

RECEIVED

By NSARB at 9:26 am, Oct 31, 2025

EXHIBIT 111

ResearchGate

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/257791040>

The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN)—A Network for a New Era of Ecosystem Responsible Aquaculture

Article in *Fisheries* · July 2013

DOI: 10.1080/03632415.2013.791285

CITATIONS

42

READS

3,753

16 authors, including:



Thierry Chopin

University of New Brunswick

319 PUBLICATIONS 11,493 CITATIONS

SEE PROFILE



Shawn M.C. Robinson

Longline Environment

140 PUBLICATIONS 5,670 CITATIONS

SEE PROFILE



Stephen F. Cross

University of Victoria

25 PUBLICATIONS 880 CITATIONS

SEE PROFILE



D. Knowler

Simon Fraser University

72 PUBLICATIONS 13,496 CITATIONS

SEE PROFILE

The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN)—A Network for a New Era of Ecosystem Responsible Aquaculture

Thierry Chopin

Scientific Director of the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) and Department of Biology, University of New Brunswick, P.O. Box 5050, Saint John, NB, Canada E2L 4L5. E-mail: tchopin@unbsj.ca

Bruce MacDonald

Department of Biology, University of New Brunswick, Saint John, NB, Canada

Shawn Robinson

Fisheries and Oceans Canada, St. Andrews, NB, Canada

Stephen Cross

Department of Geography, University of Victoria, Victoria, BC, Canada, and Kyuquot SEAfoods Ltd., Courtenay, BC, Canada

Christopher Pearce

Fisheries and Oceans Canada, Nanaimo, BC, Canada, and Fisheries and Aquaculture Department, Vancouver Island University, Nanaimo, BC, Canada

Duncan Knowler

School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC, Canada

Anthony Noce

Fisheries and Oceans Canada, Ottawa, ON, Canada

Gregor Reid

Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN), University of New Brunswick, Saint John, NB, Canada, and Fisheries and Oceans Canada, St. Andrews, NB, Canada

Andrew Cooper

Fisheries and Oceans Canada, St. Andrews, NB, Canada

David Speare

Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, PE, Canada

Les Burridge

Fisheries and Oceans Canada, St. Andrews, NB, Canada

Curran Crawford

Department of Mechanical Engineering, University of Victoria, Victoria, BC, Canada

Manav Sawhney

Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN), University of New Brunswick, Saint John, NB, Canada

Keng Pee Ang

Cooke Aquaculture Inc., Blacks Harbour, NB, Canada

La Red de Acuicultura Multi-Trófica Integrada en Canadá (RAMTIC) – la red para una nueva era de acuicultura ecológicamente responsable

RESUMEN: *La Red de Acuicultura Multi-Trófica Integrada en Canadá (RAMTIC) es una red estratégica del Consejo de Investigación en Ingeniería y Ciencias Naturales que dio inicio en el año 2010. Se concibió a partir del hecho de que la acuicultura, a pesar de ser el sector de producción de alimentos de más rápido crecimiento, está relacionada con temas de índole ambiental, económica y social. La acuicultura multi-trófica integrada (AMTI) ofrece una solución innovadora al problema de la sustentabilidad ambiental, estabilidad económica y aceptabilidad social de la acuicultura, ya que se fundamenta en un enfoque manejo basado en el ecosistema. El AMTI es el cultivo de especies propias de la acuicultura que provienen de distintos niveles tróficos, y es acompañado de funciones ecosistémicas complementarias de modo que el exceso de nutrientes de una especie es aprovechado por el lote de organismos del siguiente nivel trófico, propiciando así interacciones cinegéticas entre especies. La RAMTIC proporciona la investigación y desarrollo interdisciplinarios y personal altamente capacitado en: (1) diseño ecológico, interacciones a nivel ecosistema y eficiencia de bio-mitigación; (2) innovación de sistemas e ingeniería; (3) viabilidad económica y aceptación social; y (4) ciencia regulatoria. La RAMTIC debiera ser capaz de transformar las preocupaciones ambientales y socioeconómicas en ganancias y en alimento marino novedoso y de calidad, si se limitara el enriquecimiento orgánico e inorgánico que ocasionan las operaciones de alimentación en acuicultura, y se produjeran lotes adicionales de organismos cultivados para su extracción. La RAMTIC va más allá de atender temas de naturaleza científica y de ingeniería; está lidiando con los componentes socioeconómicos, políticos y de gobernanza.*

Clare Backman

Marine Harvest Canada Ltd., Campbell River, BC, Canada

Marilyn Hutchinson

Grieg Seafood BC Ltd., Campbell River, BC, Canada

All authors are part of the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN), Department of Biology, University of New Brunswick, Saint John, NB, Canada.

ABSTRACT: *The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) is a Natural Sciences and Engineering Research Council strategic network that was initiated in 2010. It was triggered by the fact that aquaculture, though the world fastest growing food production sector, is associated with environmental, economic, and societal issues. Integrated multi-trophic aquaculture (IMTA) offers an innovative solution for the environmental sustainability, economic stability, and societal acceptability of aquaculture by taking an ecosystem-based management approach. IMTA is the farming, in proximity, of aquaculture species from different trophic levels, and with complementary ecosystem functions, so that one species' excess nutrients are recaptured by the other crops and synergistic interactions among species occur. CIMTAN is providing the interdisciplinary research and development and highly qualified personnel training in the following linked areas: (1) ecological design, ecosystem interactions, and biomitigative efficiency; (2) system innovation and engineering; (3) economic viability and societal acceptance; and (4) regulatory science. By mitigating organic and inorganic enrichment of fed aquaculture operations and producing additional extractive crops, IMTA should transform environmental and socioeconomic issues into benefits, trusted quality seafood, and novel seafood-based products. CIMTAN is going beyond addressing questions of a natural science and engineering nature and is addressing socioeconomic, policy, and regulatory governance components.*

Thus, understanding both the environmental impacts (Lotze et al. 2006) and the significance of aquaculture (Soto et al. 2008) is important if we want to design the responsible food production systems of tomorrow and make the Blue Revolution greener to enter the era of a more responsible Turquoise Revolution (Chopin 2012).

INTRODUCTION

As the human population continues to grow, we need to secure more and more of our food from aquatic environments (marine and freshwater; Food and Agriculture Organization [FAO] 2010). Capture fisheries, while continuing to have their role, will not fill the widening gap between the demand and the supply as their yields have remained stable or, in some cases, experienced declines. Aquaculture, which is already supplying around 50% of the aquatic food we eat, will increase that share of the production for our daily intake of proteins, carbohydrates, and lipids (FAO 2011). However, the development of intensive fed aquaculture (e.g., finfish and shrimp) at the amazing rate of 8.3% per year since 1970 (FAO 2011) has been associated with concerns about the environmental impacts of such monospecific practices, especially where activities are highly geographically concentrated or located in suboptimal sites whose assimilative capacity is poorly understood and, consequently, prone to being exceeded (Chopin et al. 2001; Naylor et al. 2003; Diana 2009).

