Integrated Multi-Trophic Aquaculture (IMTA): responsibly farming our waters by taking advantages of ecosystem services within a circular economy approach.

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Saint John, N.B., Canada
September 1995: conference in St. Andrews, New Brunswick, Canada
“Mixed, integrated, poly-, or multi-level aquaculture - whatever you call it, it is time to put seaweeds around your cages!”

1995-2000: “preaching in the desert” period
Differentiate our practice from monoculture
Obvious term: polyculture
However, cultivating three species of fish together, does not address the problems of co-cultivating three fed species together

October 31, 2003: Chopin first ever mentioned Integrated Multi-Trophic Aquaculture at the Aquaculture Association of Canada Annual Meeting in Victoria, BC, Canada

March 2004: workshop in Saint John, New Brunswick, Canada

Integrated Aquaculture + Multi-Trophic Aquaculture = Integrated Multi-Trophic Aquaculture (IMTA)

Since, more than 1,400 publications on IMTA have been published
But the practice is much older...

~ 2200-2100 BC  “You Hou Bin” detailed integration of fish with aquatic plants and vegetable production in China

~ 2000 BC  Earliest representation of Nile tilapia grown in integrated agriculture-aquaculture drainable ponds, with floating plants and fruit trees, on the Tomb of Thebaine in Egypt

~ 500-1848 AD  Ahupua’a integrated agriculture-aquaculture freshwater to marine farming systems in Hawaii

~ 1600 AD  Château de Fontainebleau in France self-sufficient castle 65 km south of Paris royal FIMTA: carp pond of Henri IV (1553-1610)
Integrated Multi-Trophic Aquaculture (IMTA)

Fed Aquaculture (Finfish) + Suspension Extractive Aquaculture

Organic (Shellfish) + Inorganic (Seaweeds)

Deposit Extractive Aquaculture (Invertebrates)
Mineralizing Aquaculture (Microbes)

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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 is how we started in Canada, in order to be able to conduct experiments at sea, within the limitations of the regulations presently in place, rather than extrapolating from small tank experiments in laboratory conditions, which may not reflect what really occurs in the environment.

This is only one of the variations on the central/overarching IMTA theme. But, there are many variations on IMTA.
This is also IMTA...

integrated agriculture aquaculture (IAA)
This is also IMTA…

integrated green water aquaculture (IGWA)

integrated biofloc aquaculture (IBFA)
This is also IMTA...

freshwater IMTA (FIMTA) or aquaponics

CIMTAN FIMTA
IMTA site in the Bay of Fundy, New Brunswick, Canada
IMTA does not mean that fish have to be part of the system
This is also IMTA... Sanggou Bay, China
This is co-cultivation of seaweeds and invertebrates
Agricultural run-offs

Land-based aquaculture run-offs
Magellan Aqua Farms Inc. – sea scallops
Chopin Coastal Health Solutions Inc. – seaweeds
Fed species vs. extractive species

- Exogenously fed (feed given by humans) = fed species
- Endogenously fed (feed already present in the ecosystem) = extractive species

Dunbar et al. (2020) proposed excretive species vs. extractive species Please, NO!

- All organisms feed on something and excrete something (including invertebrates and seaweeds)
- What would be the fate of an organism if it was not excreting? Sooner or later, it would become internally toxified and/or explode

So, let’s be clear

- Endogenously fed extractive species rely on feed already present in the ecosystem (even if partially originating from the co-products of the co-cultured exogenously fed species in IMTA systems)
- So, there is no “zero-input” food; there is no free lunch!
Western world groups working on IMTA have spent two decades developing small-scale/pre-commercial, IMTA operations by modifying fish sites to co-cultivate invertebrates and seaweeds (the FIS approach; 70-80’s / 00’s / 00’s).

Commercial scaling-up has not been easy: while the biological and environmental advantages of this practice are generally accepted, adoption barriers have been mostly economic and regulatory.

Asian countries have a long tradition of using different IMTA systems. The modifying site approach has been diametrically opposed: seaweed sites have seen the development of smaller invertebrate, and later fish, infrastructures (the SIF approach; 50’s / 80’s / 90’s), within vast dedicated areas.
A major rethinking is needed regarding the functioning of an “aquaculture farm”

Western IMTA has generally developed within the restrictive limits of existing finfish sites, which does not reflect the ecosystem scales at which aquaculture farms really function.

Because different nutrients (small particulate organic nutrients, large particulate organic nutrients, dissolved inorganic nutrients) need to be recaptured, different spatial and temporal strategies should be designed.

The “Integrated” in IMTA should be understood as cultivation in proximity, not considering absolute, and often arbitrary, distances (500 m, 1 km or 5 km), but considering the connectivity of water bodies and sediments in terms of ecosystemic functionalities.
A major rethinking is needed regarding the functioning of an “aquaculture farm”

This means that the different components of an IMTA system do not have to be right at the same location, but that entire bays / coastal areas / regions could be the units of IMTA management, within an Integrated Coastal Area Management (ICAM) strategy, hence challenging traditional aquaculture regulations/policies.

