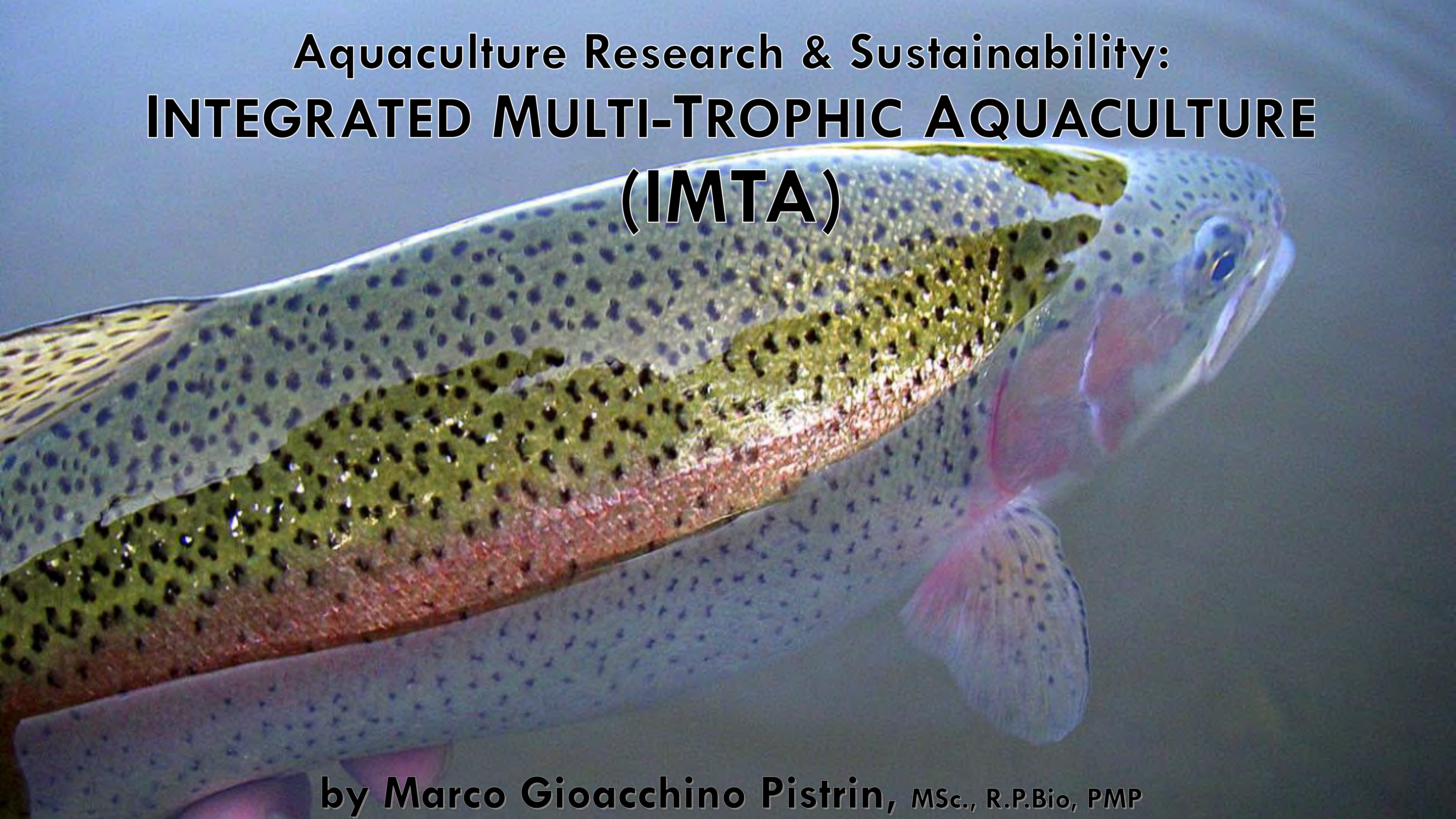
AQUA FARM

PORDENONE



Aquaculture Research & Sustainability:

INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA)

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Professional Background:

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Regione Sicilia – Assessorato Agricoltura, Sviluppo Rurale e Pesca Mediterranea

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Sustainability

WHY IS SUSTAINABILITY IMPORTANT IN AQUACULTURE?

Aquaculture is projected to be the prime source of seafood by 2030, as demand grows from the global middle class and wild capture fisheries approach their maximum take. When practiced responsibly, fish farming can help provide livelihoods and feed a global population that will reach nine billion by 2050. But for an aquaculture system to be truly sustainable, it must have:

- **Environmental sustainability —** Aquaculture should not create significant disruption to the ecosystem, or cause the loss of biodiversity or substantial pollution impact.
- **Economic sustainability —** Aquaculture must be a viable business with good long-term prospects.
- **Social and community sustainability —** Aquaculture must be socially responsible and contribute to community well-being.