As aquaculture production continues to expand, it is paramount that we avoid the same mistakes experienced with the

increased intensification of agriculture during the Green Revolution. Thus, understanding both the environmental impacts (Lotze et al. 2006) and the significance of aquaculture (Soto et al. 2008) is important if we want to design the responsible food production systems of tomorrow and make the Blue Revolution greener to enter the era of a more responsible Turquoise Revolution (Chopin 2012).

For the aquaculture sector to continue to grow, it will need to develop innovative and responsible technologies and practices. Sustainable aquaculture should be ecologically efficient, environmentally benign, product diversified, profitable, and societally beneficial (Troell et al. 2003; Chopin et al. 2010). Integrated multi-trophic aquaculture (IMTA) has the potential to achieve these objectives by cultivating, in proximity, species from different trophic levels, and with complementary ecosystem functions, in a way that allows one species' uneaten feed and wastes, nutrients, and by-products to be recaptured and converted into fertilizer, feed, and energy for the other crops and to take advantage of synergistic interactions among species while biomitigation (partial removal of nutrients and CO₂ and supplying of oxygen) takes place. IMTA is the central and overarching theme; it can have many different variations, adapted to the local conditions (open-water or land-based systems, marine or freshwater systems, temperate or tropical systems). Proximity should be understood as not necessarily considering absolute distances but connectivity in terms of ecosystem functionalities, in which management at the bay area level is paramount (lease limits drawn on a map by humans do not always mirror the reality of nature).

Farmers combine the cultivation of fed species, such as finfish or shrimps fed sustainable commercial diets, with extractive species, such as seaweeds and aquatic plants, which recapture inorganic dissolved nutrients, and suspension and deposit feeders, which recapture organic particulate nutrients, for their growth. In this way, all of the cultivation components have an economic value (harvestable, healthy seafood and value-added marine bio-based products), as well as a key role in recycling processes and in providing biomitigative services for the surrounding ecosystem. The aim is to ecologically engineer systems for increased environmental sustainability (ecosystem services and green technologies for improved ecosystem health), economic stability (improved output, lower costs, product diversification, risk reduction, and job creation in coastal and rural communities), and societal acceptability (better management practices, improved regulatory governance, and appreciation of differentiated and safe products). In this way, some of the externalities of fed monoculture are internalized, hence increasing the overall sustainability, profitability, and resilience of aquaculture farms (Neori et al. 2007). A major rethinking is needed regarding the definition of an "aquaculture farm" (reinterpreting the notion of site-lease areas) and regarding how it works within an ecosystem in the context of a broader framework of integrated coastal zone management. The economic values of the environmental and societal services of extractive species should be recognized and accounted for in the evaluation of the whole value of these

IMTA components. This would create economic incentives to encourage aquaculturists to further develop and implement IMTA. Seaweeds and invertebrates produced in IMTA systems should be considered candidates for nutrient and carbon trading credits within the broader context of ecosystem goods and services. Long-term planning and zoning promoting biomitigative solutions, such as IMTA, should become an integral part of coastal regulatory and management frameworks (Chopin 2011).

Research and development on IMTA has been conducted on both the east and west coasts of Canada since 2001. Significant progress has been made over the last 10 years, but the need for a concerted and strategic approach became obvious and led to the early discussions on the need for a network approach in the spring of 2008. During 2009, the possibility of forming a Natural Sciences and Engineering Research Council of Canada (NSERC) strategic network was solidified among 26 scientists from eight universities, six federal government laboratories (Department of Fisheries and Oceans Canada, DFO), one provincial government laboratory (Research and Productivity Council of New Brunswick), and three industrial partners. A Research Network Agreement was signed by all members on January 6, 2010, making it the official starting date of the Canadian IMTA Network (CIMTAN), supported for 5 years by the NSERC, DFO, the University of New Brunswick, Cooke Aquaculture Inc., Kyuquot SEAfoods Ltd., and Marine Harvest Canada Ltd. to the amount of CAD\$9.577 million. Grieg Seafood BC Ltd. joined the network in April 2012.

In this article, we describe the objectives of CIMTAN and provide an overview of the network and its ongoing and future research. We also discuss the benefits, applications, and significance of a network approach. This article is part of a series in *Fisheries* that is focused on NSERC strategic networks that are currently active in Canada and have specific relevance to fisheries, aquaculture, and aquatic science (see Hasler et al. [2011] for introductory article).

CIMTAN OBJECTIVES

CIMTAN is focused on developing a network of researchers, with complementary expertise, from across Canada to further develop IMTA approaches to strategically enhance economically sustainable food production systems. The ultimate goal of CIMTAN is to develop aquaculture systems that can be adopted by its industrial partners to efficiently mitigate organic and inorganic enrichment of fed aquaculture operations. By actively recapturing this material to turn it into the production of extractive crops of commercial value, environmental and socioeconomic issues are transformed into benefits, trusted quality seafood, and novel seafood-based products, not only for its industrial partners but also for coastal and rural communities and all Canadians.

With a strong pan-Canadian academic, government, and industry partnership, CIMTAN is providing the interdisciplinary research and development and highly qualified personnel training in the following linked areas of IMTA: (1) ecological

design, ecosystem interactions, and biomitigative efficiency; (2) system innovation and engineering; (3) economic viability and societal acceptance; and (4) regulatory science, to facilitate the commercialization of IMTA in Canada.

Training of highly qualified personnel is a very high priority of CIMTAN, and the goal is to train 114 individuals, from undergraduate summer students, to master and doctoral graduate students, postdoctoral fellows, and technicians. Developing a versatile and interdisciplinary workforce is important if we want the scientists, policy influencers, decision makers, regulators, and industrialists of tomorrow to be innovative and build a more diversified and responsible aquaculture sector (deeply in need of expertise with appropriate interdisciplinary training) within the broader sector of sustainable and responsible coastal zone management.

The majority of the projects are conducted at commercial aquaculture sites, providing a direct opportunity for interactions with our industrial partners, who have been actively involved in the choice and development of the selected projects from the onset of the CIMTAN idea. They are actively involved in their implementations, are viewing the results firsthand, and will have the capacity to apply these results to their operations.

