Aquaculture Europe 2012 - Securing our Future

aquaculture europe

VOL. 36 (4) DECEMBER 2011

IMTA – Upscaling an ecosystem approach to farming the sea

INTEGRATED MULTI-TROPHIC AQUACULTURE

The importance of aquaculture for EU food production

Pascal Divanach awarded EAS Honorary Life Membership

eas

THE MEMBERS' MAGAZINE OF THE EUROPEAN AQUACULTURE SOCIETY

4th Quarter 2011
Afgiftekantoor: 8400 Oostende Mail

Progression Of The Integrated Multi-Trophic Aquaculture (IMTA) Concept And Upscaling Of IMTA Systems Towards Commercialization

THIERRY CHOPIN

CANADIAN INTEGRATED
MULTI-TROPHIC AQUACULTURE
NETWORK (CIMTAN),
UNIVERSITY OF NEW BRUNSWICK,
P.O. BOX 5050, SAINT JOHN,
NEW BRUNSWICK, E2L 4L5, CANADA
TCHOPIN@UNBSJ.CA

Dr. Thierry Chopin, well-known seaweed expert, and Scientific Director of the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN).
(Photo credit: Hemmings House Pictures)

INTRODUCTION

We all know it: the human population on this planet continues to grow; it wants more and more food from aquatic environments (marine and freshwater); fisheries, while continuing to have their role, will not fill the widening gap between the demand and the supply; aquaculture is already supplying around 50 % of the aquatic food we eat and it will increase that share of the production for our daily intake of proteins, carbohydrates and lipids (FAO, 2010). However, if it wants to continue to grow, the aquaculture sector will need to develop more innovative, responsible, sustainable and profitable technologies and practices.

Integrated multi-trophic aquaculture (IMTA) has the potential to achieve these objectives. IMTA is the farming, in proximity, of several species at different trophic levels. IMTA is the central/overarching theme, and, like in the music of Johann Sebastian Bach, 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). The species selected should be well-adapted to these conditions and be appropriately chosen at multiple trophic levels, based on their complementary functions in the ecosystem, as well as for their existing, or potential, economic value. Proximity should be understood as not necessarily considering absolute distances but connectivity in terms of ecosystemic functionalities, in which management at the bay area level is paramount (lease limits drawn on a map by humans do not always consider nature reality).

IMTA is an ecologically engineered ecosystem management approach, which, in fact, does nothing more than mimic a simplified natural trophic network (which is different from a linear food chain). It should provide environmental sustainability, economic stability and societal acceptability. IMTA programs, in different states of development and configuration, are taking place in at least 40 countries (Barrington *et al.*, 2009; Chopin, in press).

The theme of the 2011 Aqua Nor Forum was "Upscaling aquaculture systems", with the third session looking more precisely into how to scale up the ecosystem approach. In that context, I was asked to comment on what it will take to scale up IMTA and increase its acceptance and adoption. I will try to answer that question based on what we have learned over the last 16 years, working on developing an IMTA system in the Bay of Fundy, on the east coast of Canada, and also based on what I have seen around the world.

Our variation on the IMTA concept has evolved from the experimental to the early commercial scale and combines the cultivation of a fed component (finfish) with an inorganic extractive component (seaweeds recapturing dissolved nutrients and carbon dioxide and providing oxygen), an organic particulate extractive component (shellfish recapturing small organic particles) and an organic solid extractive component (deposit-feeding invertebrates recapturing larger organic particles) (Fig. 1).

WHAT WILL IT TAKE TO SCALE UP IMTA AND INCREASE ITS ACCEPTANCE AND ADOPTION?

First... understanding that changes rarely happen overnight

We should recognize that what we are really talking about here are major philosophical changes to our approach to food (seafood and other) production systems. Things take time to materialize and penetrate into the minds of people. Reactionary forces could even come from surprising sources, which one might have expected would be all for the evolution of aquaculture towards improved practices.

It takes time, dedication, perseverance and an inter-disciplinary approach to progress along the complex Research & Development & Commercialization (R&D&C) continuum for an idea to flourish into complete commercial adoption. Most often the solutions do not reside in one discipline or one approach, but can be found at the interfaces of many disciplines that one has to explore, if not master. This is the reason why our IMTA project has, since its inception, been inter-disciplinary in nature, combining expertise from the environmental, economic and social sciences. It also takes time to understand each other, as we all come with our jargons, biases, and different methods of evaluation/analysis. Biological methods have their raisons d'être refined over centuries, as do social science methods: we have to understand them and their origins, instead of setting up a hierarchy of values.