Sustainable aquaculture is a dynamic concept and the sustainability of an aquaculture system will vary with species, location, societal norms and the state of knowledge and technology.

Fish Culture Practices

Monoculture:

This is the practice of culturing only one species of fish

Polyculture/Composite Culture:

This is the practice of culturing more than one species in the same aquacultural unit

Fish may exploit food at different trophic levels but traditionally the co-culture of different fish species is typically from the same trophic level.

Integrated Multi-Trophic Aquaculture (IMTA):

This mimics natural ecosystems. Integrating species from several trophic levels and RECYCLES waste-products.

- Sea-based IMTA (Net Pen – Open Ocean)

Salmon – Mussels – Sea cucumber – Kelp
→ Little control

- Land-based IMTA (RAS – Integrated)

→ **aka *IMRAS**
→ Aquaponics
→ Better control
→ Bio-filter in recirculating systems

- An example of this is cultivating sea-weed near mariculture fish pens. Nutrients in the fish waste aid in feeding the ubiquitous algae, which in turn can improve the water quality for fish.
- An example of this is cultivating other species downstream of the primary aquacultured species. Nutrients are retained in the RAS facility and by action of a multitude of plural and complementary organisms, nutrients are cycled and allow for a more profitable closed loop system

What is IMTA?

<u>Fed Aquaculture</u>:

- Open sea cages are potentially inexhaustible sources of organic wastes and are known to disperse these nutrients to the surroundings by current and tidal flows
- How do we take advantage of such an “expensive energy source”?

<u>Suspension Extractive Aquaculture – ORGANIC</u>

- Rafts of mussels are strategically anchored where they can potentially absorb small polluting particulate matter – such as fish faeces, uneaten fish feed and exogenous food sources carried by the tides

Suspension Extractive Aquaculture – INORGANIC

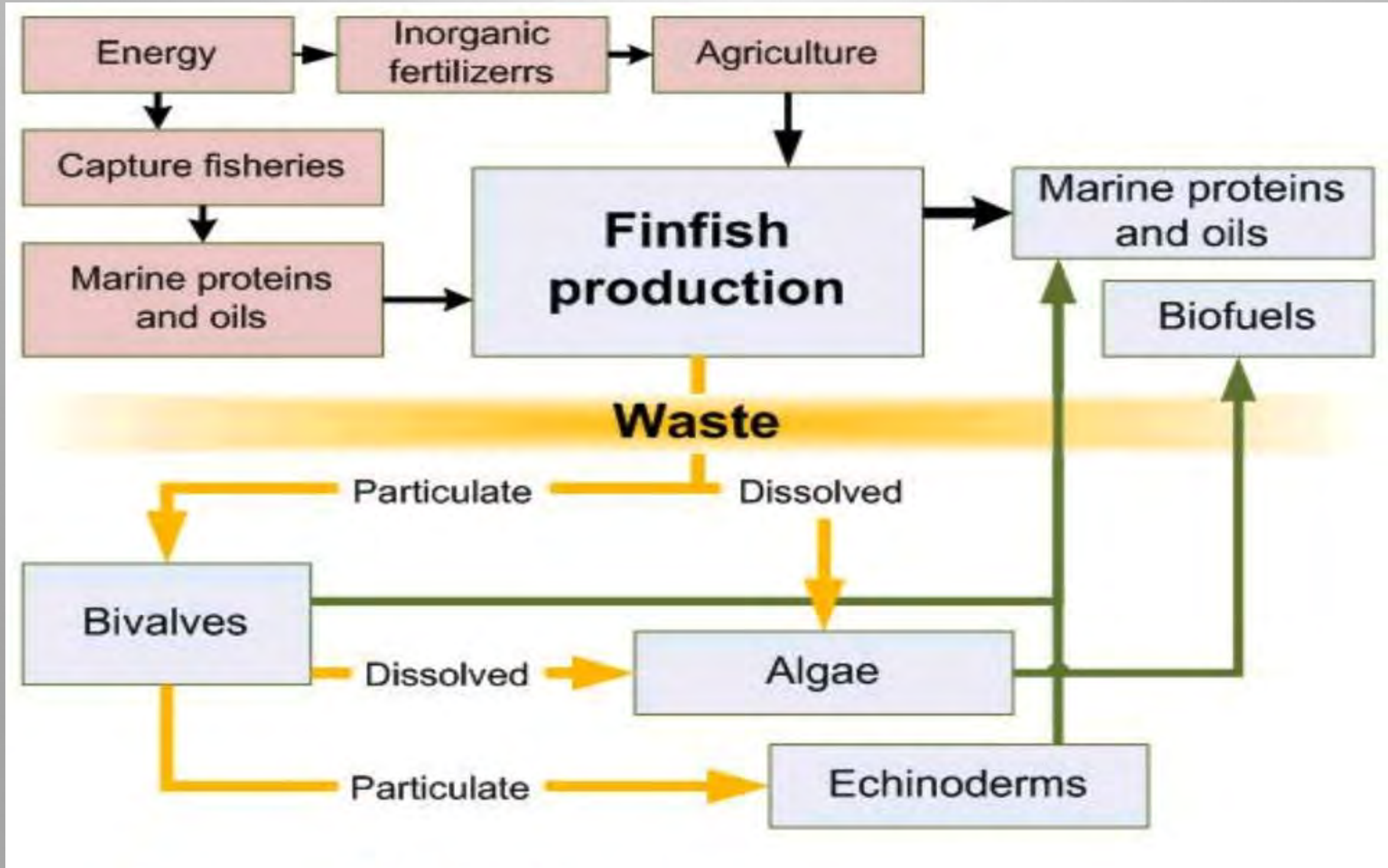
- Long-lines of seaweed extract inorganic nutrients, such as nitrogen and phosphorous, from the water and fish waste products.