CIMTAN will generate new knowledge on alternative aquacultured species chosen based on their biomitigative functions and economic value. This will increase organic and inorganic biomitigation to develop even more efficient IMTA systems within an ecosystem approach and to diversify the Canadian aquaculture sector. New culture, technological, and engineering advancements and designs will strengthen the position of Canada as a responsible aquaculture production nation. The IMTA contribution to ecosystem health will need to be understood and quantified because ecosystem health generally means fish health and, ultimately, human health. In addition, CIMTAN is going beyond addressing questions of a natural science and engineering nature and is examining socioeconomic, policy, and regulatory governance components that are required for the full development of the sector. CIMTAN should create the conditions for increased economic opportunities in coastal and rural regions, including First Nations' communities, providing sustainable, quality seafood to Canadians, concomitant with increased societal acceptance of the aquaculture sector and public policy development for improved government decision making.

CIMTAN RESEARCH THEMES

The network is organized into three linked domains reflecting the four areas identified above: domain 1 is environmental, domain 2 is engineering, and both are linked by the cross-cutting domain 3 (economic and social), because biological, environmental, biotechnological, and engineering issues are always linked to economic aspects and social acceptability. Each domain is co-led by a scientist at an academic institution and one at a DFO laboratory, in recognition of the significant role played by this federal government department in this network.

Domain 1: Environmental System Performance and Species Interactions

Domain 1 is investigating how an IMTA system operates, its relative efficiency, and effects. The need for such a domain is driven by the fact that we are currently at a stage in the IMTA system development where a number of interested parties (regulators, nongovernmental organizations, and other scientists) are asking for more data on the degree of assimilation of IMTA sites. Therefore, one of the objectives of this domain is to generate more scientific data to enable a more detailed evaluation of the IMTA recycling and mitigation concept.

Domain 1 is essentially made up of two components: (1) an internal component that deals with how the system works and is efficient within the aquaculture operation and (2) an external component that deals with how the system works with pathways of effects and impacts on the surrounding environment with respect to dispersion of nutrients and the interactions with associated wild organisms. Domain 1 is made of eight projects, which are described below.

Quantifying the Capture and Conversion Efficiencies of Species Being Considered for Organic Extraction in Open-Water IMTA Systems

The potential of an organism as an organic extractive species within IMTA sites depends primarily on its ability to efficiently capture, absorb, and convert particulate waste into new production. On the east coast of Canada, the first organisms used for the organic extractive component have been the mussels *Mytilus edulis* and *M. trossulus* (Figure 1; Lander et al.

2004). Mussels ingest and efficiently absorb organic material from both fish food and feces (Reid et al. 2010; MacDonald et al. 2011). The sea cucumber *Cucumaria frondosa* is now being assessed for extraction efficiency because of its commercial value and possible complementary extraction of different particles not exploited by mussels (Figure 2). Sea cucumbers were exposed to experimental diets in the laboratory, where organic composition can be manipulated and controlled, and the natural assemblage of particles found at IMTA sites. Despite high individual variability in this species, a significant positive relationship was found between absorption efficiency and the quality of the food, thereby enabling the prediction of the response of the organisms for a variety of habitats. Several species are being considered for use as organic extractive organisms on the west coast of Canada, including the green sea urchin (*Strongylocentrotus droebachiensis*), the basket cockle (*Clinocardium nuttallii*), the blue mussel (*M. edulis*), the California sea cucumber (*Parastichopus californicus*), and the Pacific prawn (*Pandalus platyceros*). Ingestion rate, absorption efficiency, fecal production rate, energy budget, and biophysical properties of excreted feces are being determined in laboratory experiments for individuals fed either Sablefish (*Anoplopoma fimbria*) aquaculture waste or “natural” diets.

Cultivation of Complementary Inorganic Extractive Species for Increased System Performance

Since 2001, the inorganic extractive component of the IMTA system on the east coast has been the two kelps *Saccharina latissima* and *Alaria esculenta* (Figure 3; Chopin et al. 2004). On the west coast, *S. latissima* has been cultivated since 2007. These two species are cultivated first in the laboratory,



Figure 1. A sock of blue mussels, *Mytilus edulis*, with siphons wide open as they filter organic particles at an Integrated Multi-Trophic Aquaculture (IMTA) site in the Bay of Fundy, New Brunswick, Canada. Photo credit: S. Robinson.



Figure 2. The sea cucumber, *Cucumaria frondosa*, held in individual flow-through containers in a laboratory absorption efficiency experiment. The sea cucumbers are exposed to various organic diets comprised of natural particles, supplemented with cultured microalgae or fish feed used at Integrated Multi-Trophic Aquaculture (IMTA) sites. Photo credit: L. Orr.



Figure 3. Harvesting of the kelp, *Saccharina latissima*, at an Integrated Multi-Trophic Aquaculture (IMTA) site in the Bay of Fundy, New Brunswick, Canada. Kelps remove dissolved inorganic nutrients from the ecosystem while providing diverse commercial products. Photo credit: T. Chopin.

from September to November, and then at the sites from November to June–July. They need to be harvested in late spring–early summer before natural erosion of the blades, and their fouling, compromise the harvest and quality of the derived products. Consequently, there is a period of the year (summer) when seaweeds are absent at the sites and inorganic biomitigation is not taking place. This project is investigating two new macroalgal candidates, *Palmaria palmata* (dulse) on the east coast and *Ulva* sp. (sea lettuce) on the west coast, whose cycles

and characteristics allow growth of the macroscopic stages during the summer to provide biomitigative biomass during that time of the year and, consequently, an overall increase in the inorganic biomitigative capacity of the IMTA systems. Research is also underway to explore the use of seaweeds for partial substitution in fish feed formulations as alternate sources to fish meal and land plant proteins.

The Role of Microbes in the Nutrient Recycling of Organic Material from IMTA Sites

Understanding the various paths and processes by which energy flows through an IMTA site is one of the main objectives in the creation of sustainable aquaculture systems using ecosystem-based approaches. As food at one trophic level is recycled through another, the energy associated with organic particles is stripped out and converted to inorganic waste products such as ammonia, carbon dioxide, and heat. This transfer occurs right down to the lowest trophic levels where the bacteria reside. The objective of this project is to determine the role that bacteria play in nutrient recycling at a Salmon aquaculture site and to evaluate the relative scale of their ability to convert organic particles into inorganic components. Specifically, this project is enumerating bacteria and their respiration rates at and away from finfish aquaculture sites in both the water column as well as the benthos. This is done on a seasonal basis at IMTA sites on both the east and west coasts. This research is also identifying the bacterial communities associated with the aquaculture sites and how they evolve over the year. These results will fit into a model being prepared on energy flow through an IMTA system.