When major reforms in our way of thinking are at stake, one has to understand that it is not a three year grant, nor a program in place long enough to win the next election, that can allow for serious progress and reliable answers to be obtained. Success in the long term requires continuity of appropriately supported investigations if we want them to be meaningful and bring lasting changes.

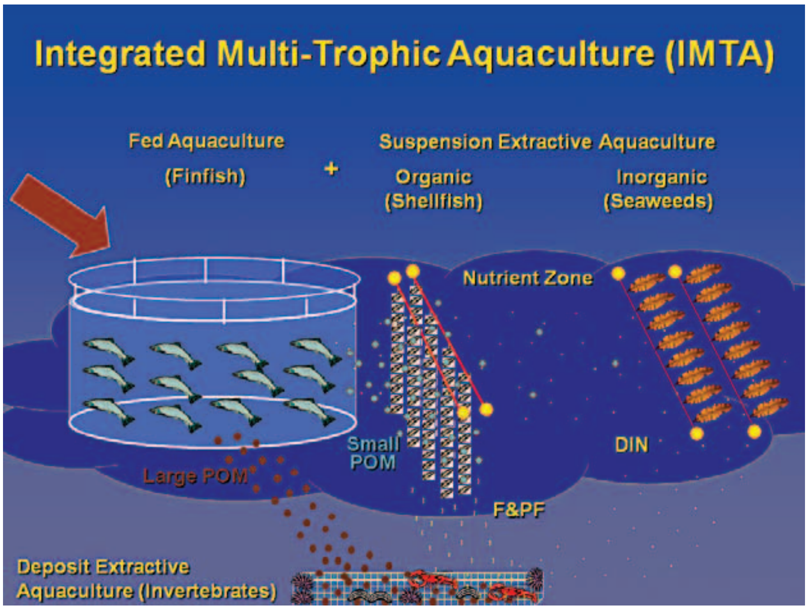

Figure 1. Conceptual diagram of an integrated multi-trophic aquaculture (IMTA) operation including the combination of fed aquaculture (e.g. finfish) with suspension organic extractive aquaculture (e.g. shellfish), taking advantage of the enrichment in small particulate organic matter (POM), inorganic extractive aquaculture (e.g. seaweeds), taking advantage of the enrichment in dissolved inorganic nutrients (DIN), and deposit organic extractive aquaculture (e.g. echinoids, holothuroids and polychaetes), taking advantage of the enrichment in large particulate organic matter (POM) and faeces and pseudo-faeces (F&PF) from suspension-feeding organisms. The bioturbation on the bottom also regenerates some DIN, which becomes available to the seaweeds.

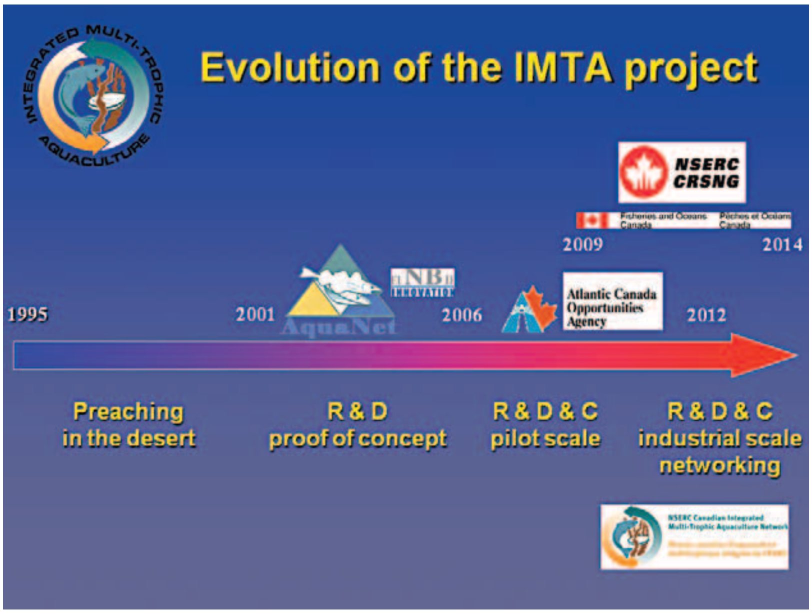

Figure 2. Evolution of the IMTA project on the east coast of Canada and its four periods of development.

