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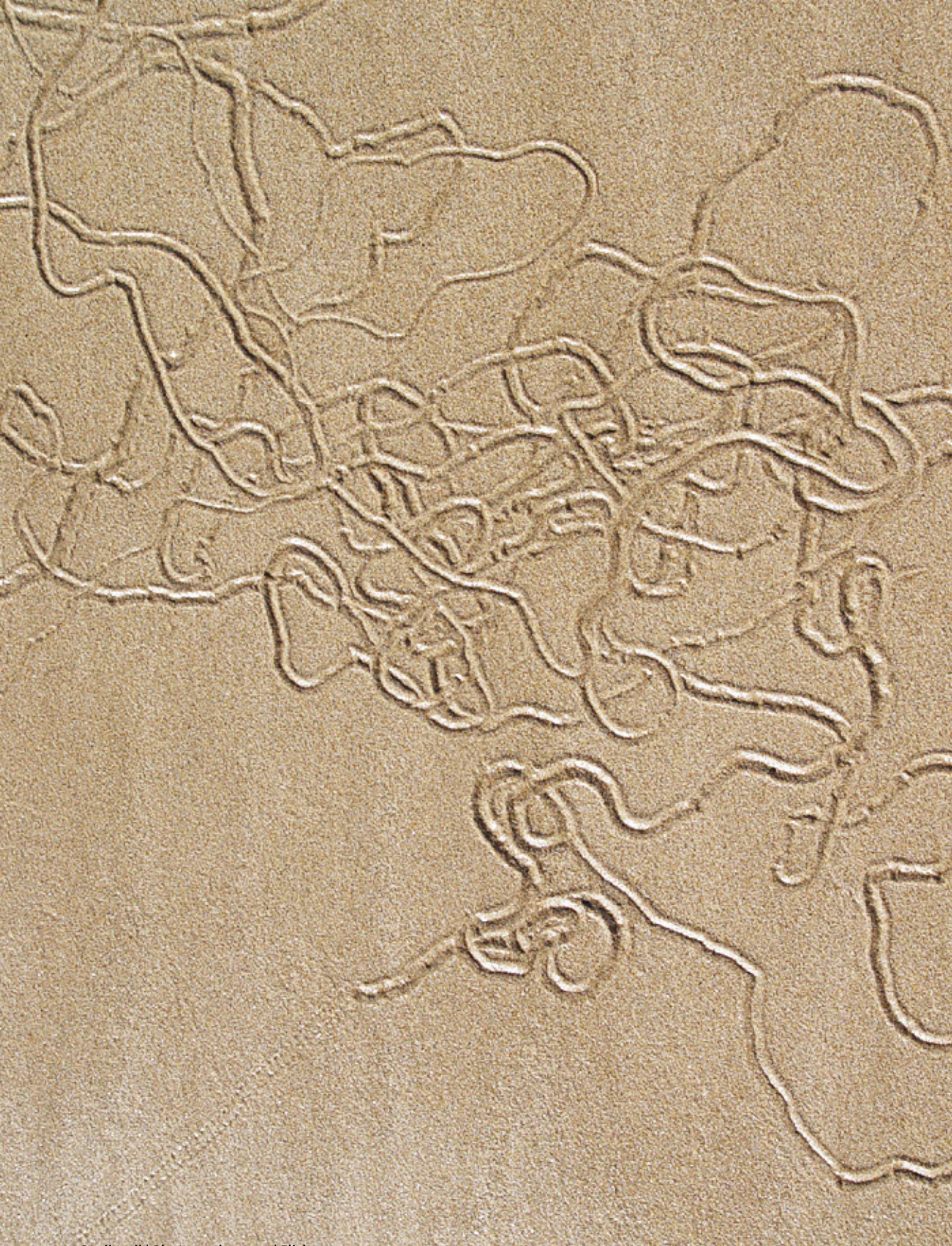


Snail trail | Photo: coda, 2007 | Flickr cc

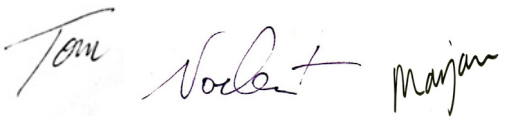
These are turbulent political times, particularly in the western democracies, where established orders and principles are being challenged by a wave of reactionary populism. Long simmering embers of dissatisfaction and resentment have flashed into flame in several countries, with the United States being the most consequential. Whether this flame will be cleansing, as adherents hope, or irrevocably destructive, as opponents fear, remains to be seen.