Quantifying Energy, Nutrient Dispersal, and Scales of Influence on Wild Species from Open-Water IMTA Sites

The project goal is to measure the abundance and distribution of wild species associated with IMTA cage sites and to learn how they are associated with nutrient availability in both the near and far fields. Current investigations include designing an appropriate field methodology with respect to feasibility and experimental design. The research thus far has quantified rates of biocolonization (biofouling) using standardized collectors that are similar to those used for monitoring invasive tunicates. Each collector consists of a series of polyvinyl chloride plates that serve as a substrate for native organisms such as bryozoans, hydrozoans, tunicates, and algae. These species colonize new substrates quickly and are suitable to measure early responses to nutrient availability (Chopin et al. 2012). Collectors are deployed at both finfish only and IMTA sites as well as at reference locations within the same geographic area but far from aquaculture activity. Upon retrieval, total accumulated biomass and surface area colonized are measured and compared among sites relative to other environmental variables. The next phase of investigation will be to deploy a full array of collectors around several IMTA and finfish only sites along with simultaneous measurement of environmental correlates such as temperature, salinity, current, chlorophyll, and oxygen.

Use of Blue Mussels as a Biological Means to Reduce the Horizontal Transmission of *Loma salmonae* (Agent of Microsporidial Gill Disease of Salmon)

As a general hypothesis, it is likely that the transmission of pathogens—and in particular the exchange of pathogens between the farm site and the “near-farm” environment—could be modified through IMTA practices. This may apply best or, alternatively, may be most successfully modeled for those organisms

that possess methods of infection and transmission that allow extended periods of extracorporeal (off-host) survival and for which the severity of infection is quantifiable as a continuous outcome and directly (linearly) related to exposure to infectious dose. Given these considerations, the disease known as microsporidial gill disease of Salmon, a serious endemic gill disorder in farmed and wild Chinook Salmon (*Oncorhynchus tshawytscha*), and other Pacific Salmon, has potential as a model through which to better understand disease transmission in this modified aquaculture setting. The goal of this project is to develop a suitable laboratory in vivo branchial xenoma expression model for microsporidial gill disease of Salmon and to use it to explore our specific aims, which include determining to what extent blue mussels may remove, deactivate, or retain *Loma salmonae* spores released from infected fish (Figure 4). Additionally, the project is seeking a further understanding of the temporal kinetics of spore survival in marine environments and sediments, in addition to their survival within or on structures that may be used in IMTA settings.

The kinetics of horizontal transmission of fish pathogens is often poorly understood and limited by quantifiable disease models for realistic (low-dose) challenges of susceptible hosts. Such models are needed to fully characterize the role of a novel environmental variable, in this case the filtering and subsequent digestive activity of a bivalve. Recent work has led to the development of a repeatable low-dose horizontal transmission model for *L. salmonae* (Harkness and Speare 2011), and the effects of

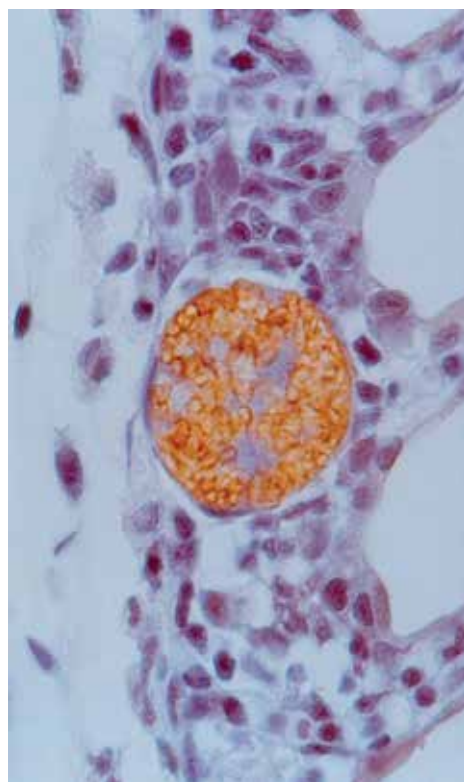


Figure 4. Monoclonal antibody–stained spores of *Loma salmonae* within a xenoma developing within the gill microvasculature of an infected Chinook Salmon, *Oncorhynchus tshawytscha*. Photo credit: D. Speare.

immunostimulation and immunosuppression have been quantified within this *in vivo* model system (Speare et al. 2011).

Can Filter-Feeding Bivalves Ingest Planktonic Sea Lice, Leading to Reduced Lice Numbers on Cultivated Salmon?

A possible benefit of adding filter-feeding shellfish to the typical monoculture model of Salmon farming is the potential for reducing viral, bacterial, and parasitic diseases in the cultured fish as a result of the filtering of planktonic dispersal particles (e.g., bacteria, viruses, larvae, and nauplii) by the shellfish (Skår and Mortensen 2007; Molloy et al. 2011). This project is examining a number of filter-feeding shellfish species for their ability to ingest planktonic naupliar and copepodid stages of sea lice under laboratory conditions and assessing the effects of commercial scale quantities of shellfish on lice levels at a commercial Salmon farm site. The laboratory phase of the project, currently underway, is designed to determine which of four species of suspension-feeding bivalves (i.e., basket cockle [*C. nuttallii*], Pacific oyster [*Crassostrea gigas*], Pacific scallop [*Mizuhopecten yessoensis* × *Patinopecten caurinus*], and mussel [*Mytilus* spp.; a mix of *M. edulis*, *M. galloprovincialis*, and their hybrid]) consume lice larvae and their ingestion rates at various temperatures (5, 10, 15°C). If successful, bivalves grown by Salmon farms could potentially reduce the abundance of sea lice on caged Salmon using a biological control approach, possibly reducing the need for costly chemotherapeutants.

Presence, Effect, and Bioaccumulation of Therapeutants in Polychaetes

Coculture of the clam worm (*Nereis virens*), a sediment dweller commonly found in the Bay of Fundy, is being considered as a means to process the heavier organic solids that settle out from fish farms. This worm is often sold as bait. Ecto-parasites, commonly called sea lice, often affect cultured Salmon and require the use of drugs and pesticides to control the infestations. As a consequence of treatment regimes, these compounds are released to the surrounding environment (Haya et al. 2004; Burridge et al. 2010). The project goal is to determine the potential effects of two of the anti-sea lice therapeutants, the food-borne drug Slice® (active ingredient emamectin benzoate), and the pesticide AlphaMax (active ingredient deltamethrin). Ongoing toxicity studies are assessing acute and chronic effects of these therapeutants on the worms. Data emanating from these studies will be used to assess the feasibility of culturing worms under Salmon farms and may be considered by regulatory agencies when assessing risks associated with therapeutant use in finfish aquaculture.