For example, the IMTA program on the east coast of Canada is starting to collect the fruits of its tireless efforts as it enters its 11th year of activities. I first spoke about what has become IMTA in an abstract for the conference "Coldwater aquaculture to the year 2000" held in September 1995, in St. Andrews, New Brunswick. The title was "Mixed, integrated, poly-, or multi-level aquaculture – whatever you call it, it is time to put seaweeds around your cages!". From 1995 to 2000, our program was in its "preaching in the desert" period (Fig. 2): talking about the concept and getting strange looks, at least in the western world! From 2001 to 2006, we entered the R&D proof of concept period and the acronym "IMTA" was created in 2004 at a workshop in Saint John, New Brunswick, when Jack Taylor and I combined "multi-trophic aquaculture" and "integrated aquaculture" into "integrated multi-trophic aquaculture". We are presently in the third period, the R&D&C pilot scale period (2006 to 2012), overlapping with the fourth period, which started in 2009, and can be described as the R&D&C industrial scale and networking period, with the establishment of the Canadian IMTA Network (CIMTAN).

Governance and regulatory structures pertaining to aquaculture will need to be revised

In Canada, aquaculture is regulated under the Fisheries Act, first promulgated in 1868. Despite being amended several times, this legislation needs major overhaul and it is time to contemplate an Aquaculture Act, adapted to this farming activity. Even if an Aquaculture Act is enacted, vigilance will be needed so that it does not hinder the development of IMTA practices and the commercialization of IMTA products, or inappropriate regulations and policies will be seen as impediments by companies who will see no incentive in developing IMTA. The monospecific management of fisheries, in many countries, has had devastating consequences on stocks because species interactions have been neglected. We have to be sure that aquaculture management does not fall into the same cracks, and consider the cultivation of multiple species in proximity and their interactions (which occurs anyway, as pure monoculture is rarely the case and is more an abstract human conception).

For example, an earlier version of the Canadian Shellfish Sanitation Program (CSSP) prevented the development of IMTA because of a clause that specified that shellfish could not be grown closer than 125 m of finfish net pens. This paragraph was clearly not written with IMTA in mind, but it seriously impinged its development. After four years (2004-2008), the paragraph was amended so that IMTA practices could develop to commercial scale legally, based on recent, reliable and relevant data and information provided by the IMTA project on the east coast of Canada and three government departments. This suggests that new aquaculture practices should be accompanied by timely regulatory review to avoid market delays for new products. As governments, in different parts of the world, move to revise current regulatory regimes, it will be necessary to press the importance of accommodating and indeed encouraging new sustainable solutions such as IMTA.

A major rethinking will be needed regarding the definition of an "aquaculture farm" by reinterpreting the notion of site-lease areas and regarding how it works within an ecosystem and in the broader context of Integrated Coastal Zone Management (ICZM), where integration can range from the small scale (a leased site with its spatial limits) to the larger scale of a region connected by the functionalities of the ecosystem. Biomitigative solutions, such as IMTA, should become an integral part of coastal regulatory and effluent management frameworks.

If organic particles released by the fed component settle quite rapidly, dissolved inorganic nutrients travel longer distances; consequently, the understanding of their impacts and their mitigation should be approached and modelled differently. When aquaculture sites are located closely to one another, the incursions of the nutrients released from different sites overlap, especially in regions with significant tidal currents, and the site origin of the nutrients is not that important for biomitigating organisms such as seaweeds. The nutrient sequestration has, then, to be considered at the bay management level (like for diseases) and seaweed cultivation sites could be conceived as nutrient scrubbing stations (moreover earning nutrient trading credits, see below).

The conversion of traditional monoculture sites into IMTA sites will also not occur overnight

This will also be progressive. Not only because things take time, but also because the aquaculture companies that will embrace IMTA will need to develop markets and distribution circuits to absorb the co-cultured biomass. It is not easy to break the vicious circle of the producer telling you on one side "I will grow IMTA biomass if you can demonstrate to me that there is a market for it" and the distributor telling you on the other side "I will consider IMTA products if you can show to me that there is a constant supply of it". Each sector needs interactions with, and incentives from, the others for the whole chain of custody to occur. When the "stars" (the seafood producer, the scientific IMTA team and the seafood distributor) are finally "aligned", then the whole process, driven by sustainability-based transformational change initiatives, can be completed.

If the IMTA biomass cannot find applications and be sold, it will have to be dumped somewhere else, which does not solve any problems, but just shifts them to another location. Consequently, it is not realistic to request that fish aquaculture companies transform all their sites, or a significant portion of their sites, into IMTA sites within a short period of time to satisfy certification standards that are being developed.