"Multi-Trophic" refers to the incorporation of species from different trophic or nutritional levels in the same system.

What is IMTA?

Conceptual diagram of a "complete" marine IMTA system. Thickness of arrows roughly indicates the relative magnitude of carbon flow between trophic levels assuming minimal loss due to dispersion.

Salmonids



A diagram of the IMTA concept.

IDREEM, 2016

Macroalgae/Seaweed

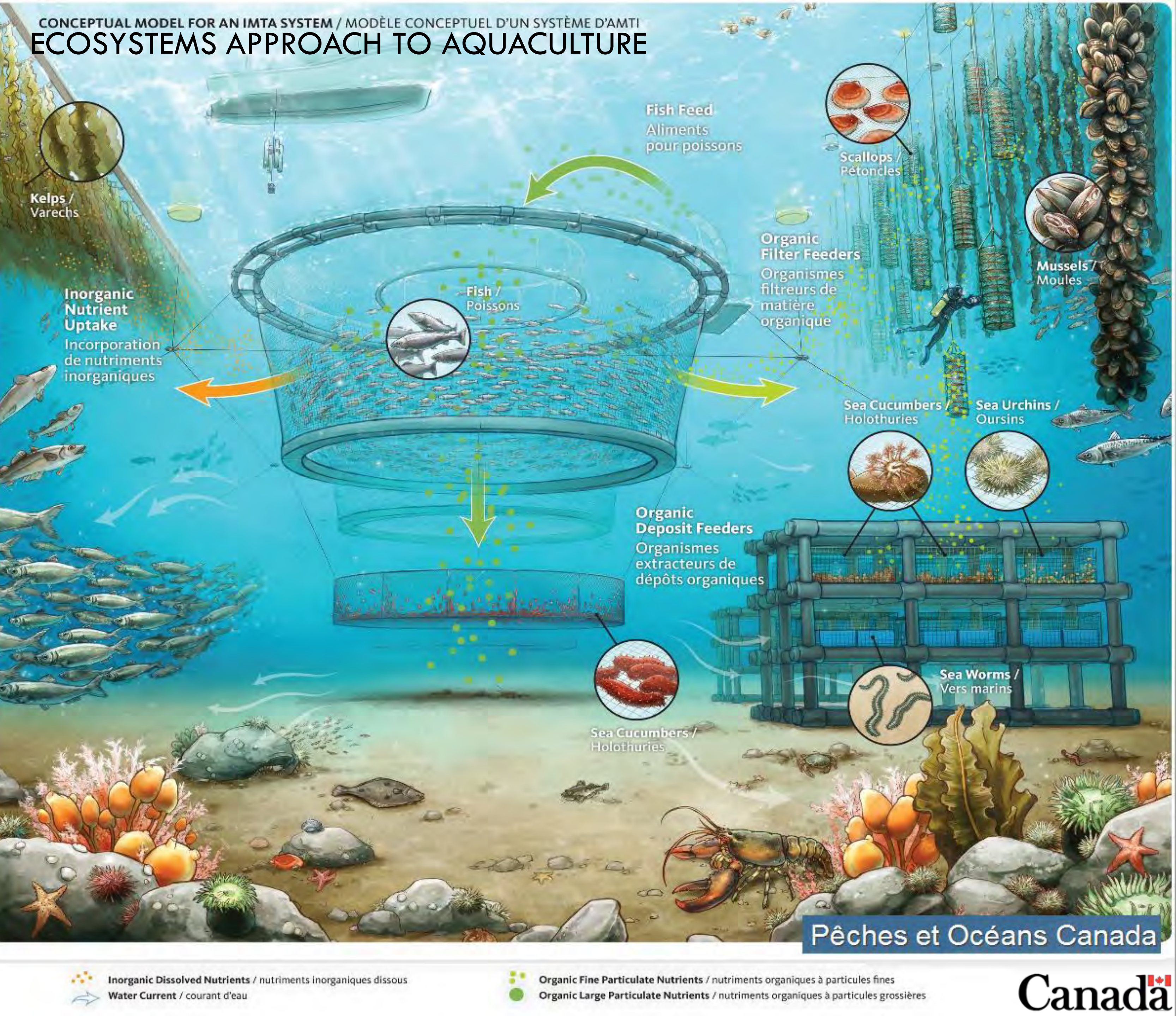
macroscopic, multicellular, marine algae