The placement of the different components of an IMTA system, and the scale at which it will be managed, will certainly trigger changes to regulations, as they were designed without IMTA in mind in most countries.

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.
We know that IMTA systems should and will continue to evolve because the IMTA concept is extremely flexible and 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.

**IMTA is a concept, not a formula**

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 or potential.

Nothing says that only one company should be in charge / producing all the IMTA components. There may need to be several companies coordinating their activities within the ICAM.
Until now, seaweeds (and the other extractive species) have been valued only for their biomass and food trading values.

However, to calculate IMTA’s full value, they also need to be valued for the ecosystem services they provide, along with the increase in consumer trust and societal/political license to operate that they give to the aquaculture industry (circular economy approach).
Ecosystem services provided by seaweeds

- Seaweeds are excellent nutrient scrubbers (especially dissolved nitrogen, phosphorus and carbon)

- With IMTA, seaweeds can be cultivated without fertilizers and agrochemicals
Mentalities will have to change

What were previously considered wastes, or by-products, of one species are now co-products, which can be used as recovered fertilizer and feed resources, and energy, by other species, considered additional crops providing economic diversification in more efficient and responsible food production systems, while bioremediation of coastal nutrification takes place.
IMTA is more than a story of nutrients
Ecosystem services provided by seaweeds

- Seaweeds are excellent nutrient scrubbers (especially dissolved nitrogen, phosphorus and carbon)
- With IMTA, seaweeds can be cultivated without fertilizers and agrochemicals
- Seaweeds do not need to be irrigated
- Seaweed cultivation does not need more arable soil and land transformation (deforestation)
- Seaweeds can be used for habitat restoration and for increasing biodiversity (you can have more habitat and eat it too!)
Ecosystem services provided by seaweeds

- Seaweeds is the aquaculture component providing O₂, while the other animal and microbial components consume O₂

- Seaweeds “sequester” carbon dioxide >>> slowing down global warming

- By “sequestering” carbon dioxide, they could also reduce coastal acidification
Ecosystem services provided by seaweeds

- 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, hence increasing the resilience of the aquaculture sector.
Increasing the societal/political license to operate (increasing aquaculture societal acceptability)

- Seaweed cultivation (and IMTA systems) could be associated with wind farms, in integrated food and renewable energy parks (IFREP), for a reduced cumulative footprint by combining the two activities.
The value of these important services to the environment and, consequently, society are, however, never accounted for in any budget sheet/business plan of seaweed farms and companies.
So, let’s calculate the economic value of just the nutrient bioremediation services provided by the world seaweed aquaculture production.
The value of the ecosystem services provided by the extractive components of IMTA systems will have to be recognized, accounted for and used as financial and regulatory incentive tools.

For example: **seaweeds** 32.4 million tons  US$13.3 billion

<table>
<thead>
<tr>
<th>Composition</th>
<th>NTC</th>
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<tbody>
<tr>
<td>0.35% N</td>
<td>US$10-30 kg(^{-1})</td>
</tr>
<tr>
<td>0.04% P</td>
<td>US$4 kg(^{-1})</td>
</tr>
<tr>
<td>3.00% C</td>
<td>US$30 t(^{-1})</td>
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>>> Ecosystem services: at least US$1.214 billion to US$3.482 billion

*i.e. as much as 26.2 % of their present commercial value*

>>> Developing a system of **nutrient trading credits**
There is more money to be made with nutrient trading credits (NTC) than with carbon trading credits (CTC)

Nitrogen trading credits: between US$1.134 and 3.401 billion

Phosphorus trading credits: US$51.82 million

Carbon trading credits: US$29.15 million
The recognition and implementation of NTC would give a fair price to seaweed and extractive aquaculture. They could be used as financial and regulatory incentive tools to encourage single-species aquaculturists to contemplate innovative practices, such as IMTA, as a viable alternative to their current practices.
We need to integrate the economic and societal aspects of IMTA

- 11 publications (theses and papers) on the economic value and benefits of IMTA between 2007 and 2019
A discounted cash-flow analysis of salmon monoculture versus IMTA in eastern Canada (Carras et al. 2019)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Comparison $\text{NPV}<em>{\text{IMTA}}$ versus $\text{NPV}</em>{\text{SM}}$ (5 and 10 % discount rates)</th>
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<tbody>
<tr>
<td>- no price premium</td>
<td>$\text{NPV}<em>{\text{IMTA}} &gt; \text{NPV}</em>{\text{SM}}$ by 5.9 and 5.7 %</td>
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<tr>
<td>- no loss of salmon harvest</td>
<td></td>
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<tr>
<td>- 10 % price premium on IMTA salmon and mussels</td>
<td>$\text{NPV}<em>{\text{IMTA}} &gt; \text{NPV}</em>{\text{SM}}$ by 26.3 and 27.3 %</td>
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<tr>
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<td>$\text{NPV}<em>{\text{IMTA}} &gt; \text{NPV}</em>{\text{SM}}$ by 9.5 and 9.4 %</td>
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<tr>
<td>- loss of salmon in Year 6</td>
<td></td>
</tr>
<tr>
<td>- 10 % price premium on IMTA salmon and mussels</td>
<td>$\text{NPV}<em>{\text{IMTA}} &gt; \text{NPV}</em>{\text{SM}}$ by 36.5 and 38.6 %</td>
</tr>
<tr>
<td>- loss of salmon in Year 6</td>
<td></td>
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<tr>
<td>- one-time 10 % decline in salmon market price sustained over a 10-year period</td>
<td>$\text{NPV}<em>{\text{IMTA}} &gt; \text{NPV}</em>{\text{SM}}$ by 7.3 and 7.2 %</td>
</tr>
<tr>
<td>- 2 % drop/annum in salmon market price</td>
<td>$\text{NPV}<em>{\text{IMTA}} &gt; \text{NPV}</em>{\text{SM}}$ by 7.4 and 7.2 %</td>
</tr>
</tbody>
</table>