If, in the western world, people generally know what to do with the production of shellfish, people generally wonder what to do with the seaweed biomass, something that always surprises Asian people who have a long tradition of using seaweeds. In our project, we are presently working on the use of seaweeds for direct human consumption with three restaurants who prepare delicious recipes with our IMTA products (Fig. 3), for the formulations of cosmetics, and as a substitution in salmon feed formulations.

I have been quite surprised by the projects on fishmeal substitutions and biofuels/biogases/bioalcohols using terrestrial crops. They have been ill-conceived for several reasons:

- Prices of some staple food crops have already risen considerably because of their announced use as energy crops. This is not encouraging for the regions of this globe that are heavily dependent on these crops.
- If aquaculture wants its share of these crops, in addition to the existing markets, then extra arable soil will have to be found, triggering even more deforestation.

Figure 3. Maple glazed Cooke Aquaculture eco-label salmon, IMTA kelp (*Saccharina latissima*) salad and roasted red pepper chutney… one of the delicious dishes prepared by Jean-François Fortin, Executive Chef at the Fairmont Algonquin, St. Andrews, New Brunswick. (Photo credit: Thierry Chopin)

- More terrestrial crop cultivation will also mean increased irrigation at a time when this planet is encountering some serious water management issues.
- With increased agricultural developments, fertilizer and pesticide applications would almost certainly increase.

Another approach is to develop marine agronomy, with organisms already living in seawater, such as seaweeds. They could be the real answer for these biomass productions, especially in an IMTA setting where the fed component provides the fertilizers.

Evolving aquaculture practices will require a shift toward understanding the workings of food production systems rather than focusing on monospecific technological solutions

With monoculture, people calculate Food Conversion Ratios (FCR), in which three aspects are considered: the anthropogenic feed input, the output to the environment and the harvesting of the sole crop, fish (Fig. 4a). With IMTA, things are admittedly more complex and Food Assimilation Trophic Transfer Integrated Efficiency Ratios (FATTIER) need to be calculated. This time, the anthropogenic feed input, input from the environment, output to the environment, output to the IMTA components and the harvesting of the different IMTA components have to be considered (Fig. 4b). This means understanding and quantifying 37 arrows instead of 3, and this is why modelling IMTA is a complex exercise: we are working on it and are proceeding cautiously instead of releasing magic numbers that could appease some in the short term, but could prove inaccurate in the long term.

There is more than fish in the oceans!

Oceans cannot function with only fish, and aquaculture is not only fish aquaculture! Our seafood solutions cannot come from only this group of organisms. So, if we want aquaculture to work, we, especially westerners, have to stop being obsessed with fish aquaculture! If we want to better manage marine environments, we need to revisit the concept of marine agronomy (Doty, 1979), learning from mistakes made in agriculture over the centuries to do a better job with aquaculture. It is interesting to note that traditional agricultural practices, such as crop diversification, rotation and fallowing are now being transposed to aquaculture practices.

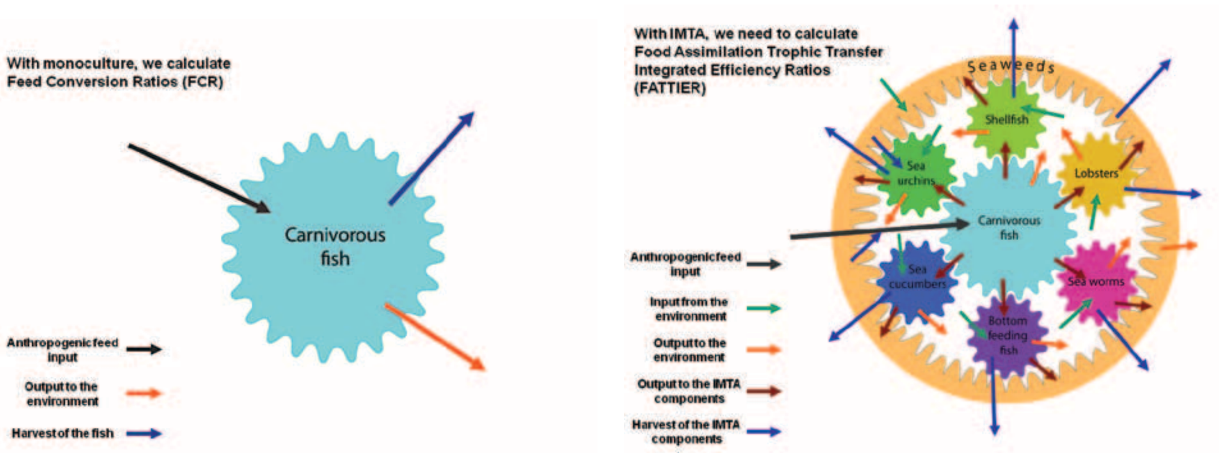

Figure 4. Monoculture efficiency can be measured through the calculation of Food Conversion Ratios (FCR; 4a - left). With IMTA, more complex Food Assimilation Trophic Transfer Integrated Efficiency Ratios (FATTIER) need to be calculated (4b - right).

