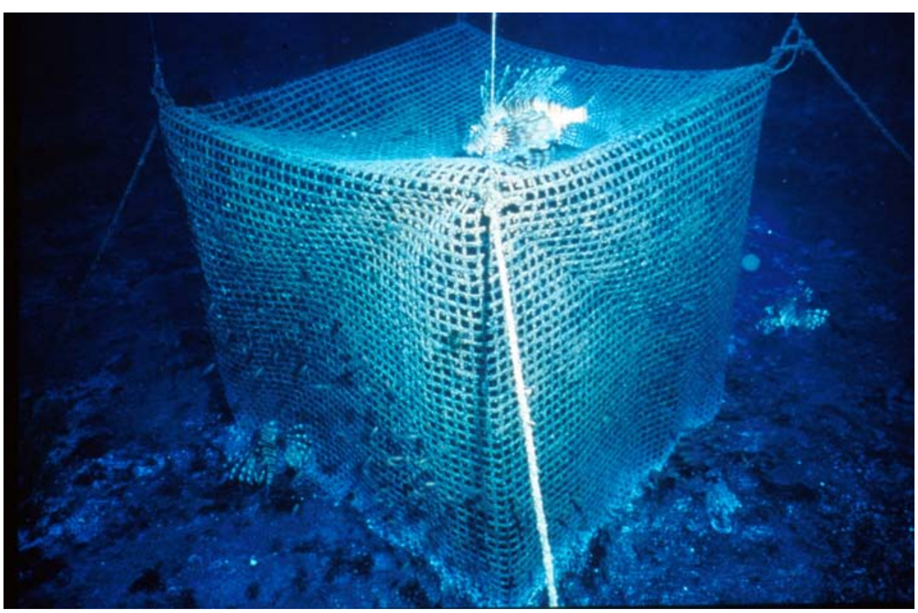

Figure 4
A benthic enclosure ($1\ m^3$) open to the sediment that is stocked with grey mullets and situated below the Ardag fish cages (northern Gulf of Aqaba, Red Sea) at 24 m depth, August 1998.

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Integrated Multi-Trophic Aquaculture: The Interactions with Environment Canada

Amar Menon

The development of sustainable integrated multi-trophic aquaculture (IMTA) operations requires that certain regulations and legislative requirements be met. Some of the key components of the Environment Canada mandate and legislation applicable to IMTA are the Canadian Environmental Assessment Act (CEEA), Canadian Environmental Protection Act (CEPA), Fisheries Act (section 36), Migratory Birds Convention Act (MBCA), Species at Risk Act (SARA), and the Canadian Shellfish Sanitation Program (CSSP) from a seafood safety perspective.

Environment Canada provides expert advice for environmental assessments of aquaculture projects and activities covered under CEEA. The aim is to ensure that aquaculture projects are sited, designed, operated, and decommissioned in a manner consistent with federal environmental legislation and policies. Environment Canada has produced guideline documents for marine-based finfish aquaculture, shellfish aquaculture, freshwater aquaculture, and land-based aquaculture that provide guidance on the information required for environmental assessment.

This paper presented a brief summary of research and development undertaken by Environment Canada in the area of aquaculture. It also outlined a number of challenges and options for consideration by the industry with respect to the development of IMTA in Canada. Application for IMTA must go through the environmental assessment review process and meet the requirements for CSSP. Before shellfish from IMTA operations can be marketed, an amendment would have to be made to the CSSP manual of operations to allow shellfish raised in closed proximity to finfish net-pens to be marketed. A monitoring and HACCP program should be in place to ensure the products produced from the process are safe for human consumption.

There are several environmental concerns to consider in the commercialization of IMTA. Not withstanding the economical and environmental benefits of the system, one must be concerned with the safety of the shellfish product for human consumption. Although the extent of the risk is unknown and has not been documented, a precautionary approach will be necessary until more information is available to determine the potential risk of chemicals and toxins accumulated by shellfish in IMTA under different geographical and environmental conditions.

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Integrated Multi-Trophic Aquaculture: An Industry Perspective

Patrick Fitzgerald

This paper describes the history of the involvement of Heritage Salmon Ltd. with the integrated multi-trophic aquaculture project (IMTA), discusses the potential benefits of IMTA to the salmon industry, and lists some of the hurdles that will have to be overcome to make the project a commercial success.

Introduction

I would like to start by presenting some of the background on how Heritage Salmon Ltd. became involved in the IMTA AquaNet project. I will also describe the current status and the future of the project and how IMTA could fit into a salmon farming operation (Fig. 1). I want to touch on some of the species of concern (mussels and seaweeds), industry experience with these species, our current interest in the project, what we see as positive, negative, and unknown about the project, and where we would like to go from here.

Traditionally, mussels have been considered a fouling species. The tremendous biomass that can accumulate on salmon cages can cause a great deal of mechanical damage to the structures and netting. Fish farms can literally sink from the weight of the mussels and nets can be torn and damaged if there is any amount of current. The physical presence of the mussels can inhibit water flow through the net, starving the fish of oxygen and reducing their growth. The nets themselves become almost unmanageable from the mass of mussels that accumulates (Fig 2). As a result, mussels can have a significant financial impact on a fish farm and have not been a favoured species.

Seaweeds are also fouling organisms. Their presence on the structures can impede the flow of water into the cages and, especially at night, they consume oxygen and can contribute to stress from low

Figure 1
Salmon farm in the Bliss Harbour area of the Bay of Fundy harvesting salmon using a harvesting barge (pictured in the background).

oxygen. Their presence on the site can also mask any potential problems with gear (Fig. 3). For example, if you have kelps growing all over the grid, you cannot tell if you have a loose shackle or if a net is starting to tear. If there are a lot of kelps or rockweeds in the cages, they can become mixed up with the feed, making the feed unavailable to the fish. Ultimately the feed rots, making a mess of the site.

In the past, fouling has had a high financial cost as it reduces fish growth, increases stress on the fish, and causes chronic oxygen depletion. Because of that, you generally have poorer feed conversion ratios (i.e., it takes more pounds of feed to grow a pound of fish). The cost of changing nets increases and it becomes quite an exercise to change the nets. If you have 25 pens on a site, for example, it would take the better part of a month to change all the nets. The cost of treating the nets with antifoulant is also significant. Currently, for a net that costs $10,000, about $3,000 of the cost is directly attributable to the antifoulant. So we spend a lot of money not to have these organisms on the site. Up to this point, they have cost us a fair amount of grief.