Mathematical Modeling for Open-Water IMTA—Developing Tools to Support System Design and Measures of Sustainability

Matter and energy flux within open-water IMTA systems, and between IMTA systems and the environment, need to be qualified and quantified in order to assess farm design and develop measures of sustainability (Reid et al. 2009). Empirical

measures of concentrations in open-water systems, as a means to assigning causality to a particular process or culture niche, have obvious challenges in such a highly variable and “leaky” environment. Some degree of modeling will, therefore, be essential to determine efficiencies and track delivery of nutrients to cocultured species (Reid 2011). Because most commercial-scale aquaculture in Canada occurs in open-water systems, IMTA will also be practiced in this context. IMTA system modeling must, therefore, be developed beyond the laboratory and small-scale pilot projects if it is to have real-world application. Consequently, the primary objectives of this project are to (1) reconcile existing ecological, animal, and seaweed husbandry efficiency measures; (2) continue the development of both a semistochastic nutrient transfer model to determine the overall IMTA system efficiency of nutrient and energy recovery and a mechanistic and deterministic model with time steps for better IMTA system understanding; and (3) determine methods to quantify system functions for open-water IMTA farm management, economics, and coastal zone policy development.

In September 2012, two new projects were added to domain 1: evaluating the performance of proposed and existing IMTA sites using an ecosystem modeling approach; and a variation on the IMTA theme for land-based, freshwater aquaculture operations: the development of freshwater IMTA for salmon and aquatic plants. These projects are not included in this article.

Domain 2: System Design and Engineering

Finfish aquaculture in Canada is largely based on salmonid production and concentrated in coastal British Columbia and New Brunswick. Despite a focus on the same salmonid species, the use of comparable feeds, employment of similar husbandry approaches, and provision of product to similar markets, both regional industries have evolved using distinctly different cage systems for their farm operations. In eastern Canada, the farms comprise independent circular plastic net-cages secured within an anchor grid. In western Canada, the industry uses primarily linked square or rectangular galvanized steel net-cages.

In terms of modifying these systems to support an IMTA approach, the logistical challenges are entirely different in the two regions. The circular cage grid system is considered an extensive infrastructure model, including space among the cages and within the anchor grid (Figures 5A and 6). IMTA development at these types of sites requires independent structures for the extractive species components, placed outside of the cage arrays. In this model, vessel access to all components would be maintained, but in fact the resulting IMTA system could be considered relatively leaky given the space around all of the individual component structures. Because IMTA components could be placed all around the fish cages, sites with bidirectional tidal flow could be considered for such development. The square, steel cage production system typical of the west coast is viewed as an intensive infrastructure model, with all containment structures in very close proximity (actually attached; Figures 5B and 7). Integration of extractive species within this type of system will require careful consideration of how access

to fish cages will be maintained and how grow-out systems for the additional species can be designed and constructed without compromising the structural integrity and functionality of the original steel cage infrastructure.

The challenges resulting from adapting these systems to support IMTA integration are considerable. Domain 2 includes four projects designed to meet these challenges, providing critical information on ecological engineering (how new species can be effectively integrated into an existing finfish production system) that will allow future adoption by industry.

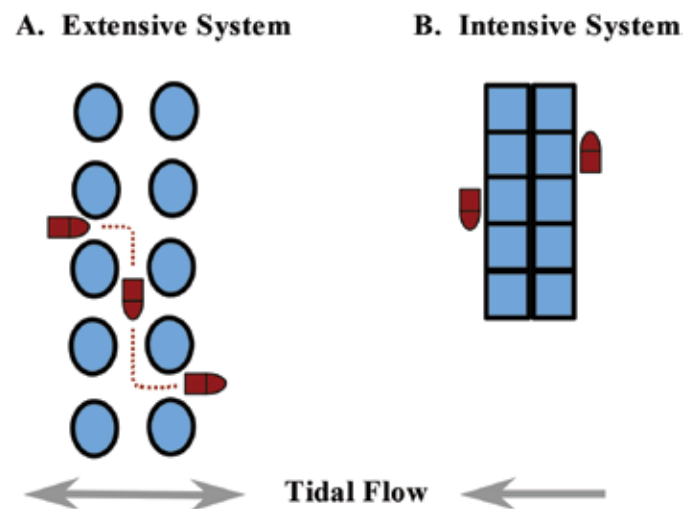


Figure 5. Current Canadian finfish aquaculture infrastructure, exemplified using a 10-cage configuration. (A) Circular cage system, typical of the east coast, will lend itself to extensive Integrated Multi-Trophic Aquaculture (IMTA) development. (B) Steel, square-cage intensive system, typical of the west coast, will require structural modification and innovation to support IMTA development.

Quantifying Temporal and Spatial Patterns of Nutrient and Organic Particle Plumes in IMTA Systems—The Basis for System Design

Delimitation of the spatial and temporal patterns and dynamics of the nutrient and particulate release, accumulation, and resuspension from different IMTA system configurations will provide critical information as to how leaky these approaches are and show how the extractive species components of these systems should be configured to maximize the ability to effectively intercept these waste streams. How these dispersion processes function within the natural fluctuations in nutrients, particulates, and inherent biotic assimilative capacity (e.g., phytoplankton) is also essential to understanding how IMTA systems should be designed and operated (Reid 2011). Results from this project will help develop an appropriate balance of species components of the IMTA system, as well as assist with production infrastructure design and engineering for effectively incorporating these species components into a multispecies design. Direct and indirect methods are being explored for delimiting the spatial extent of these waste plumes, comparing existing and new (optical) profiling techniques with indirect productivity measures of seaweed sentinels (kelps).

Extensive versus Intensive IMTA Systems—Hydrographic Influences and the Implications to Infrastructure Design and Operational Efficiency

Documentation of the dispersion and dilution pathways, specifically the near-field hydrographic flow properties, is being determined for both extensive and intensive IMTA production systems in order to provide for the most efficient ecological and structural design. This project supports a comprehensive evaluation of flow impedance by infrastructures, the effects of waste stream deflection (developed back-eddies, redirection of flows),



Figure 6. One of the Integrated Multi-Trophic Aquaculture (IMTA) sites in the Bay of Fundy, New Brunswick, Canada, operated by Cooke Aquaculture Inc.: Salmon cages on the left, mussel raft on the right foreground, and seaweed raft on the right background. Photo credit: T. Chopin.



Figure 7. The Integrated Multi-Trophic Aquaculture (IMTA) site of Kyuquot SEAfoods Ltd. on Vancouver Island, British Columbia, Canada. The right row of cages contains Sablefish; shellfish in the left row; and submerged kelp grid even more to the left (rectangle outlined by yellow buoys). The shellfish SEA-Tram system is visible across the first shellfish square. Photo credit: S. Cross.

the vertical entrainment of particles (potential persistence of nutrients), the effects of increased biomass on dissolved oxygen dynamics, the alteration of phytoplankton supply through the systems, and structural adaptation of IMTA to capitalize on the effect of flow on dissolved nutrient and particle movements.