We should not forget that farmed seaweeds (93.8 % of the worldwide harvested seaweed resource) represent 46.2 % of the total world mariculture (FAO, 2010). The problem is that 99.8 % of the 15.8 million tons of cultivated seaweeds (worth US$7.4 billion) come from China, Indonesia, the Philippines, Korea and Japan, hence the frequent ignorance of these facts in the western world (Chopin and Sawhney, 2009; Chopin, in press). Molluscs represent 43.0 % of the total world mariculture and finfish only 8.9 %. So, in many parts of the world, aquaculture does not equal salmon aquaculture and westerners have to admit that they have a much skewed perception of aquaculture.

Moreover, with IMTA, because we culture species together, we are starting to understand some species interactions, which could prove to be positive from the perspective of disease controls. For example, in laboratory experiments, it has been shown that blue mussels are capable of inactivating the infectious salmon anemia virus (ISAV) and the infectious pancreatic necrosis virus (IPNV) (Skår and Mortensen, 2007; Robinson, pers. comm.). Blue mussels, and other shellfish such as scallops, can ingest copepodids, the planktonic and infectious stage of sea lice (Molloy *et al.* 2011; Robinson, pers. comm.). Consequently, shellfish rafts could be strategically placed to serve as a kind of sanitary/biosecurity cordon around fish cages to combat some diseases. Using biofilters, such as shellfish, could allow some biological control of outbreaks of pathogens and parasites, hence reducing the number of costly chemical treatments.

The combinations of co-cultured species will have to be selected very carefully

The co-cultured species will have to be 1) complementary in terms of ecosystem functions, 2) appropriate for the habitat, culture technologies and environmental conditions, 3) providing both efficient biomitigation and commanding an interesting price as raw material or for their derived products, and 4) their commercialization should not generate insurmountable regulatory hurdles.

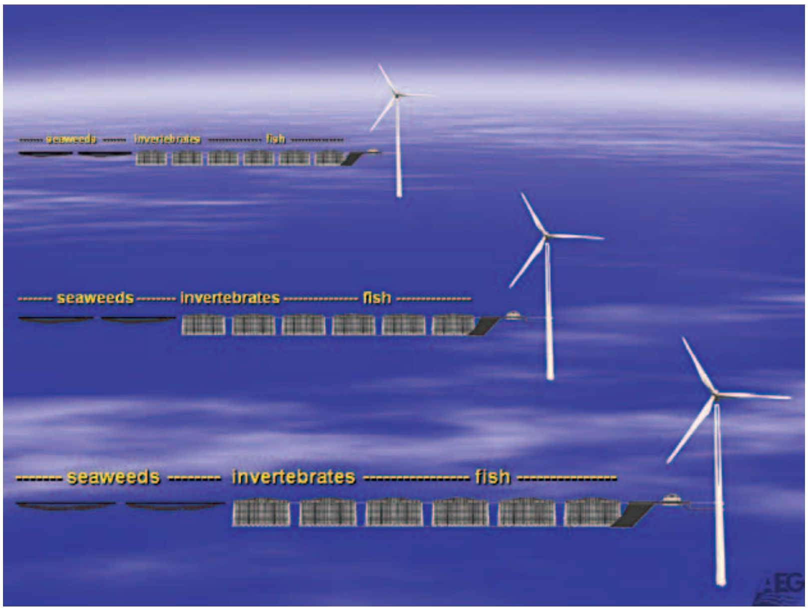

Figure 5. Combining IMTA with, for example, wind farms into integrated food and renewable energy parks (IFREP) could be a means for reducing their cumulative footprint, while integrating green energy with food, and increasing the societal acceptance of aquaculture.

As mentioned above, there are many variations on the flexible IMTA theme, and people interested in developing IMTA in their region will have to consider environmental, economics and societal aspects before settling on a combination of organisms and infrastructures that best suits their conditions. Again, no magic combination exists, but a certain number of guiding principles, mostly based on common sense, have to be considered.