What is clear, however, is that reflection on basic values and beliefs has been brought to center stage for the citizens of these countries as not seen in decades. In that sense, all activities have become political. Witness the planned march on Washington of U.S. scientists scheduled for April 22, 2017, the traditional Earth Day. The main message from these usually apolitical professionals: facts and science, matter.

We at ZQ feel compelled to re-affirm our beliefs, starting with an echo of the sentiment that will be carried to Washington in April. The search for truth, either in science or art, is more important than ever. Collaboration and working together are the keys to success. Nature's abundance, restorative power, and awe-inspiring complexity should be honored, studied, and preserved, so that everyone, no matter what background, can benefit from her bounty and live a peaceful and prosperous life.

This issue celebrates the search for nature's secrets, whether it is deciphering the communication of birds, as Heidi Fischer recounts the work of wildlife biologist Erick Greene, or the serendipitous discovery of a common molecular structure seen in a moment in Sir Harold Kroto's illustrious career, or in the photographic reduction of the mechanics of flight, as pursued by artist Xavi Bou. We also interview those who translate these lessons to useful applications: Thierry Chopin about his work in aquaculture, and Brook Kennedy about his Macronaut lens for your mobile phone.

We hope you find your own re-affirmation in these inspiring stories. Happy reading! ×



Tom McKeag, Norbert Hoeller and Marjan Eggermont

Seaweed strand

Photo: robanhk, 2008 | Flickr cc

Interview

Thierry Chopin

Dr. Thierry Chopin was born and educated in France. He obtained his Doctorate from the University of Western Brittany, Brest, France. He moved to Canada in 1989 and is presently a Professor in the Department of Biological Sciences at the University of New Brunswick in Saint John, Canada. He is the Scientific Director of the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) (http://www2.unb.ca/chopinlab/index.html). Integrated Multi-Trophic Aquaculture (IMTA) is the practice which combines, in appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish) with inorganic extractive aquaculture species (e.g. seaweeds) and organic extractive aquaculture species (e.g. shellfish/other invertebrates/herbivorous fish) to create a balanced ecosystem management approach to aquaculture for environmental sustainability (nutrient biomitigation and other ecosystem services), economic stability (product diversification, risk reduction and job creation in coastal communities) and societal acceptability (better management practices and improved regulatory framework).

Dr. Chopin is Past President of the Aquaculture Association of Canada, the Phycological Society of America and the International Seaweed Association. He is an advisor to the International Foundation for Science, in Stockholm, and a member of the Editorial Boards of the journals *Aquaculture International, Perspectives in Phycology, European Journal of Phycology, Journal of Applied Phycology* and *Aquatic Living Resources*. Dr. Chopin is also Honorary Consul of France and was awarded the distinctions of Chevalier in the Ordre National du Mérite and in the Ordre des Palmes Académiques.

Thierry Chopin with dried samples of sugar kelp (*Saccharina latissima*)

Photo: Amélie Gosselin

How did you get started in integrated aquaculture?

My specialties are the physiology and biochemistry of seaweeds, which are the large marine algae. There are approximately 10,500 species of seaweeds, distributed among the red, brown and green algae. In Brittany, France, my doctoral dissertation was on the impact of phosphorus and nitrogen in seawater on the production in red algae of carrageenans, which are sugars used in the food, pharmaceutical and many other industries. I came to New Brunswick in 1989 and continued to work on seaweeds. I got progressively involved with aquaculture in the Bay of Fundy. Salmon aquaculture was in full development and fish excrete large quantities of inorganic dissolved nitrogen and phosphorus, which could have a significant impact on the marine habitat. Seaweeds feed off these nutrients, suggesting that integrating seaweeds with salmon aquaculture could create a bioremediation system to help balance nutrient cycles.