In all scenarios, IMTA is more profitable than salmon monoculture.
We need to integrate the economic and societal aspects of IMTA

- 11 publications (theses and papers) on the economic value and benefits of IMTA between 2007 and 2019

The aquaculture industry always tell us “show us that IMTA makes sense economically”
All these studies are based on numbers provided by the industry
So, you wonder why they do not accept them readily and adopt IMTA more rapidly…

- Intangible societal benefits of IMTA

> Gaining consumer trust and societal and political license to operate (increasing aquaculture societal acceptability)
New York consumers are generally indifferent in their opinion of farmed fish and overwhelmingly support an IMTA approach.

Current attitude toward farmed fish

- Completely Positive: 6%
- Mostly Positive: 28%
- Indifferent: 48%
- Mostly Negative: 14%
- Completely Negative: 4%

Consumer opinion of IMTA

- Completely Support: 16%
- Mostly Support: 72%
- Mostly Oppose: 9%
- Completely Oppose: 3%
We need timely and enabling regulatory changes instead of the current hampering regulatory hurdles.

In several countries (including Canada and Norway) aquaculture legislation has been built around salmon farms, particularly to combat diseases in intensive monocultures. It is now clear that these regulations may inadvertently prevent innovation in aquaculture practices.
IMTA contributes to the UN Sustainable Development Goals
We should realize that we are still in the infancy of western IMTA (after all, we have been improving agriculture for centuries and it is still not perfect).

Science and society need time to think and evolve.

The adoption of IMTA will not happen overnight, especially in the western world, which presently prefers monocultures, linear processes and short-term profits.

We will need patience, determination and persistence to get people to see the environmental, economic and societal advantages of growing complementary species together, creating circular economy processes and seeking sustainability in the long term.

First battery electric car: Prius (development since 1993; first sales in 1997)
First hydrogen fuel cell car: Mirai (development since 1992; first sales in 2014)
But still not predominant vehicles – No real incentives and refueling logistics issues

The new horizon for Toyota is 2050. What will it be for IMTA?
Seaweed: A Planet-Saving, Anti-Burping Drug For Cows

Seaweeds are having their moment

Could Seaweed Help Save Us From Climate Catastrophe?

I hope it is more than a moment…

Seaweed are nature’s climate warriors
Cultivating them at scale could counteract ocean acidification, climate change and loss of biodiversity
Seaweed could provide food security for millions

Will seaweed save the world?

Seaweed 'forests' can help fight climate change without risk of fire

Seaweed feeding the world

Kelp: the ocean’s ecosystem engineer

Seaweed eats carbon; it is this benevolent resource and we should cover the world’s oceans with seaweed farms just for that reason alone. It’s like an end all be all carbon solution

Seaweeds: the underwater superheroes

Seaweeds: the Ocean hero, the “zero-input” food

Ride the seaweed wave; brand you sustainability goals with seaweed

I hope it is more than a moment…
It is also our collective responsibility to identify, and denounce the Silver Bullet Solution Salespersons, as we should remember that in between periods of promising the moon, there are periods of “purgatory” that are difficult for scientists and entrepreneurs who still believe in a rational development of the field, and could be avoided by reducing the rhetoric and sticking to the science.

Oil crises of 1973-79: Marine Biomass Project and the Gas Research Institute

35-40 years of “purgatory”

2015-….: seaweeds for biofuels, methane reduction, carbon sequestration, etc.

? years of “purgatory”
Restorative / regenerative aquaculture

The latest fashion… seaweeds and sea cucumbers are the new poster children of “benign aquaculture”, but:

- What needs to be regenerated?
- Regenerated to what state? Was there ever a climax state, or nirvana, of perfect nutrient balance and habitat for all without flux?
- Will too many extractive species, removing too many nutrients from the ecosystem, not become a problem?

>>> will we have to regenerate the regenerative aquaculture?

>>> there is a point when too much of a good thing (yes, including seaweeds and invertebrates) can be harmful

>>> old adage: everything in moderation

>>> and we are back to the IMTA concept!
At recent conferences, people talk a lot about the Blue Growth / Blue Economy / Blue Revolution. However, we should also recognize that it needs to become **greener**. It is, consequently, time we combine the two and we talk about the **Turquoise Growth**

**Turquoise Economy**

**Turquoise Revolution**

Thank you very much

*Muito obrigado*