The AquaNet Project

What caught our interest in this integrated multi-trophic aquaculture (IMTA) project was the preliminary work done by Shawn Robinson and his group on mussels, and the work done by Thierry Chopin and his group on seaweeds. They came to us with some preliminary data showing greatly enhanced growth of these species close to our salmon cages. The great enthusiasm of these investigators and their students made it hard to say "no".

On our fish farm, prior to the advances of antifoulants, we had seen tremendous increases in the biomass of seaweeds and shellfish on cages. When left unchecked, cages had sunk as the crew were not able to keep up with net changes because the mussel biomass increased so fast. So we knew that mussels and seaweeds were growing quickly on the farm site. It was good that someone was going to quantify their growth enhancement on the farm.

We became involved in the IMTA project to see if the concept is feasible, to determine the impact on the salmon site, and to find out what the end product would be like. We also wanted to see if the shellfish and seaweeds had a positive effect on the environmental quality at the finfish site. Most of the energy available to the shellfish and seaweeds comes from the excess salmon feed at the site. We wanted to be able to convert the energy from the organic and inorganic waste ma-

Figure 2
Juvenile mussels (*Mytilus edulis* and *M. trossulus*) that fell off salmon nets when they were being changed in the spring using a work barge with a net roller. The mean shell length of the mussels was about 17 mm.

terial into other products. If we are putting the stuff into the water and it is drifting around, then perhaps it could be captured by other species that we could then sell. Also, just to add to the general body of knowledge on IMTA, we were happy to provide a platform for further research on the AquaNet IMTA project and hopefully, at the end, to make some money on it.

Figure 3
Kelps and rockweeds attached and trapped to the side of a salmon cage.

The Pros and Cons

There are a lot of positives as to how IMTA could fit into existing operations. Salmon sites are already present in the area (some have been in operation for up to 20 years), the food source from the salmon is already present as we are feeding the fish, the required particulate organic and dissolved inorganic matter is in the water column and is available for these other organisms, and the operation of these components is relatively low maintenance once the lines and the rafts are seeded (i.e., once you get the farm set up you are not feeding these organisms every day). The other spin-off is that IMTA is environmentally friendly: it extracts some of the excess nutrients from the water around the existing sites. Compared to finfish farming, IMTA requires relatively low capital investment. Setting up a mussel or seaweed raft does not involve a lot of sophisticated equipment. The majority of on-growing equipment is already in place (i.e., boats, barges, boom trucks) and we already have the personnel. There

Table 1. Perceived pros and cons of integrated multi-trophic aquaculture (IMTA) based on past industry experience with seaweeds and mussels.

Pros
Salmon sites already exist
Food source is already present
Operation is relatively low maintenance once the rafts and lines are seeded
Environmentally friendly
Relatively low capital investment
Majority of on-growing infrastructure is already in place
Shellfish monitoring program is in place
Cons
Lack of processing facilities in the area
Local expertise is focused on finfish

is already a shellfish monitoring program in place for soft-shell clams, so labs are equipped with up-to-date equipment to monitor shellfish for a lot of the biotoxins of concern.

What we see as a negative is the lack of processing facilities in the area. Although there are a lot of idle fish processing plants in Charlotte County, there are no shellfish processing facilities. Also, the expertise in the aquaculture industry is mostly focused on finfish. We don't have any shellfish aquaculturists in the area; in fact we know very little about the requirements for the set-up of the site, the appropriate stocking densities, handling and grading techniques, and the problems that can occur. We also don't know how many of these other alternate species a site can support. Over the years most salmon sites have determined how many tonnes of salmon can be produced, but there is likely an optimal ratio of how many tonnes of shellfish and seaweeds can be grown with each tonne of finfish. We don't know what that might be. In our area, salmon is the main driver of the industry. We cannot, nor would our shareholders, put up with impaired performance of the finfish due to the other cultured species. Therefore, we cannot have one species being grown at the expense of another. Everything has to be a positive for this operation.

The Future

So what do we need? We need the blessing of the regulators to allow co-culture of seaweeds and shellfish in proximity to salmon. I don't think that seaweeds have been much of a problem, but a couple of talks at this workshop showed that we have a way to go yet on shellfish. We will have to enter into some fairly serious discussions and see if we can get some experimental exemptions or find some way through the regulatory framework. We need a site that will work with our oxygen budget as this is our biggest concern right now. Both of these species are oxygen consumers (mussels need oxygen all day long; seaweeds are net oxygen producers, but respire at night). Traditionally, oxygen has been the limiting factor for finfish production on certain sites. We are very cognisant of the effect of oxygen stress on fish and certainly would not want to aggravate that. We need more training and expertise in shellfish and seaweed cultivation techniques. As I mentioned before, we have many people in the area who are capable in finfish culture, but there is relatively little expertise in shellfish and seaweed culture. We know how to market finfish and well-established markets exist for shellfish from the Atlantic Provinces. We have to see further developments with the seaweeds, as Thierry Chopin has alluded to before. It will be important to be able to sell seaweeds at different times of the growth cycle if they are to be used for certain products. This is

Table 2. Requirements for the salmon industry to continue with the development of integrated multi-trophic aquaculture (IMTA).

'Blessing' of the regulators to allow the culture of seaweeds and shellfish in proximity to salmon
Additional information on oxygen budgets
Determination of the optimal ratio between salmon, mussels, and seaweeds at a salmon site
More training and development of expertise in shellfish and seaweed cultivation techniques
Market development, especially with seaweeds
Determination of the environmental benefits of IMTA

stuff that we just don't know much about. We also have to determine the environmental effects of this concept. If this is going to be a good thing and the regulators like it, we want to be able to measure the performance increase in the site.

So where do we go? Right now, we are constructing rafts for deployment at several Heritage Salmon Ltd. sites. We have identified four sites where we are going to deploy the mussel and seaweed rafts. We are applying for permits to have these other species on the site. I have been in conversation with growers and suppliers in Nova Scotia and Prince Edward Island. We will have to bring in some expertise to help us get going in seeding the mussel rafts and hanging the lines in order to move this forward. Mind you, I don't want to have 100 tonnes of mussels next year and not know what to do with them!