Dr. Shawn Robinson of Fisheries and Oceans Canada, in St. Andrews, was also interested in exploring how shellfish and other invertebrates consumed organic solid salmon farming by-products, recreating trophic cycles found naturally in the environment. We learned that mus-

Low tide along the shore of the Bay of Fundy, Canada: the brown kelps and red dulse are covering the lower intertidal zone | Photo: Thierry Chopin

sels, suspended in the water column, preferred small organic particles, while sea urchins, sea cucumbers and lobsters on the ocean floor preferred larger particles.

What do you see as the major opportunities for aquaculture?

We face major challenges feeding a human population that is not only growing but is also seeking greater dietary diversity. At the same time, we need to reduce the pressure on remaining fish stocks. Aquaculture has been growing rapidly, delivering almost half the world's seafood, but has developed a controversial reputation in some parts of the world due to high density operations, environmental degradation, algal blooms, and the increased risk of disease. IMTA can help address many of the environmental impacts of aquaculture.

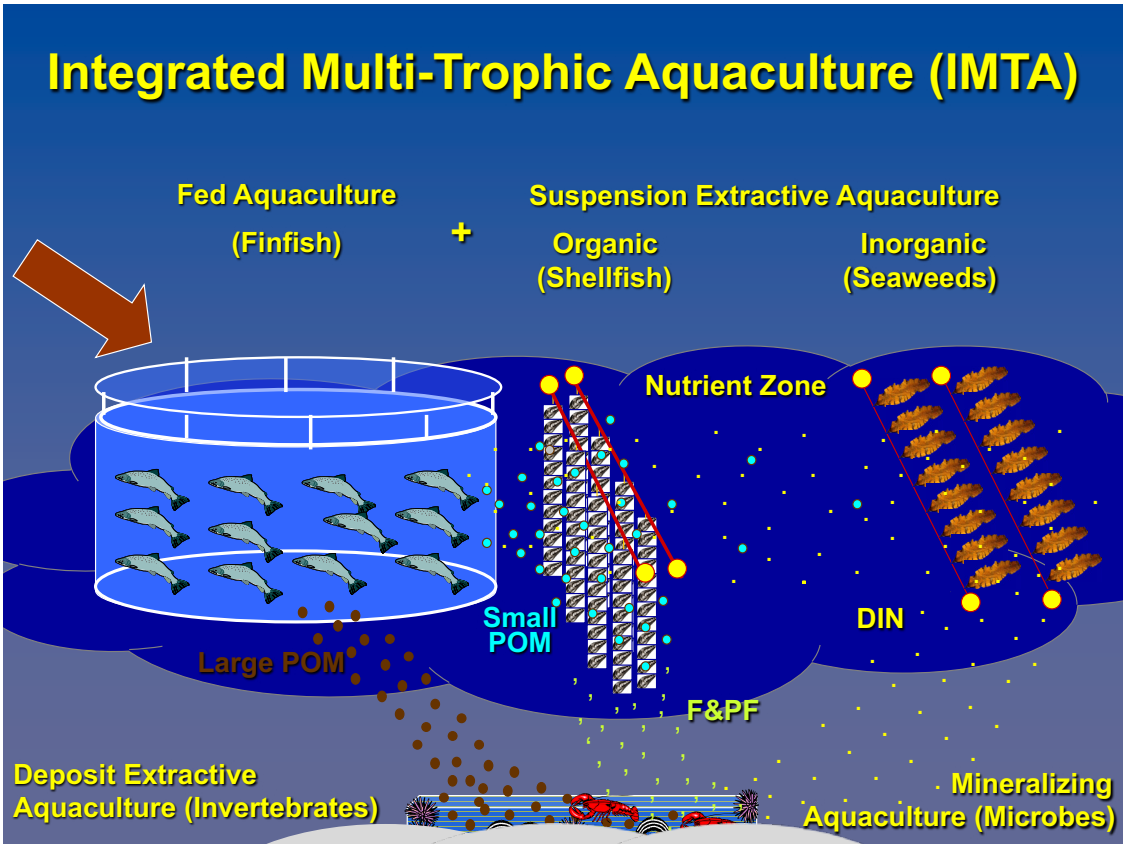
In addition, IMTA can diversify and broaden the salmon aquaculture industry away from a monoculture model, improving business cases, increasing resilience and improving the societal acceptability of this industry. Farmed shellfish already has an established market in the western world. Seaweeds, mostly cultivated and used in Asia for human consumption, can be used in many applications from feed for sea urchin, abalone and fish farming to a source of high-value products in the pigment, cosmetic and nutraceutical industries. Seaweeds can also have an impact on climate change by sequestering carbon dioxide and decreasing coastal acidification. Shellfish hatcheries are noticing increased mortality in larvae which cannot properly calcify their shells. It would be interesting to combine seaweed and shellfish aquaculture operations where seawater would go through seaweed tanks first to reduce acidity, before being piped into the mussel tanks where it would help larvae calcify properly. The IMTA multi-crop diversification approach (fish, seaweeds and invertebrates) could be an economic risk mitigation and management option to address pending climate change and coastal acidification impacts. To give seaweeds and IMTA their full value, extractive species must be valued for not only their biomass and food trading values, but also for the ecosystem services they provide (circular economy approach). The value of these ecosystem services should be recognized, accounted for and used as financial and regulatory incentive tools (for example, the development of a nutrient trading credit system).