Malpeque Oysters

Mussels, clams, scallops, geoduck

Detritus feeders

Sea stars, Sea urchins, Sand dollars, Sea cucumbers, and Sea lilies



Aquaculture Comes Full-Circle!

Definition of IMTA (DFO Canada)

Integrated Multi-Trophic Aquaculture is a form of aquaculture in which organisms from different trophic levels, with complementary resource needs, are produced in the same system.

Typically, these aquaculture systems integrate the production of a *fed organism*, such as fish or shrimp, with that of *extractive organic aquaculture* such as shellfish and *extractive inorganic aquaculture* of seaweed (macroalgae)

CREATING VIABLE ECOSYSTEMS IS KEY TO SUCCESS IN IMTA

SWOT Analysis of IMTA

Strengths • Efficient use of marine space • Recycling of nutrients • Reduced feed demand producing extractive species • Increased crop diversity and overall productivity • Production with a "green" image • Maintain and expand marine activities in rural areas	

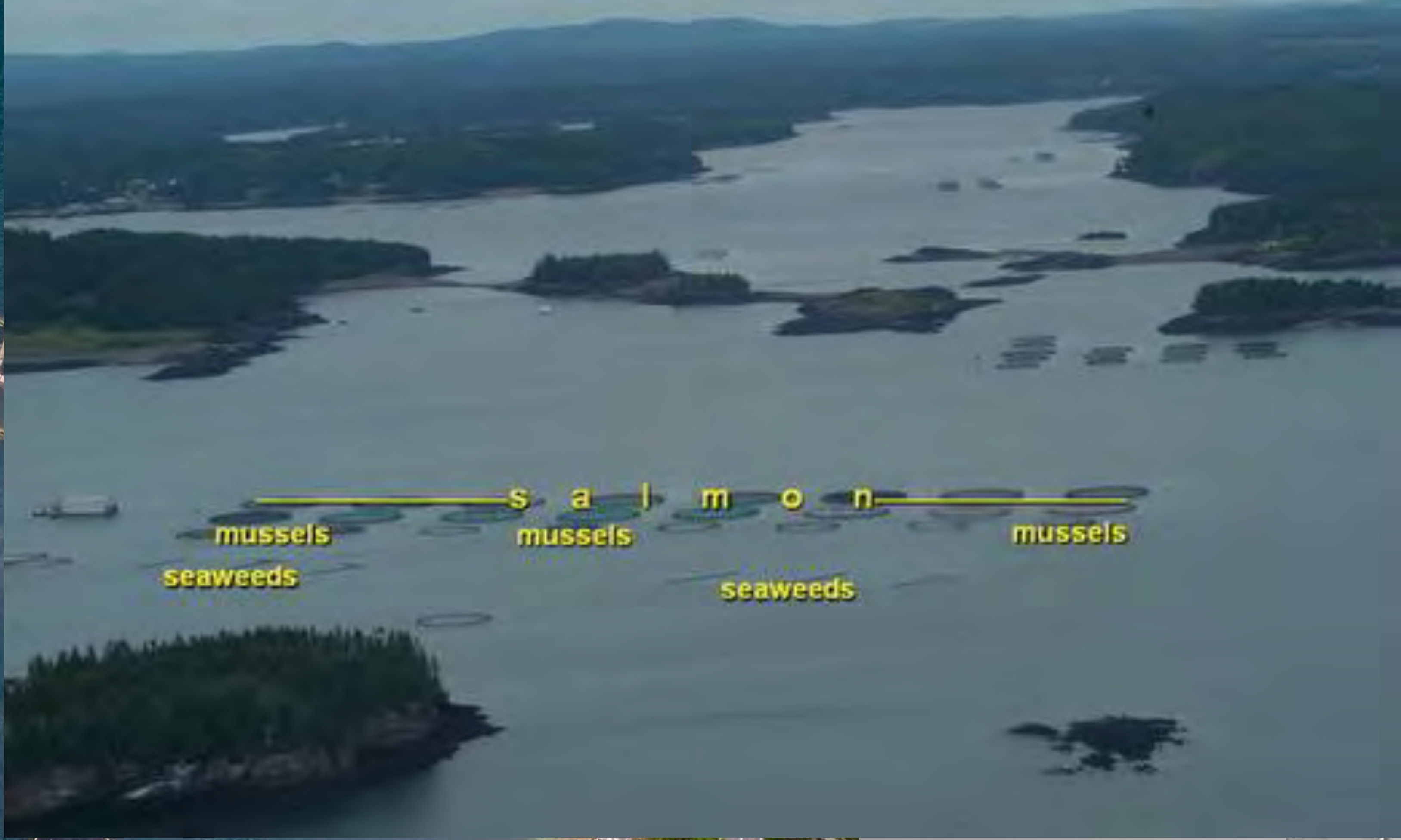
What is IMTA?