This is a quick history of how we became associated with this project, where we see the benefits of it, and also some of the hurdles we will have to go through.

Author

At the time of the workshop, **Patrick Fitzgerald** was with Marine Operations, Heritage Salmon Ltd., 874 Main Street, Blacks Harbour, NB Canada E5H 1E6.

Question Period

Question: What do you see as the stumbling block in this project?

Answer: If you had asked me yesterday, I would have said that the biggest stumbling block was that I had not done a complete economic analysis of the concept. We are a salmon company and this is an add-on. What I would hope to see is that this part of the operation would carry itself economically and perhaps even profitably. Today, I'm seeing a big stumbling block with the regulators as far as getting permits to grow the mussels within 125 m from the fish cage. That is the number one problem today. We need to learn to walk before we run, but we're willing to try. We are quite enthused about it. We wouldn't even be trying if we didn't think there was potential here.

Question: There is a potential for development of some of the bioactive compounds found in seaweeds. These could be more valuable than the fish being grown. If this were so, would you balance off the production of salmon?

Answer: Well we would, but we can't answer that today. We need to know what the market potential is for the seaweeds (i.e., what are they used for, how are they processed, what is extracted from them). If knowledge came to light that at certain times of the year this component is worth a certain amount of money, we would examine the whole site to look at the costs going in and the revenue coming out. We would be obviously looking at maximizing our revenue. We would not be saying "it is not salmon, so we won't be selling it".

Defining the Appropriate Regulatory and Policy Framework for the Development of Integrated Multi-Trophic Aquaculture Practices: The Department of Fisheries and Oceans Perspective

Jack Taylor

Research conducted on integrated multi-trophic aquaculture (IMTA) suggests there is great potential for this concept in Canada. Collaboration between industry and government is needed if IMTA is to develop in Canada. There are a number of policy and regulatory issues related to food safety, environmental assessment, and public confidence that need to be addressed before commercial-scale projects can be approved.

Introduction

Integrated multi-trophic aquaculture (IMTA) offers many advantages including enhanced food and nutraceutical production from a small footprint, improvements to local environmental conditions around fish farms, and improved efficiency of regulatory systems. In Canada we are only at the research stage; however progress to date suggests that there is great potential for IMTA.

This discussion will focus on the regulatory and policy issues surrounding IMTA. It will examine the progress in IMTA research around the world and in Canada and discuss the state of readiness of our policy and regulatory system for this type of activity. Finally, strategic issues for further consideration will be identified.

IMTA is at an advanced stage of research in Canada. Research in IMTA production techniques is being undertaken in the Bay of Fundy, New Brunswick and in British Columbia. Research is sufficiently advanced so as to indicate the need to consider the policy and regulatory implications of IMTA. For example, currently, under the Canadian Shellfish Sanitation Program (CSSP) bivalve molluscs cannot be harvested within 125 m of netcages out of concern for possible faecal coliform contamination. For commercial-scale projects to be approved, amendments to the CSSP Manual of Operations will be required. This is but one example of the task that lies ahead if IMTA is to be fully realised.

Federal Regulatory Framework

As lead federal agency for aquaculture, the Department of Fisheries and Oceans (DFO) seeks to achieve aquaculture objectives through:

- Establishing an enabling policy and regulatory environment;

- Investing in science and knowledge development to continually improve environmental performance and support innovation; and
- Supporting sustainable development initiatives consistent with DFO's mandate and objectives (e.g., a National Aquatic Animal Health Partnership).

Key mandates and legislation with influence on IMTA are:

- *Fisheries Act*—conservation and sustainable use of fisheries resources (promoting environmental performance);
- *Canadian Shellfish Sanitation Program* (CSSP)
  - DFO is responsible for enforcement of closed areas, opening and regulating new fisheries, and aquaculture development;
  - Environment Canada is responsible for monitoring growing water quality and classifying harvesting areas;
  - Canadian Food Inspection Agency (CFIA) is responsible for regulating processing plant operations and monitoring harvest areas for marine biotoxins and pathogens.

A great many federal departments and agencies are involved in food production, processing and sale including:

- **Canadian Food Inspection Agency—**food safety, animal health;
- **Environment Canada**—environmental protection and water quality, Canadian Wildlife Service;
- **Transport Canada—**the mandate of the Navigable Waters Protection Act is safe, effective, environmentally-sound marine services including safe navigation;
- **Canadian Environmental Assessment Agency—**the Canadian Environmental Assessment Act provides the mandate of environmental assessment of projects requiring federal authorization;
- **Agriculture and Agri-Food Canada** (AAFC)—trade and international marketing;
- **Industry Canada** and regional development agencies (e.g., Atlantic Canada Opportunities Agency (ACOA), DEC, Western Economic Diversification (WD))—strategic initiatives and innovation; and
- **National Research Council (NRC)—**research.

In addition, a new federal direction towards a "smart" regulatory approach may impact on IMTA. The smart regulatory approach aims to provide Canadian companies with a competitive international advantage through support for continuous performance improvement and more efficient and timely service delivery. It encompasses approaches of strategic risk assessment, adaptive management and stewardship to support more effective and efficient regulatory compliance strategies.

The Government of Canada's smart regulatory approach could go a long way in addressing the strategic issues affecting IMTA such as food safety, environmental assessment, and public confidence. Through effective federal-provincial-territorial cooperation, science-based risk management, a national integrated environmental assessment process and an appropriate risk communication strategy, IMTA could be effectively incorporated into the appropriate regulatory frameworks to ensure success.

Strategic Development Objectives

In order for IMTA to be fully realised, the federal government is developing a regulatory framework to ensure that safe products are produced responsibly. Moreover, continued investment in building sustainable economic activity that benefits communities, as well as initiatives to build public confidence in the product and the technology, will contribute to the success of IMTA. Strategic regulatory issues that need to be addressed include food safety and environmental assessment, as well as public confidence.

Regulatory framework: food safety

Current federal regulations restrict the harvesting of shellfish within 125 m of a source of organic waste. However, IMTA research is demonstrating that salmon waste do not appear to produce the same health issues as human waste (faecal contamination, disease transmission). The effects of chemotherapeutant use on food safety needs further risk assessment in order to address the trade challenges (US National Shellfish Sanitation Program). Moreover, the provinces may have leasing restrictions based on federal requirements that also need to be addressed, which could lead to extra costs associated with monitoring and possibly affect public confidence in the product.