IMTA could also be a model of benign aquaculture practices compatible with activities in Marine Protected Areas, where local human populations could find sustainable employment, instead of being uprooted to allow development of reserves for well-off tourists. Aquaculture ecotourism would go a long way toward helping the aquaculture industry gain societal trust.

IMTA systems could also be associated with offshore wind farms for a combined, reduced footprint.

What are the major challenges facing IMTA?

Aquaculture tends to be highly specialized. Western marine biologists tend to focus on animals - few are familiar with seaweeds and their benefits. Implementing IMTA requires collaboration across a wide range of disciplines and in-



IMTA concept: 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, decapodes 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 and microbial mineralization on the bottom regenerates more DIN, which becomes available to the seaweeds.
Illustration: Thierry Chopin

dustries, but inter-disciplinary collaboration can be inhibited due to differences in language and experimental methods.

Funding inter-disciplinary research can be challenging. The Natural Sciences and Engineering Research Council (NSERC) does not generally support social scientists, while the Social Sciences and Humanities Research Council (SSHRC) does not support natural scientists. Although I have found that novel solutions frequently appear at the interface between disciplines, universities are also often internally structured into silos. Early career natural scientists may also be concerned that publishing papers with economists and social scientist could affect their CV when the time comes for a promotion.

Regulations governing aquaculture are often designed with a single species/group of species in mind, just like fishery regulations, and can inhibit a more holistic approach by not considering species interactions and an ecosystem-based management approach. For example, we were told early on that our IMTA project would be a nice academic project, but would not be allowed to go commercial. What, then, would be the incentives for the aquaculture industry to get involved with IMTA, or change its practices, if the products could not go to market? We were inheriting an unrelated regulation that would not allow growing any species closer than 125 meters from a wharf or a sewage effluent. Consequently, we would not be able to grow one species closer than 125 meters from another. It took us eight years of accumulating data to reverse 12 lines banning polyculture in the Canadian Shellfish Sanitation Program and now have two pages allowing Integrated Multi-Trophic Aquaculture, if the proper monitoring program is in place.

We need other regulatory changes if we want to implement IMTA at the appropriate scale. We need enabling and flexible regulations for the development and implementation of innovative aquaculture practices, using an integrated coastal area management (ICAM) strategy.

How have you overcome these challenges?

In 2009, we found a structure, the NSERC Strategic Network program, that, while mostly supporting natural science research, allows around 20% joint efforts with economic and social scientists. We were successful with our funding request that supported the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) from 2010 to early 2017 - 28 scientists in eight universities, six federal laboratories, one provincial laboratory and four industry partners on the east and west coasts.

Based on my experience with the Atlantic Innovation Fund from the Atlantic Canada Opportunities Agency from 2006 to 2012, and with NSERC from 2010 to 2017, very small players struggle to implement the necessary systems, while large players, who need IMTA the most, prefer to focus on their core business, typically salmon. Small and medium-sized enterprises (SMEs) seem to be the most interested – they are flexible and innovative and want to differentiate themselves, particularly as their industries are affected by consolidation.