Design and Pilot-Scale Testing of New Infrastructure Components, Including Integration of Energy Alternatives to Increase Operational Efficiencies

Aquaculture sites can be located remotely, far from the electrical grid. Because the intent of IMTA is to reduce the environmental impact of aquaculture operations, the provision of clean power to aquaculture sites is being investigated to avoid the need for diesel generators. Work to date has been focused on gathering resource data for the west coast IMTA demonstration site and performing initial component sizing. The use of on-site bioreactors to process seaweeds to produce biodiesel was explored but found to be unfeasible due to inefficiencies of scale. There were insufficient seaweeds available from target site operations with which to create the required quantity of biodiesel for energy self-sufficiency. An alternative approach is being pursued employing wind and solar energy sources to power aquaculture operations. An initial energy system model was assembled in HOMER that includes the net hoist power requirements, the source of the primary load, and power consumption (Hoevenaars and Crawford 2010). An energy audit has also been conducted on the on-site aquaculture staff residence. These data sets have been included in the custom energy usage model that is being developed to optimize the aquaculture power usage system, with particular consideration of proper simulation of the high power, low energy requirements of the site (Hoevenaars

and Crawford 2012). As the custom power model is refined, it will be used to size renewable energy systems for current and future aquaculture sites.

Optimizing IMTA Species Component Stocking Densities and Infrastructure Orientation to Maximize Overall System Efficiency

Hydrographic processes will dictate how dissolved nutrient and particulate plumes flow among the different IMTA infrastructure components, defining how best the IMTA production systems should be designed and configured in order to fully capitalize on the dispersion pathways of these waste streams (Reid 2011). However, the interception of these streams by the various extractive species can, in itself (at commercial production levels), affect how efficient the resulting IMTA system will be. Proximity to the fed (fish) component, density of the grow-out structures (nets, cages, trays), vertical and horizontal orientation with respect to the flows, within-production unit densities, and spatial and temporal integration of multispecies and multiyear classes within each type of IMTA system are all issues being addressed by this project in order to ensure continual and optimal system performance.

Domain 3: Economic Analysis and Social Implications

There is growing recognition that the successful development of aquaculture is highly dependent upon the needs, capacities, and aspirations of people living in coastal communities (World Bank 2006). Though Canada's aquaculture industry is relatively small in comparison to that of other nations, its largely undeveloped coastline affords great potential for further growth.

In recent years, however, the expansion of coastal aquaculture has been overshadowed by a variety of environmental concerns and controversies. IMTA has the potential to address many of the environmental issues that confront Canada's aquaculture industry, but it also raises new challenges and research needs in the natural and social sciences. Domain 3 draws together social science researchers who investigate key issues associated with the wider adoption of IMTA in Canada. In particular, what is the economic and financial attractiveness of IMTA in comparison to competing aquaculture technologies and what are the implications of IMTA for coastal livelihoods?

It is important to recognize that IMTA is a food producing activity that relies on managed systems that are embedded within broader marine or freshwater ecosystems. A particularly useful concept that captures the two scales for analysis cited above is the "agro-ecosystem" (Conway 1993). This concept refers to biophysical impacts and interactions and to impacts involving the socioeconomic system, such as the effects that IMTA has on local communities in terms of social acceptability and sustainable livelihoods. An extended socioeconomic border is drawn around the biophysical system at the site level to include environmental impacts from production and the marketing and distribution system, both of which involve off-site concerns at a wider scale. For this network, it is this wider boundary and the inclusion of socioeconomic considerations at this scale that is of importance in defining the ecosystem of interest.

At the site level, domain 3 is primarily concerned with examining the management of an IMTA operation, addressing questions such as whether IMTA is financially viable (Whitmarsh et al. 2006; Ridler et al. 2006, 2007). It may also have a social or community dimension in that the operation must be—at minimum—supported by the community. In carrying out the analysis at the off-site or external level, one can draw on the concept of the agro-ecosystem to consider the extent to which IMTA mitigates the externalities associated with conventional practices. Externalities refer to the third-party effects of aquaculture, typically including nutrient enrichment and other downstream environmental impacts.

At the level of institutions and governance, the aquaculture industry is overseen in Canada by a combination of federal, provincial, and local authorities. In recent years, both the federal and provincial governments have been striving toward a more efficient regulatory framework, balancing the need to protect the environment, sustain fisheries, and enable a competitive industry to flourish. The existing regulatory environment, however, has been developed in the absence of IMTA. The current governance structures pertaining to coastal aquaculture in Canada may need to be reviewed with the aim of identifying changes in the policy and regulatory environment that are needed to facilitate the operation of IMTA sites.

Domain 3 consists of two projects. One project concentrates on the economic and financial dimensions of IMTA, and a second project considers the social and livelihood implications, primarily at the community level.

Economic and Financial Modeling of IMTA

Assuming that IMTA is an environmentally favorable means of food production for society, its adoption depends on the profitability of the system and whether the necessary economic incentives to promote adoption are in place. This project aims to (1) examine the net economic benefits of IMTA and compare them to those of conventional aquaculture systems, (2) assess the private financial incentives for IMTA production at the site level, and (3) investigate appropriate financial incentives for the wider promotion of IMTA. This project uses both financial and economic analysis tools, where financial analysis examines the business's revenues and costs and economic analysis examines the net effects of an activity, including its effects on external parties. Studies carried out under this project examine (1) the impacts of commercial-scale IMTA on the current British Columbia shellfish industry, (2) consumer attitudes and willingness to pay for IMTA, and (3) the comparative economics of nutrient dynamics in IMTA, closed containment systems, and conventional net-pen Salmon aquaculture.

Social Implications of IMTA

Canadian coastal communities are small, widely dispersed, and have a high degree of diversity, both economically and culturally. In recent years, many of these communities have experienced economic hardships due to downturns in the capture fishery and forestry sectors. One of the goals of this project is to investigate the potential that IMTA has for contributing to the development of sustainable coastal livelihoods in remote communities. This requires a consideration of the capacity and interest of people for participating in aquaculture, as well as the policies and training needed to facilitate their involvement. Developing a better understanding of the social and institutional aspects of implementing IMTA in coastal communities directly complements the natural science aspects and is an essential component in the overall process of helping IMTA reach its full potential. Recognizing that the health of social, economic, and ecological systems are inextricably linked, this project has been developed with an explicit acknowledgement of the need to move across traditional academic disciplines and managerial "silos." Accordingly, this project is divided into three cross-cutting streams: (1) aquaculture governance, (2) the potential contribution of IMTA to Canada's coastal economy and social sustainability, and (3) First Nations and IMTA.