STUDY QUESTIONS

1. Are the *Extractive Species* simply assimilating exogenous wastes and potentiating the available energy sources directly from the operations surrounding the *Fed Species* or is this a matter of capturing nutrients by extractive species that are simply nutrients naturally present in the ecosystem?
2. Are all aquacultural waste inputs directly proportional to biomass accretion?
3. Is there a homogenous distribution of released Dissolved Inorganic Nitrogen (DIN) within a defined IMTA area and thus no further nutrient transfer possible?
4. Why have higher productivity of molluscs and seaweeds been observed in the vicinity of sea cages, and similarly there are indications that in open sea IMTA systems only a minor fraction (<5%) of the input nutrients ends up in other cultures.

TASMANIA, AUSTRALIA

BRITISH COLUMBIA, CANADA



IMTA Theoretical Outcomes

The desired IMTA design will achieve:

1. High bioremediation efficiency in a limited space,
2. Higher growth rates of extractive organisms than in monocultures
3. Increased farm revenues.

This way the developed IMTA system will provide both environmental and socioeconomic benefits and will thus contribute towards a more sustainable and productive form of aquaculture.

Figure 1: IMTA model outline. The model consists of five sub-models interconnected via relationships of nitrogen release and assimilation.

Estimates of the nutrient bioremediation potential and productivity of an IMTA consisting *FED SPECIES*, *ORGANIC EXTRACTIVE SPECIES*, and *INORGANIC EXTRACTIVE SPECIES* are calculated by:

- qualifying and quantifying the matter and energy flux within the IMTA and its surrounding environment.

Lamprianidou et. al 2018

Predictive Modeling at Sterling University: Scottish Sea-Sites

1. At a salmon monoculture site 38% of feed nitrogen (N) and 30% of feed phosphorous (P) is incorporated into fish biomass while the remaining nutrients are released to the environment.
2. The model predicts that a salmon farm producing 1000 t of salmon in an 18 month period, releases approximately 37 t of dissolved nitrogen during the at-sea stage of production
3. This is in agreement with the DIN release rate by salmon farms in Scotland, which ranges between 35 and 45 kg N t^{-1} of salmon produced (Davies, 2002).
4. During an 18 month production period 470 t of seaweed of the genus *Porphyra* can be harvested, by harvesting in a way that sustains the total biomass to maximum 50t wet weight at all times.
5. This way, 35.4 t of dissolved nitrogen can be assimilated by the seaweed biomass and removed from the ecosystem via the process of seaweed harvesting.
6. Consequently, the addition of seaweed, of the genus *Porphyra*, to a salmon culture system increases the dissolved nutrient retention of feed N by 80.2%.

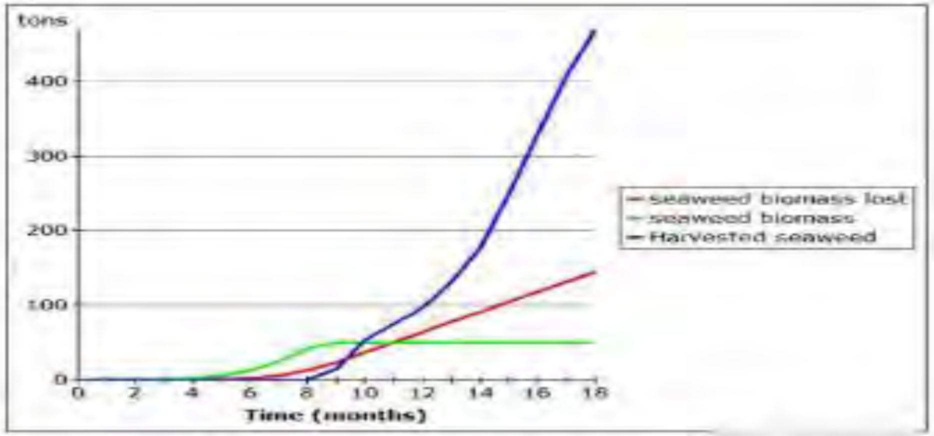


Figure 2: Model output depicting the cumulative biomass of harvested seaweed and of seaweed lost due to natural causes as well as the fluctuation of seaweed biomass during an 18-month period.