We were also fortunate because we attracted innovative students. We wanted to cultivate sea

cucumbers that would be among the species recycling the large organic particles falling to the sea floor. However, sea cucumbers are famous for being "Houdinis of the sea" and can easily escape from cages. If you make the cages with a very fine mesh material, they do not receive the food they are supposed to process. A student from British Columbia thought literally outside the box and designed one with an open top with lids that flapped from the weight of the sea cucumbers, discouraging them from getting out.

Training highly qualified personnel (HQP: undergraduate, Master and PhD students, postdoctoral fellows, technicians and research scientists) was a very high priority for CIMTAN. The initial and ambitious target of training 114 HQP over the entire life of the Network was exceeded, as 137 HQP were trained. Our CIMTAN HQP have either pursued higher academic degrees or found jobs in a variety of sectors (academic institutions; federal/provincial departments and laboratories; aquaculture and feed companies; engineering, consulting and financial companies; renewable and power networks; non-governmental organizations, museums and municipal authorities), where they are appreciated for their inter-disciplinary training and approaches to problem solving.

Our HQP are also fantastic ambassadors of IMTA at their workplaces and will gradually change some attitudes, especially in regulating agencies. For IMTA to be implemented and scaled up, we still need to address some serious regulatory hurdles. We need a major rethinking regarding the functioning of an "aquaculture farm". It does not work only within the limits of a few buoys on the water, but should be managed using an integrated coastal area management (ICAM) strategy, according to the movement of the different elements considered:

- large particulate organic nutrients should be managed within the site;

- small particulate organic nutrients should be managed within the site or around its immediate vicinity;

- dissolved inorganic nutrients should be managed at the ICAM scale (as is already accepted for managing disease vectors and parasites).

This means that different strategies (in space and time) will be needed to recover these different nutrients, and that entire bays/coastal areas/regions should be the units of IMTA management. It is, indeed, opening the Pandora's box of regulations. Harmonization and coordination between provincial and federal regulations and between departments and agencies will also be needed.

How has your work developed?

In September 1995, I gave a presentation entitled "Mixed, integrated, poly-, or multi-level aquaculture - whatever you call it, it is time to put seaweeds around your cages!" at a conference. I could see several faces in the room saying "What is this guy talking about?"

From 1995 to 2000 was the period of "preaching in the desert". We started to be taken seriously when we joined AquaNet, the Network of Centres of Excellence for Aquaculture in 2001. In March 2004, at a workshop in Saint John, New Brunswick, we gave a name to what we were doing. I came up with "Integrated Aquaculture"

A line of sugar kelp (*Saccharina latissima*) at an IMTA site in the Bay of Fundy, New Brunswick, Canada | Photo: Thierry Chopin

The principles of marine IMTA (MIMTA) can also be applied to land-based, freshwater systems (FIMTA), also called aquaponics. Yarrow, mint, lettuce, chamomile and nasturtium after six weeks of growth at 13-15°C in effluent collected at a commercial salmon hatchery. | Photo: Thierry Chopin

and Jack Taylor (Fisheries and Oceans Canada) with "Multi-Trophic Aquaculture". By combining the two, "Integrated Multi-Trophic Aquaculture", or "IMTA", was born and in 12 years more than 1,300 publications referring to IMTA have been published worldwide.

Over the years, we have been progressing along the continuum from R (Research) to D (Development) to c (small scale commercialization), hoping to soon enter C (larger scale commercialization). Here too, we need to think outside the box. We need to change our attitudes and business models to evolve from the linear approach (one species – one process – one product), used far too often with fishery and aquaculture products, towards the Integrated Sequential Biorefinery (ISBR) approach (one species – several processes – several products). This fits very well with the circular economy approach, in which by-products are no longer considered wastes but co-products, which can be valued in other applications. Seaweeds can be used in the production, on one hand, of a wide range of bio-based, high-valued products (food and feed products/ingredients/supplements, biopolymers, fine and bulk chemicals, agrichemicals, biostimulants, pharmaceuticals, cosmeceuticals, nutraceuticals, functional foods, biooils, botanicals, pigments) and, on the other hand, of lower-valued commodity energy carrying molecules for heat and power (biofuels, biodiesels, biogases, bioalcohols) and biomaterials.