Regulatory framework: environmental assessment

At this stage, the benefits of IMTA are not being recognized in environmental assessments and management strategies. In order to address this gap, the effects need to be measured and sufficient evidence produced to demonstrate the value of IMTA. Moreover, recognition of IMTA in regulatory decisions and frameworks will need to be addressed.

Public confidence

In the past, the federal government has assumed that a solid regulatory framework is sufficient to generate public confidence in an industry. It remains to be determined if there are special needs for IMTA.

Moving Forward

The next step toward realizing IMTA in Canada will require government and industry collaboration. Further research needs to be undertaken on priorities and funding. The government needs to analyse impacts of potential regulatory change (both domestic and trade). The results of on-going research need to be effectively communicated to industry, government and public/consumers, and followed by collaborative development of a commercialization strategy. Strategies to encourage further investment and funding should also be addressed collaboratively in the near future.

Author

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New Brunswick's Role in Developing and Administering the Culture of Alternate Species

Sandi McGeachy

Sandi McGeachy and Barry Hill

Production of Atlantic salmon in New Brunswick reached approximately 40,000 tonnes in 2003, valued at close to $250 million. The salmon farms are located in southwestern New Brunswick in the upper Bay of Fundy. Through the Aquaculture Act and Regulations, industry development is administered by the Province's Department of Agriculture, Fisheries and Aquaculture (DAFA). One of the mandates of the Department is to work with industry and other government organizations to ensure the sustainable and orderly development of aquaculture. This is completed through a licencing and leasing process as well as through the technical and fish health initiatives of DAFA. The Province supports the sustainable development and diversification of aquaculture. Integrated multi-trophic aquaculture (IMTA) has potential to mitigate the environmental impacts of finfish culture as well as diversify the industry's economic base. These are two of DAFA's goals and research into these areas should be supported.

Legislative Mandate

Under the auspices of the New Brunswick Aquaculture Act and Regulations (assented 1988), the Department of Agriculture, Fisheries and Aquaculture regulates the aquaculture industry. The Act defines aquaculture as "the cultivation of aquatic plants and animals…". Thus the culture of mussels, finfish, and aquatic plants, such as seaweeds, falls under the authority of the Province. Licencing and leasing of submerged Crown Lands also falls under Provincial jurisdiction. An aquaculture licence identifies the species to be cultured and applicable strains. Licences are generally issued for a 5- to 10-yr period, while leases are granted for 20 yrs. Section 28 of the regulations states that mollusc sites must be 300 m from a lobster pound, wharf, or breakwater, unless written permission from the appropriate person or agency is submitted to the Minister. Mollusc sites are not located in an area, that in the Minister's opinion, is subject to chemical or bacteriological contamination. Provincial and federal roles relating to the aquaculture industry are defined under the Canada-New Brunswick MOU on Aquaculture Development.

Policies

The Province of New Brunswick has various policies dealing with aquaculture. The Bay of Fundy Marine Aquaculture Site Allocation Policy[3] is one of the critical policies outlining the process for marine site development. Other policies deal with fish health and the culture of rainbow trout, Arctic charr, and alternate species. The Department is currently completing a draft policy on the Criteria for Development of Alternate Species for the Bay of Fundy.[2] This policy outlines the objectives in developing and commercializing alternate species. The major components deal with siting, fish health, and environmental and economic viability. This draft policy also states that commercialization of alternate species over the next 6 to 7 years will take place on existing salmon sites and that no new marine sites will be allocated. Research and development proposals must be based on sound scientific merit. With respect to shellfish and seaweed culture in conjunction with finfish culture in the Bay of Fundy, efforts must be made to assess the economic viability and the ability to meet Canadian Food Inspection Agency (CFIA) requirements.

Guidelines for Bay of Fundy Shellfish Aquaculture

Guidelines established for the culture of shellfish in the Bay of Fundy concentrate at an R&D level. All proposals must be in agreement with existing Fisheries and Oceans Canada, Environment Canada, and CFIA requirements. Primary work on shellfish has been undertaken at existing shellfish sites and to a limited extent on existing salmon sites such as those identified by Chopin and Bastarache.(1) Some outstanding issues that must be addressed for shellfish culture deal with defining a PSP marketing window(s) which is acceptable to CFIA and Environment Canada, developing local spat collection protocols (mainly for scallops), and defining the relationship of culture systems with respect to currents, nutrient loading, and oxygen utilization. One other area of shellfish culture that must be monitored is the effects and potential interactions of shellfish health and finfish health (i.e., ISAv). Projects or research leading to further knowledge in the above noted areas is considered a priority. The work currently being carried out by Chopin and co-workers will be highly valued by both federal and provincial regulators.

DAFA Concerns and Issues

The Department's major concerns in defining shellfish and seaweed culture in the Bay of Fundy is food product safety (responsibility of CFIA).If the issues dealing with food safety for culturing shellfish or aquatic plants in tandem within the same leased area as finfish are addressed, the Department would see this as being beneficial. Other areas of concern fall under fish health interactions and site carrying capacity. Quantification of site loading for all parameters such as oxygen and currents in addition to the work by Chopin and co-workers on nitrogen and phosphorus is important. The interaction of these biotic and abiotic factors is crucial to full scale IMTA. Procedures and issues surrounding the procurement of wild seedstock for species such as scallop also need to be resolved.

Conclusion

The Department is supportive of slow, cautious shellfish and seaweed aquaculture development in the Bay of Fundy. Research in food safety, fish health, and carrying capacity would be very beneficial.

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Defining the Appropriate Regulatory and Policy Framework for the Development of Integrated Multi-Trophic Aquaculture Practices: Summary of the Workshop and Issues for the Future

Shawn Robinson

Shawn M.C. Robinson and Thierry Chopin

A meeting was held in Saint John, New Brunswick on March 25-26, 2004 to discuss the concept of integrated multi-trophic aquaculture (IMTA) with all the sectors of the aquaculture industry. The goal of the meeting was to identify the challenges that have to be addressed with respect to information and regulations regarding this practice. The format of the meeting included 11 informational talks on the first day and breakout discussion groups on the second day. Questions on two themes were posed to the groups: 1) What work is needed to allow the development of IMTA at the biological, economic, and social levels? How can the technologies be advanced? Who will do the work? What are the timelines? and 2) What regulations and policies need to be amended and how? Who will effect the amendments? How do we initiate these amendments/changes? What are the timelines? There was a consensus from the meeting that the IMTA concept was worth developing and that more effort should be expended immediately. Issues identified by the discussion groups were tabulated. Suggestions were made on the potential roles of government, society, and the international community in promoting the IMTA concept.