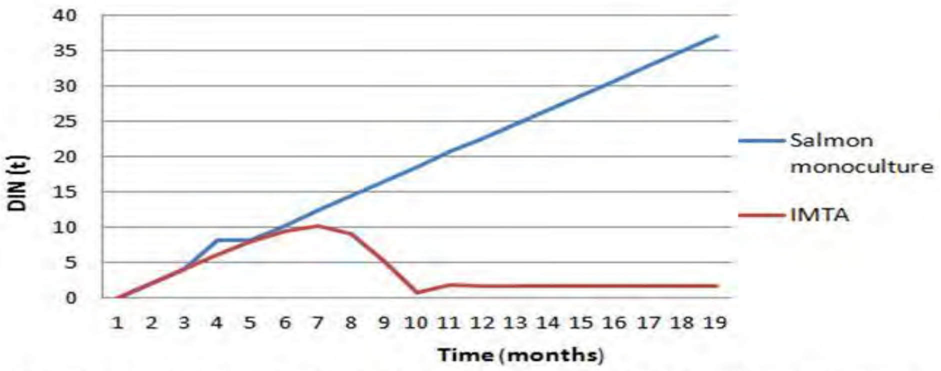
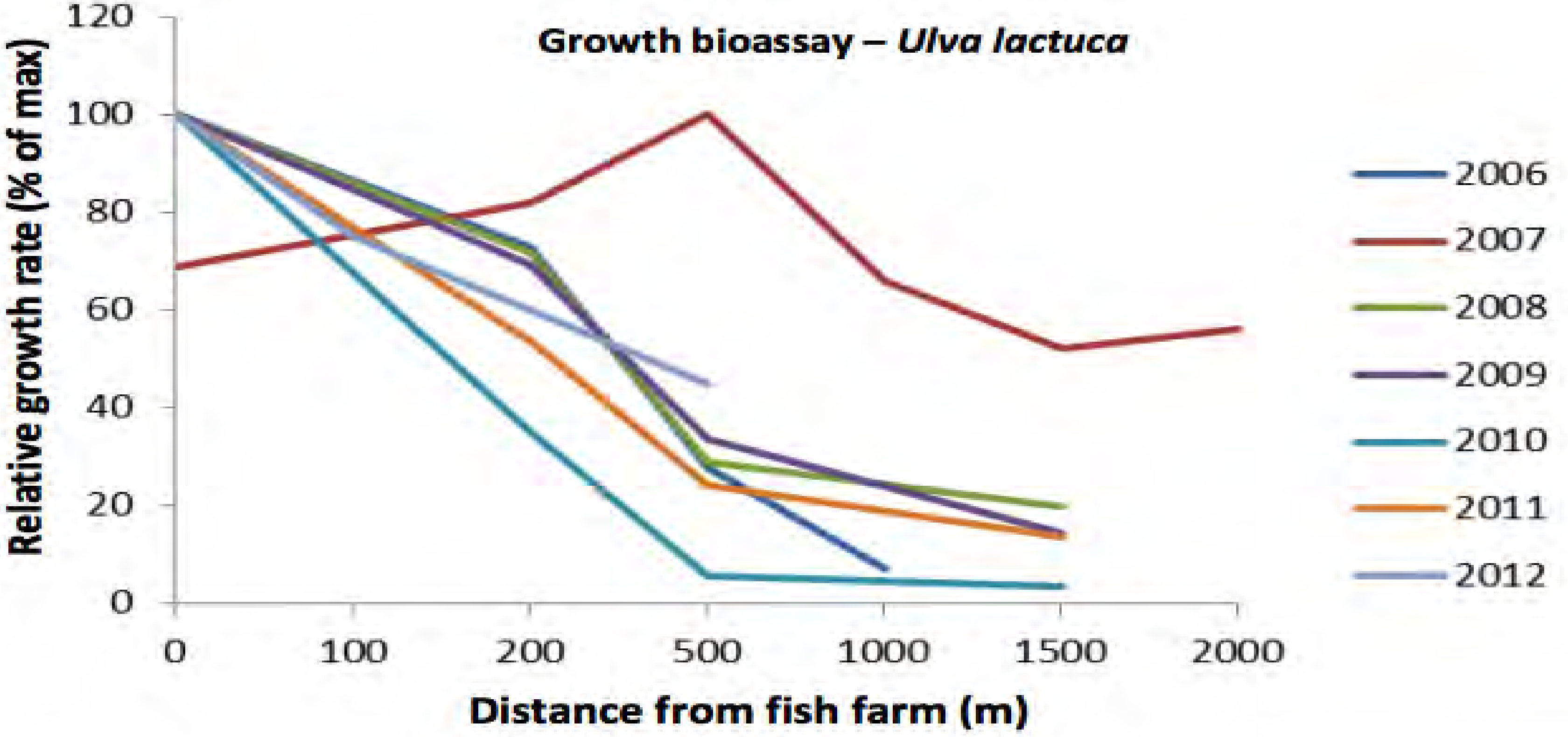


Figure 3: Model output depicting the difference in Dissolved Inorganic Nitrogen accumulation within 18 months at a salmon farm site and at a closed system IMTA.