I started my own company, Chopin Coastal Health Solutions Inc., in July 2016 to conduct consulting on IMTA in Canada and abroad and to develop some products, especially seaweed-based ones.

What insights have you developed?

IMTA was never conceived with the idea of being viewed only as the cultivation of salmon, kelps, blue mussels and other invertebrates, in temperate waters, and only within the limits of existing finfish aquaculture sites. That's how we started in Canada, to have access to conducting experiments at sea rather than extrapolating from small tank experiments in laboratory conditions, which is always dangerous. We know that IMTA systems will continue to evolve.

Because the IMTA concept can be applied worldwide to open-water and land-based systems, marine and freshwater environments, and temperate and tropical climates, there is no ultimate IMTA system to feed the world. Different climatic, environmental, biological, physical, chemical, economic, historical, societal, political and governance conditions will lead to different choices in the design of the best suited IMTA systems.

It is not enough to consider multiple species (like in polyculture); they have to be at multiple trophic levels based on their complementary functions in the ecosystem. They should also have an economic value.

Integration should be understood as cultivation in proximity, not considering absolute distances but, instead, connectivity in terms of ecosystem functionalities at the ICAM scale.

Regulators should be engaged early on as trends start to appear, rather than developing regulations that are not well though-out at the last minute, as this will delay commercialization.

How has IMTA changed you?

It is interesting to note the evolution, over three decades, in the type of conferences I have been attending: from seaweed-oriented to aquaculture-oriented scientific conferences, and most recently, to conferences attended by decision-makers and influencers such as "Bacon and Eggheads Breakfast" on Parliament Hill in Ottawa, Capitol Hill Ocean Week in Washington, and the Monaco Blue Initiative (http://www.monacoblueinitiative.org/) under the auspices of H.S.H. Prince Albert II.

For me, it is time to make the "Blue Revolution" mature into the greener "Turquoise Revolution" where production activities are no longer in conflict with the environment but protect it. IMTA definitely has its place in the circular economy, in Canada and beyond.

What key messages do you have for the practice of bio-inspired design?

Take advantage of nature's trophic relationships and reinforce the use of its ecosystem services within a circular economy approach.

Favour the inter-disciplinary approach because most problems can be solved at the interfaces of the various disciplines.

Demonstrate value at multiple levels (environmental sustainability, economic stability and societal acceptability) and for the long term.

Bring regulators to the table early on to develop open relationships that can work together towards effective regulations that enable new practices, new industries and establish new markets.

Nurture projects that combine pure and applied research to solve real-world problems and deliver meaningful results.

Explore trends to identify opportunities for diversification in a sector. Aquaculture production in Atlantic Canada has, historically, focused on finfish (mostly salmon and trout), which has been decreasing in recent years. Therefore, if we still want to talk about "aquaculture development", the "development" will need to involve other species.

Be patient, determined and persistent. Science and society need time to think and evolve. IMTA will not happen overnight, especially in the western world, which presently prefers monocultures, linear processes, and short term profits.

Which work/image have you seen recently that really excited you?

A picture of a very simple and efficient freshwater IMTA/aquaponics system in a village in northern Brazil. These people are very ingenious with almost nothing; they really know how to recycle. I hope to spend part of my sabbatical leave next year with Dr. Janaina Mitsue Kimpara from the Brazilian Agricultural Research Corporation (EMBRAPA), who is supporting this project and others involving seaweeds and marine IMTA.

What is your favorite inter-disciplinary work of all time?