The value of the ecosystem services provided by the extractive components of IMTA systems will have to be recognized and accounted for

I used to mention "biomitigative services" to please some economists who argue that the term "ecosystem services" should be reserved to the non-market services of nature provided to humans, who are the only ones who can assign a monetary value to them. I can, however, see that that distinction is less and less observed and that the two terms are frequently interchanged. Moreover, if we accept that humans are part of the ecosystem, and not a particular species on a particular pedestal, and that market-valued cultivated species can render similar services to those of their conspecific natural equivalents, then the semantic problem is solved. Yes, inter-disciplinarity can lead to the "bastardization" of terms exclusive to a discipline, but I believe it allows for broader applicability!

There has been much talk and many large conferences about carbon trading credits. I believe it is also important to introduce the concept of "nutrient trading credits" (NTC), especially in the coastal zone. The inorganic and organic extractive components of IMTA can play a key role in the sequestration of these nutrients.

If we estimate an average composition for seaweeds of around 0.35 % nitrogen (N), 0.04 % phosphorus (P) and 3 % carbon (C), and NTCs which should be around US$10-30 kg^{-1}, US$4 kg^{-1} and US$30 t^{-1} for N, P and C, respectively (Chopin *et al.* 2010), the ecosystem services of cultivated seaweeds are worth at least US$592.5 million to US$1.698 billion, hence as much as 23 % of their present commercial value. Similar calculations could be made for the organic extractive component of IMTA, paying particular attention to the sequestration of C with shellfish.

Appropriately valued services rendered by extractive aquaculture should represent financial incentive tools to encourage the practitioners of monospecific aquaculture to contemplate IMTA as a viable marine agronomy option to their current practices.

A monetary value should also be given to:

- Recapturing feed and energy otherwise lost and their conversion into other commercial crops. Feed represents around 60 % of a finfish aquaculture operation; if that feed can be used more thoroughly and, in fact, several times, substantial savings could be made.
- Reducing risk through crop diversification. This should have impacts with bankers and insurers, and on government regulations and policies.
- Increasing the societal acceptability of aquaculture. We have conducted several attitudinal surveys with different groups (Shuve *et al.* 2009; Barrington *et al.* 2010); each one has demonstrated a greater acceptance of IMTA over conventional fish monoculture.
- Differentiating and eco-certifying IMTA products, which can command premium market prices. IMTA salmon is now commercialized as Wise Source™ Salmon by the largest food distributor in Canada, Loblaw Companies Ltd. The IMTA salmon can only be differentiated if grown together with the extractive components, which should be credited for the premium price on salmon, on top of their intrinsic sale value.

If IMTA is not financially credited back for these benefits it will continue to be short-changed and its true value will continue to be incorrectly calculated. The value of IMTA does not reside only in the value of the direct sale of the co-cultured species.

Consumers' perceptions and attitudes may have to change regarding wastes and nutrients

Nutrients are good; they are even necessary for life in aquatic environments. The problem is similar to that of chocolate – I like it, but too much makes me sick – and too many nutrients can make the ecosystem sick. However, nutrients should not, particularly in the western world, automatically be equated to waste. Consumers' perceptions and attitudes may have to change regarding recycling and recapturing at sea. After all, there is the good old saying "What is waste for some is gold for others" entrenched in our common sense wisdom. Transposed to agronomy, we could say "What is waste for some species is nutrients for others". Surprisingly, this seems to be readily accepted on land and for agricultural practices; why is it not at sea and for aquacultural practices?