Introduction

On March 25-26, 2004 a meeting was held at the Hilton Hotel in Saint John, New Brunswick to bring the sectors of the aquaculture industry together to learn about the concept of integrated multi-trophic aquaculture (IMTA) and to identify the challenges, both in information and regulations, that need to be addressed as the concept evolves. For some groups, the meeting provided notification that a new production method could possibly affect their current practices. The overall response by the attendees was very positive and all sectors of the industry appeared to be satisfied with the outcome. As requested at the start of the meeting, the delegates were open and candid with their comments on what they liked and disliked about the concept and they provided extremely helpful insights on how they thought the IMTA concept would apply to their particular situation. The presentations on the first day ably summarized the background information and provided "grist for the mill" during the ensuing discussions. All the parties actively participated in the discussions and, as a result, the recommendations from the workshop are based on a fairly solid consensus developed in the plenary session. The next goal of the IMTA project is to translate the effort expended by the participants into a cohesive plan to advance the IMTA concept.

The 11 talks given on the first day provided an overview of the information available on the IMTA concept. Talks were 20 minutes in length and there was a 60-minute discussion at the end of the morning and afternoon sessions. On the morning of the second day, two evaluations were given on the previous day's information from the perspective of the Department of Fisheries and Oceans in Ottawa (DFO, Jack Taylor) and the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA, Sandi McGeachy), after which we moved to working groups to discuss the issues. The ideas generated from these working groups were then reported in the plenary session.

Synopsis of the Information Component from Day 1

"... the recommendations from the workshop are based on a fairly solid consensus developed in the plenary session."

The first talk was given by Thierry Chopin from the University of New Brunswick in Saint John (UNBSJ). He highlighted the progress made on propagating kelp in the laboratory to provide "seeded" ropes for grow-out on salmon farms. Production times in the laboratory phase have been reduced from 112 to 35 days. Biomass production of kelps at the IMTA site has increased from 8.0 kg/m of rope in 2002 to 20.7 kg/m of rope in 2004. The group found that kelp grow 46% faster near salmon sites than in reference areas with no salmon aquaculture. Markets are being investigated with the industrial partners Acadian Seaplants Limited and Ocean Nutrition Canada.

Terralynn Lander presented results from a team of researchers at UNBSJ and the DFO St. Andrews Biological Station (SABS) who looked at the relationships between the blue mussel and the particle field generated from salmon farming operations. They found that the number of small particles in the water column around salmon farms was enhanced and these particles, which appeared to mostly originate from salmon feed, were being consumed by mussels. The enhanced food levels resulted in faster growth of the mussels on the salmon site (ca. 50%) compared to mussels at a reference site. Taste tests showed that mussels at the salmon sites were indistinguishable from those grown away from salmon sites.

Kats Haya from DFO SABS discussed the work his team is doing on therapeutants and phycotoxins in the ITMA environment. Their work confirmed the seasonal nature of phycotoxins in the region and that some areas (with respect to mussels concentrating toxins) are impacted more heavily than others, indicating that spatial variability should be considered in site selection. No accumulation of therapeutants in either mussels or kelps was observed. Heavy metals also appeared to present no problems.

Blythe Chang presented work from the group led by Fred Page at DFO SABS. He reviewed some of the physical relationships experienced at IMTA sites that will have to be considered during the design and implementation stages. One of the key elements was water circulation and how it distributes food within the system and removes waste. The dynamics of this aspect are likely to be quite complex. They are beginning to look at the water circulation and oxygen dynamics within the sites.

Stephen Cross brought a West Coast perspective to the meeting. He presented his PhD work being done off Vancouver Island on scallops (*Patinopecten yessoensis*) and oysters (*Crassostrea gigas*) grown on transects radiating away from salmon farms. He tested for various substances that could originate from the farming operation and found that effects were short-term and only occurred in samples adjacent to the cages. He found no enhancement of growth rates in the shellfish at the site. Despite that, the industry still seems receptive to the concept of IMTA.

An international perspective was given by Dror Angel from Israel (at the time of the workshop he was working at the Massachusetts Institute of Technology). He talked about work he did in the Red Sea with gilthead sea bream (*Sparus aurata*). He described organic enrichment issues similar to those being experienced by the salmon industry in the Bay of Fundy. The use of multi-trophic levels appeared to have good potential to remediate some of the problems. They are currently in the developmental phase of the IMTA concept as well.

Mary Ann Green from the Canadian Food Inspection Agency (CFIA) in Ottawa then gave the perspective of the agency primarily responsible for food safety. She reviewed the issues that will have to be addressed and how three government agencies (CFIA, DFO and Environment Canada) will have to work together to handle this new form of food production. IMTA will require changes in the Canadian Shellfish Sanitation Program (CSSP) policy that deals with shellfish and she encouraged ongoing collaboration between CFIA and the researchers in the AquaNet project.

One of the major issues surrounding any culture operation is how to deal with disease. Gilles Olivier from the DFO Gulf Fisheries Centre in Moncton addressed the question of whether health management becomes more complicated when species are grown together. After presenting information on the National Aquatic Animal Health Program and international standards for handling disease issues, he reviewed the diseases affecting salmon and the factors associated with disease outbreaks. It is obviously a complex relationship, but several factors generally have to be present for a disease outbreak to occur, including the presence of the disease, the susceptibility of the host (i.e., condition), and a vector for transmission. Risk analysis might be a good tool for managers to use when assessing the suitability of IMTA, although more data will undoubtedly be needed.

Amar Menon shared his extensive experience with a presentation on how Environment Canada (EC) could fit into IMTA. The roles of EC are defined by legislation dealing with environmental assessment, environmental protection, fisheries, migratory birds, species at risk, and shellfish food safety. He felt that many of the legislative issues could be resolved, but the most immediate issue restricting IMTA was a section in the CSSP prohibiting “polyculture”. He then provided suggestions on how the policy could be re-worded to allow the development of IMTA without compromising food safety.