I was involved with a project in Senegal several years ago, where every winter large amounts of the red seaweed, *Hypnea musciformis*, washed ashore and decayed, which is not good for tour-

ism. To address the issue, we needed to find out where the seaweeds were coming from. I heard some strange hypotheses from academics at the University of Dakar suggesting that they originated from the Cape Verde Islands, which would mean that the seaweeds (still in very good shape) must have drifted some 700 km. Travelling along the Petite Côte, we stopped in a village with massive red seaweed biomass stranded on the village beach. Through a translator, I talked to an old fisherman who claimed that the red seaweeds were coming from "where the rocks change colours." The academics had warned me that talking to these villagers would be a total waste of time. I suggested we arrange to have a fisherman take us to these rocks changing colours with a pirogue. After a few miles of shallow sandy bottom, the slope of the continental shelf abruptly changes and there are large rocky formations covered with seaweeds, which prefer to grow on stable substrates rather than unstable sandy formations.

For me, it remains my best example of gaining an understanding of a "mystery" by an interdisciplinary approach and the rewards of sometimes leaving the ivory tower and accepting that traditional knowledge can also be valuable. Having worked on another red seaweed, Irish moss (*Chondrus crispus*), on Prince Edward Island, I had experienced ocean floors covered with purplish seaweeds in the winter that turn pale pinkish in the summer, due to the denaturation of the red pigments (phycobilins) by solar radiations in shallow waters.

Irish moss (*Chondrus crispus*) with bleached parts due to the denaturation of the red pigments (phycobilins) by solar radiation.

Photo: Thierry Chopin

What is the last book you enjoyed?

"La fin des haricots & autres mystères des expressions françaises" by Colette Guillemard. This book explains the origin, and the evolution through the centuries, of the meaning of 134 common expressions of the French language. Very interesting, intriguing, funny, and highly revealing of the period when they were created.

Who do you admire? Why...

I wanted a profession close to the sea because I loved sailing. So, why not become a marine biologist? But what type of marine biology? I was interested in genetics but that field was just expanding into marine biology and it was difficult to find a supervisor. I took a phycology course (phycology is the study of algae) by Dr. Jean-Yves Floc'h at the University of Western Brittany. He was interesting, passionate, captivating and enjoyable and that's how it started.

When I moved to North America, I completed a postdoctoral fellowship at Harbor Branch Oceanographic Institution in Vero Beach, Florida. My supervisor there was Dr. Dennis Hanisak, who became my second mentor. Dennis Hanisak not only cultivates seaweeds; he inoculated deeper

On the right, Steven Backman (owner of Magellan Aqua Farms Inc.) and, on the left, Thierry Chopin holding a spool with a twine covered with microscopic kelps being unwound around a rope to be put at sea. In six months, the rope will be covered with 2-3 m long kelps. | Photo: Caroline Longtin

in me the bug to become active in associations, which I had started to develop in France with my involvement in the renowned sailing centre, the Centre Nautique des Glénans. That's how I became involved with the Phycological Society of America, the International Phycological Society, the Aquaculture Association of Canada and the International Seaweed Association, which has been a wonderful journey of work, responsibilities and fun!

My father was also a great source of inspiration. A dedicated pediatrician with a great humanist approach to education and life, a type of individual that will, unfortunately, soon be on the endangered species list.

What's your favorite motto or quotation?

My wife made a wonderful sign for me this last Christmas:

Eat fish, live longer

Eat oysters, love longer

Eat seaweeds, live and love even longer

I have another favorite, from the French writer Jules Verne: "Tout ce qui est impossible reste à accomplir" or "All that is impossible remains to be accomplished".

More than ever, the good old adages "what is waste for some is gold for others" and "don't put all your eggs in the same salmon basket" apply to IMTA and crop diversification.

What is your idea of perfect happiness?

A world where common sense would be common and an 11th beatitude would be added:

"Blessed are those who can laugh at themselves, for they will not stop laughing."

If not a scientist/designer/educator, who/what would you be?

A scientific writer/translator. I have always thought that my two most important publications would be a children's book and a coffee table book on seaweeds, adapted to the respective audience, to show how beautiful these organisms can be, why they are so important in many respects, why we should not continue to ignore them, and what they can do for us and the planet. But, I need to find the time to write these books... maybe a retirement project! ×

Eat seaweeds: Maybe the new motto of the company created by Thierry Chopin, Chopin Coastal Health Solutions Inc.

Photo: Thierry Chopin

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