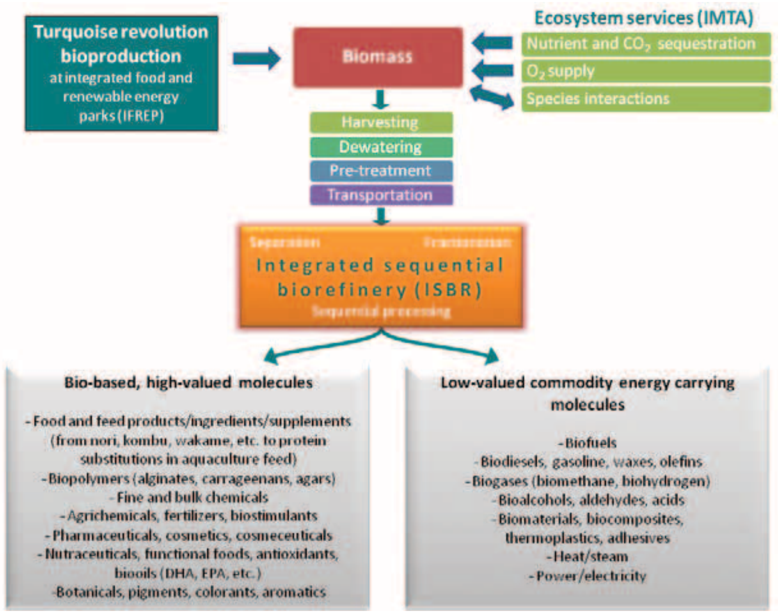

Figure 6. The emerging concept of integrated sequential biorefinery (ISBR) for the integrated use of biomass, food, feed, chemicals and energy produced by multi-purpose integrated food and renewable energy parks (IFREP) in an integrated multi-trophic aquaculture (IMTA) setting providing ecosystem services.

Will consumers come to accept eating products cultured in the marine environment in the same way they accept eating products from recycling and organic agricultural practices, for which they are willing to pay a higher price for the perceived higher quality or ethical premiums? For example, regulations require mushrooms to be specifically grown on farmyard manure and animal excrements to receive organic certification (European Community Regulations No 2008R0889 - Article 6). Confusion has been instilled in the perceptions of the consumer: people have no problems with farmyard manure and animal excrements when it comes to organic agricultural farming…! So, why do we not transpose that to IMTA, as a form of organic aquacultural farming, duly recognized through differentiation, eco-certification or eco-labelling and commanding premium market prices for its products?

Business models will have to evolve so that more than one product is generated from one site or one species

Our business models will have to change from "one species-one process-one product" to a streamed bioeconomic web approach among different industry sectors. Are we ready to evolve in our use of this planet's "last frontier" and finally deal with the concept of marine spatial planning (MSP) in coastal waters and for more exposed/offshore locations where some of the aquaculture operations will move in the future? In fact, combining IMTA with wind, underwater turbine and/or biofuel/biogas/biomaterial farms into large multi-purpose integrated food and renewable energy parks (IFREP) could be a means for reducing their cumulative footprint, while integrating green energy with food and fuel/gas/material production and processing (Fig. 5).

It all comes down to the basic question of societal acceptance. However, with a global human population continuing to grow, eating more seafood and using more energy than ever per capita per year, our choices are becoming quite constrained. We will have to use the sea more and more for industrial purposes, while still being wise enough to put aside some of it

Figure 7. Thierry Chopin during the shooting of the video for the Natural Sciences and Engineering Research Council of Canada Synergy Award for Innovation. Disseminating knowledge to various audiences and increasing the awareness of IMTA will certainly be important tasks. (Photo credit: Shawn Robinson)

for recreational purposes and also in the form of Marine Protected Areas (MPAs), not only for their natural beauty, but also for their ecosystem functions such as breeding grounds, nursery habitats and food production areas.

Are we ready to embrace the emerging integrated sequential biorefinery (ISBR) concept in which a biomass can be sequentially separated, fractionated and processed to yield, on one hand, bio-based, high-valued molecules and, on the other hand, low-valued commodity energy carrying molecules, all produced within reduced footprint requirements (Fig. 6)? Aquaculturists and different multi-sector end users will need to become inter-disciplinary in their approach and learn to collaborate and share/integrate the biomass cultivation and processing steps, while aiming at the lowest resource and energy inputs. Product functionalities will have to be maintained, as much as possible, along the process for optimal use/valorization of the multi-purpose biomass, and not necessarily the maximization of just one end product, as some co-products could reveal themselves as the real drivers of ISBRs.

Market volumes/values, ecosystem services, and public acceptance will have to be considered and included in these new business models and approaches.

Communicating the IMTA message will be key for changes to materialize

The IMTA concept is relatively new in the western world, and some times, paradoxically, rediscovered in the Asian world. Increasing the awareness of this responsible aquaculture practice will certainly be an important task. In many countries, including Canada, where extension and outreach services do not exist, researchers will have to take it upon themselves to disseminate their knowledge to various audiences: aquaculture and other marine industrial sectors, fishers and professional fishery associations, regulatory agencies, decision makers, politicians, environmental non-governmental organizations and the public at large.