Lamprianidou et. al 2018

Macroalgae Growth in Proximity to Fish Farms



ALGAE GREW LESS VIGOROUSLY THE FARTHER THEY WERE FROM FISH FARMS

Figure 4 *Growth response of Ulva lactuca deployed – in triplicate - at increasing distance (north of fish farm along the dominant current direction). Max growth rates varied between 0.08 – 0.26 d^{-1} (average 0.18). All bioassays were carried out in September when feeding intensity and NH_3 excretion was maximal (≈ 325 kg NH_3-N). Data from DHI (2013). Bioassay is detailed in Lyngby & Mortensen (1994).*

mermaidproject.eu 2012

Lumpsucker (*Cyclopterus lumpus*)

→ Revolutionizing salmon farming

Norway

These bulbous little suckers are popular at birthday parties in Japan and their roe makes an inexpensive alternative to caviar. But they are also great pest managers on salmon farms, replacing the sometimes toxic parasiticides used to kill sea lice. These *sustainability-focused* salmon farms who invest in the Lumpsucker also harvests and processes them into fish oil

Commercial Aquaponics = IMRAS

Aquaponics systems are recirculating aquaculture systems that incorporate the production of plants without soil.

It is becoming increasingly popular, with more people finding innovative ways to produce multiple crops in their recirculating systems.

Commercial Aquaponics → It has NEVER BEEN MORE difficult to MAKE GOOD Financial return

You need to augment your costs with your profit…that it why it is CRUCIAL that HIGH-VALUE species are selected

- Fish may be: Murray Cod, Arctic Char (other high-value salmonids), sturgeon, hybrid Striped Bass…
- These plants may be a crop (e.g. Basil, mint, rosemary, *Salicornia sp.*, tomatoes or watercress) or ornamental (e.g. *Aster tripolium, Mesembryanthemum crystallinum,* orchids, nasturtium…) Alternatively the nutrients may be used to create micro-algal and zooplankton blooms in ponds which can be harvested (e.g. *Spirulina sp.*) or may feed other fish species that graze on these blooms.

* IMRAS

Integrated Multi-trophic Recirculating Aquaculture Systems

Porrazzito, Sicilia

- Essentially the newest approach in aquaculture in the 21st century is to develop the necessary parameters for the design and construction of Land-based Integrated Multi-trophic Recirculating Aquaculture Systems (IMRAS) using fresh, brackish, or salt water.

- Modern technical filter technologies and long practiced hydroponic systems are combined in a very efficient, hygienic and sustainable way with almost any exchange of water. The reduction of exchanging process water makes the systems ecologically more sustainable and economically more successful.

Efficacy of Land-Based IMTA & RAS

*IMRAS

Integrated Multi-trophic Recirculating Aquaculture Systems

Universidad Católica del Norte

Centro de Producción de Semillas de Abalón, Coquimbo, Chile

On a Land-Based RAS Research Facility in Chile:

- Studies have demonstrated the inherent negative impacts of salmon farming. New studies have invariably addressed the environmental, social, and economical advantages of salmon-abalone-seaweed integrated cultivation.
- Thus, consolidation of salmon and abalone farming as an environmentally responsible aquaculture process is highly necessary, and implies an enormous opportunity for the industry to be recognized as one with positive environmental consequences, an especially important goal in places where aquaculture is closely related with salmon farming and its negative environmental impacts of the three two decades.
- The results confirmed high uptake efficiency during the entire year, equivalent to a 100% removal of the $\mathbf{NH_4}$, $\mathbf{NO_3}$, and $\mathbf{PO_4}$ produced by the land-based abalone culture, alone.

Macchiavello. *et al.*, 2014

Efficacy of Land-Based IMTA & RAS

*IMRAS

Integrated Multi-trophic Recirculating Aquaculture Systems

SALTWATER AQUAPONICS

- Gunning (2016) showed that ***Salicornia europaea*** cultivated in an aquaponic unit with oyster (***Crassostrea virginica***) farm wastewater grew very successfully at low to moderate salinities (i.e., a freshwater/seawater mix containing 33%–66% seawater) and significantly reduced the levels of ammonia, nitrite, nitrate, and phosphate in the wastewater