Linkages between Domains

The choice of IMTA species for potential commercial scale production will be based on combining the results from the biological domain 1 (their capabilities at delivering nutrients and their biological aptitude to capture these nutrients and convert them into biomass, feeding rates, growth, survival, and interactions), the engineering domain 2 (how easily can these species be held within an IMTA system, engineering design and placement of the various components, and stocking densities and temporal and spatial patterns of nutrient and organic particle plumes), and the economic and social domain 3 (value of the

species [i.e., crops], marketability, profitability, viability, and acceptability). Moreover, for a full demonstration of the efficiency and value of IMTA systems, the biomitigative services and benefits provided by extractive species need to be identified, recognized, and valued. This will be another argument toward increased societal acceptance of IMTA as an aquacultural practice.

Domain 3 links to domains 1 and 2 because of the need to develop financial and economic analyses on the sound technical foundation provided. Moreover, the governance, social sustainability, and First Nations' issues are overarching; they define the social and political context within which IMTA initiatives must develop. As such, these issues are critical to the entire research program. If they are not suitably addressed and resolved, it will not be possible to successfully implement all the technical advances gained.

BENEFITS, APPLICATIONS, AND SIGNIFICANCE OF THE CIMTAN NETWORK APPROACH

After 9 years of relatively independent investigations on the east and west coasts of Canada, it was extremely judicious and timely to implement CIMTAN by combining academic knowledge and industrial know-how to create a formal network whose strategic approach, interdisciplinary, multi-institutional, and multisectoral strength—along with shared expertise—will be greater than the sum of the individual projects. Moreover, it is noteworthy that studies at the interfaces of fields of expertise often bring strength and validated solutions to resolve complex issues.

One of the incremental benefits of a network approach includes access to an enlarged equipment and tool inventory at academic institutions and government laboratories. Conducting experimental research on the east and west coasts in a concerted manner allows the acquisition of complementary and compatible information, hence increasing research outputs and outcomes and reducing redundancies in research efforts. Moreover, by gathering data on a wide geographical and temporal basis, with a wide range of environmental conditions, more generalized trends may be discerned, which will allow for the design of more robust systems and policies, taking into consideration both the universality of some aspects and the regional specificity of others.

By being the recipients of the knowledge and technology transfer generated under the network, the Canadian-based CIMTAN industrial partners will have a significant advantage in being the first to apply innovations in a targeted area of regional, national, and international relevance and competitiveness. It is important to underline that CIMTAN will not only address issues that are production based but will also look into aspects of improved ecosystem resilience, economic quantification of the environmental benefits of the IMTA practices, development of the nutrient trading credit concept for IMTA operations, and the anticipated increase in societal acceptance of the aquaculture

sector when adopting IMTA practices supported by appropriate policies and enabling governance. CIMTAN is working closely with federal agencies such as DFO, the Canadian Food Inspection Agency, Environment Canada, Transport Canada, Agriculture and Agri-Food Canada, and their provincial counterparts, because their involvement in regulatory science will be required to enable IMTA to move from an experimental concept to a large commercial-scale reality.

The objectives of CIMTAN cover the full research and development and commercialization spectrum of investigations, conducting research at the experimental scale, developing pre-commercial practices, and transferring knowledge and technology to commercialize IMTA production systems and products. Because marine products are increasingly in demand, it appears very timely to invest financial and human resources in the aquaculture sector. Appropriate monitoring programs will be developed to ensure that IMTA provides diversified and trusted quality seafood. Healthy and novel IMTA-based bioproducts will also be developed. This will help in differentiating IMTA products, which, through better traceability and marketing, should command premium market prices.

Finally, it is hoped that the IMTA practice will bring new economic opportunities to coastal and rural communities in a manner that can be integrated with existing livelihoods and economic and social conditions in these areas. Increased revenue and employment should be generated in coastal and rural regions, which need stabilization of their workforce, including among First Nations.

ACKNOWLEDGMENTS

We greatly appreciate the support this work received from the Natural Sciences and Engineering Research Council of Canada (NSERC) strategic Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) in collaboration with its partners, Fisheries and Oceans Canada, the University of New Brunswick, the New Brunswick Research and Productivity Council, Cooke Aquaculture Inc., Kyuquot SEAfoods Ltd., Marine Harvest Canada Ltd., and Grieg Seafood BC Ltd.

REFERENCES

- Burridge, L., J. S. Weis, F. Cabello, J. Pizarro, and K. Bostick. 2010. Chemical use in Salmon aquaculture: a review of current practices and possible environmental effects. *Aquaculture* 306:7–23.
- Chopin, T. 2011. Progression of the integrated multi-trophic aquaculture (IMTA) concept and upscaling of IMTA systems towards commercialization. *Aquaculture Europe* 36(4):5–12.
- . 2012. Aquaculture, integrated multi-trophic (IMTA). Pages 542–564 in R. A. Meyers, editor. *The encyclopedia of sustainability science and technology*. Springer, Dordrecht, The Netherlands.
- Chopin, T., A. H. Buschmann, C. Halling, M. Troell, N. Kautsky, A. Neori, G. P. Kraemer, J. A. Zertuche-Gonzalez, C. Yarish, and C. Neefus. 2001. Integrating seaweeds into marine aquaculture systems: a key towards sustainability. *Journal of Phycology* 37:975–986.