Figure 1
Participants in the workshop during a working group session.

The perspective from Maine, USA was given by Sebastian Belle, Executive Director of the Maine Aquaculture Association. He outlined the multitude of regulatory authorities that aquaculturists in Maine have to contend with. Despite this, in 2003 the Maine aquaculture industry had 44 finfish leases, 47 shellfish leases, and 36 experimental sites. Several of the sites had multiple species on them. There is a general reluctance in Maine to embrace aquaculture and there are concerns over environmental impacts, leasing issues, aquatic animal health, public health, and seafood safety. New models for aquatic farming are needed and IMTA may be one of those. More resources are required for government departments to move ahead on the management issues and for research to answer some of the questions on the effect of IMTA development on the ecosystem.

The final talk of the day was from Patrick Fitzgerald of Heritage Salmon Ltd., the salmon aquaculture industrial partner of the project. He discussed the company's involvement in the project and described initial concerns with incorporating species into the culture operation that were previously considered a nuisance. However, the company was willing to support the program as they thought it might be possible to turn these nuisance species into a financial asset if the proper development work was done. The only stipulation was that salmon had to be the priority species on the site. Past experience with shellfish and seaweeds on the site convinced them that growth rates would not be a problem. Their main concerns were markets for the seaweeds and policy regulations for the mussels.

Summary of the Working Groups on Day 2

Question 1. What work is needed to allow the development of IMTA at the biological, economic, and social levels? How can the technologies be advanced? Who will do the work? What are the timelines?

> This topic identified a large number of issues, raised questions that still have to be answered (Table 1), and highlighted the fact that a lot of work is needed before answers can be provided. One of the main comments was that the project needs to reach a commercial scale on a few sites so that we can see the culture operations at the proper scale to estimate the biological and economic effects. Other issues revolved around species interactions at the sites, how the concept can be brought into the consciousness of society, and what the business model will look like for this type of culture.
>
> On the question of who should do the work to advance IMTA, there seemed to be a consensus that the existing AquaNet group should continue to assume the lead as they are involved in the issues from multiple perspectives and have the "energy" to do it. A road map or "critical path" should be established to focus efforts on what needs to be done and who will do it. This critical path should involve a broad range of people on the east and west coasts to develop an integrated plan and identify the steps required to move forward. We need to make sure the appropriate agencies are represented and all the social and economic elements are incorporated. There is a lot of good work being done, but looking at the matrix of the work needed to be done, there is obviously a need for additonal expertise. The group should be linked with industry and associated agencies. Funding agencies such as the Network of Centres of Excellence for Aquaculture (NCE-AquaNet), the Natural

Table 1. Summary of responses on what work needs to be done to advance the IMTA concept.		
Biological	**Social and Regulatory**	**Economic**
There needs to be a scale-up from the pilot-scale to the commercial-scale to examine the biological effects.	We need to gauge how well the public supports the concept.	There needs to be a scale-up from the pilot scale to the commercial scale to properly test the economic viability of IMTA.
We need information on the far-field effects of the release of organics and inorganics.	What is the diversity in jobs that will be associated with this approach?	What does IMTA mean for the marketing of blue mussels and seaweeds from this area?
What is the carrying capacity of the site and the local area?	Is there a training component that will be associated with the development and what is it?	What are the costs of production? What are the costs of services?
What are the disease issues associated with this type of activity?	Do First Nations have an interest in this type of approach? More communication and dialogue will be important.	Are there enough processors in this area? If not, how do we establish an appropriate level of processing?
What are the predator-prey interactions that occur within this type of operation?	Is there a social concern about the potential for disease transfer within the IMTA system? Is there an education component required? Do we have enough knowledge?	What type of testing system needs to be put in place and how will it be controlled? What are the costs associated with that and how will they be handled?
Can we quantify the environmental benefits and the impacts of IMTA?	Do we have enough knowledge about the PCB/dioxin issues associated with the salmon industry lately?	What are the appropriate ratios between shellfish, seaweeds, and salmon on the sites? How do we establish what the environmental benefits are?
Do we have the infrastructure and capacity to support this more extensive type of operation? How much of this is technology dependent?	While a good start has been made, strong communication pathways should be set up. It will be important to get the social, economic, and biological results out as soon as possible as many groups are taking a "wait and see" approach.	We need a better market analysis for the potential of the various species to produce alternate products (e.g., nutraceuticals). This is particularly important for sea-weeds.
Considering that the Bay of Fundy is a major habitat for ducks, etc., what sort of interactions with waterfowl can we expect? How do we deal with them?	With regard to toxic phytoplankton issues, we should document clearly how the policy came about and the key elements that pertain to IMTA issues.	Is there an issue with genetically modified organisms (GMOs) with this technique?
We need more information on the monitoring that will be required to determine the carrying capacity of the site. What variables do we need to measure as a proxy for the system (e.g., oxygen, deposition, growth, etc.).	Who should be involved in the dissemina-tion of the information/knowledge about the IMTA concept and the quality of the resulting products? How should the extension program be handled?	There needs to be a program directed towards marketing and finding out how the consumer feels about IMTA. Is this a remediation product or is it also a healthy "green" product for consumers' plates?
What are the dynamics of the PSP and DSP toxins in mussels and how do they differ from clams?	Considering the wide scope of potential participants in IMTA, how wide should the suite of funding agencies be for development?	Better management practices for the sites will have to include changes to accommodate IMTA methods.
What is the impact on the benthos? How does it vary spatially between different types of bottom and what can we use as indicators of health?	When policies are being considered, options should be kept open for innovations to happen with respect to different species and areas.	What is the cost (gross and net) to remove nutrients from the system?