This often means going outside of the comfort of the scientific Ivory Tower and using different communication platforms. As scientists, we have the scientific primary publication (which has its role) in our tool box to reach the scientific community, but, if we want our science to be relevant to and understood by society, complicated and specialized scientific publications will not do the trick. We have to think outside of the usual box; we need to find the appropriate media to reach out to other audiences, be it a National Geographic TV documentary, a video with industrial partners (Fig. 7), an article in Time Magazine, or a dance performance (see http://www.unbsj.ca/sase/biology/

chopinlab/imta/news/motus_o/index.html). These unconventional tools – which, unfortunately, do not receive any credit in a classical scientific curriculum vitae – provide a powerful way to reach, educate, and dispel some perceptions to a much wider audience, showing that aquaculture practices are evolving and that some scientists are very interested in applying their research to the common good of society.

For me, these time-consuming, but necessary, efforts are all about disseminating the message outside the scientific community to have an impact on people who are 1) generally not our usual audience but are influential, at their respective levels, in the decision making process, 2) should get the message that things are changing, and 3) need to be given a new perspective on science by translating it into new media that will reach them efficiently.

CONCLUSION: THE TIME HAS COME FOR THE TURQUOISE REVOLUTION!

Some visionary changes in environmental, economic, societal and political reasoning will have to take place to seek sustainability, long-term profitability and responsible management of coastal waters, and embrace new practices, such as IMTA, which will contribute to these goals. It will take time, perseverance and renouncement to going with fads and the quest for easily obtained magic numbers and fast silver bullets, which do not exist.

Modern aquaculture is, in fact, in its infancy when compared to agriculture. It will be needed more and more, but it can certainly be continuously improved so that it enters a new ERA of Ecosystem Responsible Aquaculture. It is time to make the Blue Revolution of the 1980s greener. It is, therefore, time for the Turquoise Revolution!

References

Barrington K, Chopin T, Robinson S (2009) Integrated multi-trophic aquaculture (IMTA) in marine temperate waters: 7-46. *In: Integrated Mariculture: a Global Review*. D. Soto (Ed.). FAO Fisheries and Aquaculture Technical Paper No. 529. FAO, Rome, 183 p.

Barrington K, Ridler N, Chopin T, Robinson S, Robinson B (2010) Social aspects of the sustainability of integrated multi-trophic aquaculture. *Aquaculture International* 18 (2): 201- 211.

Chopin T (2011) Integrated multi-trophic aquaculture (IMTA). In: Meyers RA (Ed.) The Encyclopedia of Sustainability Science and Technology. Springer, Dordrecht (in press).

Chopin T, Sawhney M (2009) Seaweeds and their mariculture. In: Steele JH, Thorpe SA, Turekian KK (Eds.) The Encyclopedia of Ocean Sciences. Elsevier, Oxford, pp 4477-4487.

Chopin T, Troell M, Reid GK, Knowler D, Robinson SMC, Neori A, Buschmann AH, Pang SJ, Fang J (2010) Integrated Multi-Trophic Aquaculture (IMTA) – a responsible practice providing diversified seafood products while rendering biomitigating services through its extractive components. In: Franz N, Schmidt C-C (Eds.) Proceedings OECD Workshop "Advancing the Aquaculture Agenda: Policies to Ensure a Sustainable Aquaculture Sector", Paris, 15-16 April 2010: Organisation for Economic Co-operation and Development, Paris, pp. 195-217.

Doty MS (1979) Status of marine agronomy, with special reference to the tropics. In: Jensen A, Stein JR (Eds.) Proceedings of the 9th International Seaweed Symposium, Santa Barbara, USA. Science Press, Princeton, p 35-58.

FAO (2010) The state of world fisheries and aquaculture 2010. Food and Agriculture Organization of the United Nations, Rome; http://www.fao.org/docrep/013/i1820e/i1820e00.htm

Molloy SD, Pietrak MR, Bouchard DA, Bricknell I (2011) Ingestion of *Lepeophtheirus salmonis* by the blue mussel *Mytilus edulis*. *Aquaculture* 311: 61-64.

Shuve H, Caines E, Ridler N, Chopin T, Reid GK, Sawhney M, Lamontagne J, Szemerda M, Marvin R, Powell F, Robinson S, Boyne-Travis S (2009) Survey finds consumers support Integrated Multi-Trophic Aquaculture. Effective marketing concept key. *Global Aquaculture Advocate* 12 (2): 22-23.

Skår CK, Mortensen S (2007) Fate of infectious salmon anaemia virus (ISAV) in experimentally challenged blue mussels *Mytilus edulis*. *Diseases of Aquatic Organisms* 74: 1-6.