- Chopin, T., J. A. Cooper, G. Reid, S. Cross, and C. Moore. 2012. Open-water integrated multi-trophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. *Reviews in Aquaculture* 4:209–220.
- Chopin, T., S. Robinson, M. Sawhney, S. Bastarache, E. Belyea, R. Shea, W. Armstrong, I. Stewart, and P. Fitzgerald. 2004. The AquaNet integrated multi-trophic aquaculture project: rationale of the project and development of kelp cultivation as the inorganic extractive component of the system. *Bulletin of the Aquaculture Association of Canada* 104(3):11–18.
- Chopin, T., M. Troell, G. K. Reid, D. Knowler, S. M. C. Robinson, A. Neori, A. H. Buschmann, S. J. Pang, and J. Fang. 2010. Integrated multi-trophic aquaculture (IMTA)—a responsible practice providing diversified seafood products while rendering biomitigating services through its extractive components. Pages 195–217 in N. Franz and C.-C. Schmidt, editors. *Proceedings of the Organisation for Economic Co-operation and Development (OECD) Workshop “Advancing the Aquaculture Agenda: Policies to Ensure a Sustainable Aquaculture Sector.”* Organisation for Economic Co-operation and Development, Paris.
- Conway, G. R. 1993. Sustainable agriculture: the trade-offs with productivity, stability and equitability. Pages 46–65 in E. B. Barbier, editor. *Economics and ecology: new frontiers and sustainable development*. Chapman & Hall, London.
- Diana, J. S. 2009. Aquaculture production and biodiversity conservation. *BioScience* 59:27–38.
- FAO (Food and Agriculture Organization of the United Nations). 2010. The state of world fisheries and aquaculture 2010. FAO, Rome. fao.org/docrep/013/i1820e/i1820e00.htm
- . 2011. World Aquaculture 2010. Food and Agriculture Organization of the United Nations, FAO Fisheries and Aquaculture Technical Paper 500/1, Rome.
- Harkness, J. E., and D. J. Speare. 2011. Resistance to *Loma salmonae* in Rainbow Trout (*Oncorhynchus mykiss*) subsequent to recovery from an initial low-dose cohabitation exposure. *Fish Pathology* 46:34–37.
- Hasler, C. T., G. C. Christie, J. Imhof, M. Power, and S. J. Cooke. 2011. A network approach to addressing strategic fisheries and aquatic science issues at a national scale: an introduction to a series of case studies from Canada. *Fisheries* 36:450–453.
- Haya, K., D. Sephton, J. Martin, and T. Chopin. 2004. Monitoring of therapeutants and phycotoxins in kelps and mussels co-cultured with Atlantic Salmon in an integrated multi-trophic aquaculture system. *Bulletin of the Aquaculture Association of Canada* 104(3):29–34.
- Hoevenaars, E., and C. Crawford. 2010. Renewable energy feasibility and optimization at an aquaculture site. In Z. Dong and H. Struchtrup, editors. *Proceedings of the Canadian Society for Mechanical Engineering Forum*. University of Victoria, Victoria, British Columbia.
- . 2012. Implications of temporal resolution for modeling renewables-based power systems. *Renewable Energy* 41:285–293.
- Lander, T., K. Barrington, S. Robinson, B. MacDonald, and J. Martin. 2004. Dynamics of the blue mussel as an extractive organism in an integrated multi-trophic aquaculture system. *Bulletin of the Aquaculture Association of Canada* 104(3):19–28.
- Lotze, H. K., H. S. Lenihan, B. J. Bourque, R. H. Bradbury, R. G. Cooke, M. C. Kay, S. M. Kidwell, M. X. Kirby, C. H. Peterson, and J. B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312:1806–1809.
- MacDonald, B. A., S. M. C. Robinson, and K. A. Barrington. 2011. Feeding activity of mussels (*Mytilus edulis*) held in the field at an integrated multi-trophic aquaculture (IMTA) site (*Salmo salar*) and exposed to fish food in the laboratory. *Aquaculture* 314:244–251.
- Molloy, S. D., M. R. Pietrak, D. A. Bouchard, and I. Bricknell. 2011. Ingestion of *Lepeophtheirus salmonis* by the blue mussel *Mytilus edulis*. *Aquaculture* 311:61–64.
- Naylor, R. L., R. J. Goldburg, H. Mooney, M. Beveridge, J. Clay, C. Folke, N. Kautsky, J. Lubchenco, J. Primavera, and M. Williams. 1998. Nature’s subsidies to shrimp and Salmon farming. *Science* 282:883–884.
- Neori, A., M. Troell, T. Chopin, C. Yarish, A. Critchley, and A. H. Buschmann. 2007. The need for a balanced ecosystem approach to blue revolution aquaculture. *Environment* 49(3):36–43.
- Reid, G. K. 2011. Spatial modelling of integrated multi-trophic aquaculture (IMTA) shellfish. *Bulletin of the Aquaculture Association of Canada* 109(2).
- Reid, G. K., M. Liutkus, A. Bennett, S. M. C. Robinson, B. MacDonald, and F. Page. 2010. Absorption efficiency of blue mussels (*Mytilus edulis* and *M. trossulus*) feeding on Atlantic Salmon (*Salmo salar*) feed and fecal particulates: implications for integrated multi-trophic aquaculture. *Aquaculture* 299:165–169.
- Reid, G. K., M. Liutkus, S. M. C. Robinson, T. Chopin, T. Blair, T. Lander, J. Mullen, F. Page, and R. D. Moccia. 2009. A review of the biophysical properties of salmonid faeces: implications for aquaculture waste dispersal models and integrated multi-trophic aquaculture. *Aquaculture Research* 40(3):257–273.
- Ridler, N., B. Robinson, T. Chopin, S. Robinson, and F. Page. 2006. Development of integrated multi-trophic aquaculture in the Bay of Fundy, Canada: a socio-economic case study. *World Aquaculture* 37:43–48.
- Ridler, N., M. Wowchuk, B. Robinson, K. Barrington, T. Chopin, and S. Robinson. 2007. Integrated multi-trophic aquaculture (IMTA): a potential strategic choice for farmers. *Aquaculture Economics & Management* 11(1):99–110.
- Skår, C. K., and S. Mortensen. 2007. Fate of infectious Salmon anaemia virus (ISAV) in experimentally challenged blue mussels *Mytilus edulis*. *Diseases of Aquatic Organisms* 74:1–6.
- Soto, D., J. Aguilar-Manjarrez, J. Bermudez, C. Bruguère, D. Angel, C. Bailey, K. Black, P. Edwards, B. Costa-Pierce, T. Chopin, S. Deudero, S. Freeman, J. Hambrey, N. Hishamunda, D. Knowler, W. Silvert, N. Marba, S. Mathe, R. Norambuena, F. Simard, P. Tett, M. Troell, and A. Wainberg. 2008. Applying an ecosystem-based approach to aquaculture: principles, scales and some management measures. Pages 15–35 in D. Soto, J. Aguilar-Manjarrez, and N. Hishamunda, editors. *Building an ecosystem approach to aquaculture*. Food and Agriculture Organization, FAO Fisheries and Aquaculture Proceedings No. 14, Rome.
- Speare, D. J., N. J. Guselle, and J. E. Harkness. 2011. Pilot study demonstrating that immunostimulation with beta-glucan fails to moderate the immunosuppressive effects of dexamethasone when co-administered to Rainbow Trout (*Oncorhynchus mykiss*) experimentally challenged with the microsporidian *Loma salmonae*. *Fish Pathology* 46:95–97.
- Troell, M., C. Halling, A. Neori, T. Chopin, A. H. Buschmann, N. Kautsky, and C. Yarish. 2003. Integrated mariculture: asking the right questions. *Aquaculture* 226:69–90.
- Whitmarsh, D. J., E. J. Cook, and K. D. Black. 2006. Searching for sustainability in aquaculture: an investigation into the economic prospects for an integrated Salmon–mussel production system. *Marine Policy* 30(3):293–298.
- World Bank. 2006. Aquaculture: changing the face of the waters—meeting the promise and challenge of sustainable aquaculture. World Bank, Washington, D.C. 