Table 1 (continued)		
Biological	**Social and Regulatory**	**Economic**
How efficient is the removal of nutrients from the system and how does it vary between eutrophic and oligotrophic areas?	Can the Canadian Aquaculture Industry Alliance fit IMTA into the codes of practice they are developing?	Should products from IMTA be developed for a commodity market (low cost) or a specialty market (higher cost)?
What are the shellfish removing from the system with regard to particulates? How much comes from the fish farm and how much from the external environment?	How should we develop a biosecurity program?	Marketing has to work in synchrony with production. What happens if there is a problem with the mussels? How will it be handled?
As the filter-feeding shellfish will pick up phycotoxins from the natural blooms, can we accurately predict what the depuration times will be to facilitate marketing?	What are the monitoring needs for PSP, DSP, and ASP to satisfy the export requirements and how do they become incorporated into the HACCP?	Is there a problem marketing mussels as both a food item and a bioremediation product?
How will the addition of more trophic levels affect the oxygen demand on the site? Will it lead to stress and disease issues in the captive animals? How does it relate to carrying capacity?		Industry codes of practice and certification programs would be good marketing tools to incorporate early on in the program.
Does IMTA have the potential to biomagnify problems with diseases, etc., on a culture site?		Are the products from IMTA suitable for organic certification and what would the potential mark-up be?
What role does fallowing have in the functioning of an IMTA site? Do we need to fallow all organisms or just the salmon?		There needs to be market acceptability work done on IMTA products.
How do we monitor an IMTA site? Does it have to be done by species?		Will there be patentable information or technology being developed and who will have the rights?

Sciences and Engineering Research Council (NSERC), the New Brunswick Innovation Foundation (NBIF), the Atlantic Canada Opportunities Agency (ACOA), the Department of Fisheries and Oceans Aquaculture Collaborative Research Development Program (DFO-ACRDP), the National Research Council Industrial Research Assistance Program (NRC- IRAP), the Nova Scotia Department of Fisheries and Aquaculture (NSDFA), and the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) would be logical starting points for the east coast.

We are still in the "R" stage with regard to the R&D for IMTA. As we progress, expenses will increase and so will financial risk. When the "D" phase begins, it may be appropriate for additional organizations to become involved.

When should this R&D be done? All the groups felt that action should be taken as soon as possible. For many of the issues, any delay will significantly hinder progress of the other related parts. There are a couple of "givens" in the timeline: 1) regulators will probably wait until "sufficient" data are provided; 2) industry will take a "wait and see" approach until new pickup trucks appear on the wharf; and 3) the whole concept will only have credibility after the first couple of crops are sold (i.e., 2 years).

It should be noted that different timetables are being followed by different parties. The research is currently being conducted under academic timelines that are in synchrony with NCE grant schedules. The current AquaNet project is scheduled to terminate in the spring of 2006. Business runs on shorter timelines than science and has to be more flexible. The timelines for changing business plans will only start once there are enough data to convince them they should start; but once they do, things will happen quickly. This suggests there will continue to be several timelines involved and there may have to be different components of the program to service them. Some of these aspects might be better led by other groups or organizations. Hopefully, this will be identified as the critical path is developed.

Question 2. What regulations and policies need to be amended and how? Who should effect the amendments? How do we initiate these amendments/changes? What are the timelines?

The most urgent issue identified with regard to regulations and policies (summarized in Table 2) was the CSSP section that bans "polyculture". This point was clearly identified by all the groups. Without a change in this policy, no shellfish can be legally sold and the industry cannot evolve. As a result, the general feeling was that the AquaNet project and Heritage Salmon Ltd. should try and move the agenda forward on this issue. For example, the regional meetings of the CSSP are happening in late April 2004 and amendments should be put forward in order to make it through the system to the Inter-Departmental Shellfish Committee (ISC) in Ottawa.

There was discussion on how the CSSP amendment should be handled. Should it go through the Maritime industry associations? Perhaps it should go through the Canadian Aquaculture Industry Alliance (CAIA) as it is a national issue? It was concluded that a change in policies is often led by interested parties. Therefore, one region may change before another depending on the level of immediate interest. The best path would be to go through the local shellfish committees, then the regional committees, and finally the national committee (ISC).

One of the key requirements for changing the regulations and policies will be to develop protocols to ensure the safety of products from IMTA operations. Industry should take the lead on the design and management of a Hazard Analysis and Critical Control Point (HACCP) plan. This might be overseen by CAIA and the industry-related associations in New Brunswick and Nova Scotia. There are also national issues related to these policies, as west coast interests are not necessarily the same as those in the east. Consequently, it makes sense that national associations should be involved. Companies selling IMTA products will need an individual HACCP plan, as well as an environmental monitoring plan. This will provide a certain level of comfort to the regulatory agencies, as they actively deal with public health issues. It should be

Table 2. Summary of responses on what regulations and policies are relevant to the IMTA concept.	
Policy/Regulation	**Issue**
Canadian Shellfish Sanitation Program (CSSP)	An amendment is needed to allow shellfish to be grown within 125 m of a salmon site (Chapter 12.2). This issue should be referred to the Inter-departmental Shellfish Committee (ISC) composed of the Canadian Food Inspection Agency (CFIA), the Department of Fisheries and Oceans (DFO), and Environment Canada (EC). This should be pushed forward by the AquaNet project on behalf of the interested parties.
DFO fishery regulation banning mussel harvest in the Bay of Fundy	Currently, harvesting blue mussel in the Bay of Fundy is prohibited due to concerns over PSP and uncontrolled harvesting. There needs to be an amendment to the regulation to permit the culture of mussels. This could be done with a variation order specifying one site initially and then expanded later as warranted. CFIA will have to be involved.
Navigable Waters Protection Act (NWPA)	The need for additional work on the certification of a new site or of an existing site will depend on the gear configuration or footprint of the site.
Canadian Environmental Assessment Act (CEAA)	We need to know how much kelps or mussels can be added to a site before triggering an environmental assessment.
DFO policy on fishing to access wild juveniles (seed)	There will be a portion of the farming operation that will likely collect juveniles (spat) from the wild using collectors. Blue mussels are a good example of this. The policy on access to wild juveniles is currently under development. We should make sure that it is not inhibitory to the communal access of spat for the IMTA model.
NB Department of Agriculture, Fisheries and Aquaculture (DAFA)	There needs to be policy clarification on the amendment to site leases with regard to how species amendments work and any differences between commercial production and R&D development (i.e., pilot-scale needs to be defined). More data are needed to give regulators a better feeling on the feasibility of this approach.
NB Department of Environment and Local Government (DELG)	DELG needs to re-examine current policies for possible future policy changes. IMTA may change some of the details that they currently require for the permitting of the sites.
Introductions and Transfers Committee (ITC)	There are concerns about moving seed and product, and the spread of biological pests and diseases. It was felt that the current controls are adequate to deal with most of these concerns and they are already being implemented in the current monoculture industries.
General concern	What are the requirements of other provinces/states/countries to accept IMTA products for their markets? How should this be coordinated? Is there legislation that needs to be either developed or modified? Does this need to be international in scope due to the transport of products?
General concern	There is need for discussion with the ISC and CFIA on concerns for human health and safety. Protocols for a management plan should be developed in conjunction with all associated parties to set the working standards for high quality and safe seafood. Products will have to go through a federally registered and inspected plant. Working linkages will have to be set up with CFIA to develop Hazard Analysis and Critical Control Point (HACCP) plans and for short-term solutions such as testing on single lots of product.
General concern	IMTA should fit into larger scale coastal zone management plans. Several initiatives are underway on various scales in many countries and IMTA development should be considered and designed to fit into those plans.
General concern	If it turns out that the IMTA system is successful and that expansion would be beneficial, how will this be handled? Is there a protocol for determining how big a site can get that takes into account economic, social, and biological issues? Also, what is the role of fallowing?

realized that the data may not be available to address all the critical control points. It should also be recognized that the system is still evolving, so the practices used today may not be the ones used tomorrow. Therefore, the HACCP plan will be a living document and is something that companies should consider early in the process, as they will have to generate a database of information about their sites. This will take a certain amount of time that should not be underestimated. Monitoring the sites will be an ongoing process.

Paralytic shellfish poisoning (PSP) is probably the most serious risk for some sites in the Bay of Fundy. However, there are measures, such as closed seasons during PSP blooms, that can practically eliminate the risk. Further analysis of PSP trends and the history of closures would be helpful to managers in their decisions on site selection and monitoring. Putting together the chronology of the mussel closures in the Bay of Fundy would best be done by DFO and CFIA. This might involve the DFO Aquaculture Coordination Office and should be done in the near future so the relevant issues can be incorporated into new policies.

When should these changes be made? Some of them, such as the CSSP, need to be changed right away. Others can be phased in over the next few years as policies are reviewed and more information becomes available. The industry needs to do their part by applying for species amendments so that managers can judge the level of demand. Creating a regulatory environment that is conducive to better culture practices is critical, as it will be important to ensure that IMTA is following established environmental guidelines to ensure public perception remains positive.

"... the HACCP plan will be a living document and is something that companies should consider early in the process … "

Issues for the Future

The challenges remaining to be solved are daunting. However, the goal is sustainability within the culture ecosystem. At the base of the production system is a need for a relatively good understanding of the essential elements of the ecosystem functions that we, as humans, are involved in. To achieve this goal, it is worth thinking about who needs to be involved in this evolution and what their roles would be.

Role of government

One of the key roles for government agencies, from the municipal to the federal level, is to understand the basic concept of IMTA and to evaluate existing and future policies. If the agencies agree with the concept of IMTA, they should promote protocols through their policies that will encourage the marine production sectors to follow those tenets. This could be done in the form of incentives or penalties similar to the economic policies currently used to regulate the environmental or health behaviour of people in land-based systems (i.e., fuel or cigarette taxes, higher premiums for life insurance for high-risk activities, incentives for identifying and recognizing the values of environmental services in countries such as the Netherlands and Sweden).

Role of society

There is still a large need for education to bring society into the mind set of incorporating IMTA into their suite of social values. Some of the social surveys done during this AquaNet study by Bryn Robinson (UNBSJ) indicated that the general public is in favour of practices based on the recycling concept. Whether this will translate to a greater appreciation of the sustainable ecological value of the IMTA concept, a willingness to support it tangibly with their shopping dollars, and demands to their elected representatives to implement IMTA, will be the ultimate test. The degree to which researchers and extension people become creatively involved with the educational component will be vital to the success of IMTA.

Role for the international community

It would be an understatement to say that gaining a working understanding of the essential functions of the ecosystem is a complex, but essential, task. Reasonable estimates of the cause and effect relationships within local ecosystems will have to be defined and this will take significant amounts of research time and funding. Although this knowledge will be needed for various ecological zones, these zones are often shared between various countries. For example, similar ecological processes are likely involved in temperate areas that are currently used to grow salmonids in sea pens in countries as diverse as Norway, Scotland, Chile, Canada, and the United States of America. Therefore, it makes sense for these countries to collaborate in their efforts to understand the ecological processes operating in their respective areas. Not only would a concerted effort allow for a greater understanding of the principles involved so that all associated areas could benefit, it would also raise public consciousness of the new paradigm on a global level.

"The degree to which researchers and extension people become creatively involved with the educational component will be vital to the success of IMTA."

Concluding Remarks

This workshop only scratched the surface on starting IMTA in Canada. Although a tremendous step was taken at the meeting in shifting the participant's attitudes on how we can adapt to this concept, there is still much to do, as evidenced by the comments summarized in Tables 1 and 2. Therefore, it is inevitable that further workshops will be held in the coming years, not only in Canada, but also in many other countries that are starting to look at this concept. It would be encouraging to think that future workshops could be as successful as this one as our concept of marine food production within an IMTA framework continues to evolve along more sustainable lines. If we are going to choose to manage our coastal zones and the associated ecological entities, then we must undertake to do the best job possible as our own survival as a species may ultimately depend on our success.

Epilogue (July 2005)

Since the workshop, steps have been taken by the three agencies involved in the CSSP to amend the policy so that 'polyculture', or IMTA, can proceed, provided certain safety measures are built into the plan. The amended policy should soon be in place. With the movement on CSSP by the federal regulators, the Province of New Brunswick has begun to reassess the possibility of mussel culture in the Bay of Fundy and is revising its policies. As a trial, Heritage Salmon Ltd. grew 20 tonnes of mussels within their salmon sites and plans to test-market them in the fall of 2005. Forty-one tonnes of kelps were also produced. Minimal effort was needed to produce the mussels and kelps, and the benefit-cost ratio appeared to be quite favorable. Tests on the product have shown that the mussels are of high quality and suitable for markets catering to white tablecloth restaurants. Cooke

Aquaculture Inc. acquired Heritage Salmon Ltd. in the summer of 2005 and has assumed the key role that Heritage Salmon Ltd. played in the AquaNet project. Its involvement is a logical extension of the commitment to the IMTA concept and its development to commercialization.

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Appendix
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