- Boxman et al. (2016) evaluated the capacity for water treatment and production requirements of two halophytes, Sea Purslane (***Sesuvium portulacastrum***) and Saltwort (***Batis maritima***), when grown in an indoor, bench-scale recirculatory Salt-Water Aquaponics system with Platy fish (***Xiphophorus sp.***). They found that the presence of plants significantly contributed to nitrate removal, such that mean nitrate concentrations were 10.1 ± 5.4 mg/L in planted treatments in comparison to 12.1 ± 6.1 mg/L in the unplanted treatments. The use of coconut fiber as a medium for the plants resulted in a significantly lower mean level of nitrate in the water (9.78 ± 5.4 mg/L) in comparison to when expanded clay was Water 2016, 8, 598 19 of 37 used (12.4 ± 6 mg/L)

- Haines (1976), Neori et al. (2004), and Granada et al. (2015) found that ***H. musciformis*** grown with the effluent from various clam species mariculture grew approximately 5 times faster than growth in unaltered deep water and about three times faster than in surface water

Gunning *et al.*, 2016

Efficacy of Land-Based IMTA & RAS

*IMRAS

Integrated Multi-trophic Recirculating Aquaculture Systems

- Abreu et al. (2011) studied G. vermiculophylla tanks at a commercial, land-based intensive aquaculture farm producing 40 tonnes of turbot (Scophthalmus rhombus), 5 tons of sea bass (D. labrax), and 500,000 Senegalese sole juveniles (Solea sengalensis).

- G. vermiculophylla grew best at a stocking density of 3 kg·WW·m−2 and water exchange rate of 200 L·h −1 , producing 0.7 ± 0.05 kg·DW·m−2 ·month−1 , while removing 40.54 ± 2.02 g·m−1 ·month−1 of N. They calculated that in one year, this system could produce approximately 156 kg (DW) of seaweed and this biomass level would remove 8.8 kg of N.

- To attain 100% N removal efficacy, it was calculated that the tank area would need to be increased to 0.36 ha, considering the cultivation conditions are kept the same (i.e., stocking density of 3 kg·WW·m−2 , 1200 L tanks with a footprint of 1.5 m−2 , and a water exchange rate of 200 L·h −1).

Abreu *et al.*, 2011

Efficacy of Land-Based IMTA & RAS

*IMRAS

Integrated Multi-trophic Recirculating Aquaculture Systems

HALOPHYTES & AQUACULTURE

- Waller et al. (2015) investigated the feasibility of nutrient recycling from a saltwater (16 psu salinity) RAS for European sea bass (***D. labrax***) through the hydroponic production of three halophyte plants; ***Tripolium pannonicum***, ***Plantago coronopus***, and ***Salicornia dolichostachya***

- Each plant species grew at a similar specific growth rate (SGR) of 9%–9.9%·day−1 . After the 35 day experimental period, both ***T. pannonicum*** and ***S. dolichostachya*** had reached marketable size with average shoot weights of 25 g and 60 g.

- The total production of plant material over the course of the experiment amounted to 6 kg, 4 kg, and 13 kg for ***T. pannonicum***, ***P. coronopus***, and ***S. dolichostachya***, respectively. The plants incorporated a total of 46 g N and 7 g P during the 35 day trial, equivalent to 9% N and 10% P that was introduced with the fish feed. For this system, it was estimated that 189 g of N resulted from fish excretion and if only the best performing halophyte (***S. dolichostachya***) was included, 1128 plants would be needed in a 14.4 m2 hydroponic area to remove all of this excreted N. During the 35-day trial, the sea bass grew from 32 g to 54 g on average, at a SGR of 1.5%·day−1 and exhibited an FCR of 0.93. The edible part of the harvested plant material was tested and found to be microbial safe and approved for human consumption

Gunning *et al.*, 2016

Successful Land-Based IMTA & RAS

Acadian Seaplants Ltd.

Fully-integrated, research-driven biotech manufacturer of unique cultivated sea-vegetables; and animal feed supplements, crop biostimulants and nutritional products derived from *Ascophyllum nodosum*.

COMMERCIAL FACILITY

Nova Scotia, Canada

Successful Land-Based IMTA & RAS

*IMRAS

Integrated Multi-trophic Recirculating Aquaculture Systems

AQUAPONICS

- ✓ Urban Organics is one of the largest and most advanced aquaponics facilities in the USA.
- ✓ The 110 year old Hamm's Beer Brewery building transformed 900m^2 of the space into a fully-operational indoor aquaponics farm which houses four 14,000L fish tanks with 7,000 Tilapia in total.
- ✓ Produce items being grown include basil, mint, watercress and lettuce.
- ✓ The monthly production rates for produce are 450–600 kg and the monthly fish harvest is 550–700 kg.

***** There is a 8,100m^2 facility being built by Urban Organics Pentair Group, LLC**

When complete, this will be one of the largest commercial aquaponics facilities in the world and will annually provide <u>125 Tonnes of fresh fish</u> and <u>182 Tonnes of organically grown produce</u>.

Environmentally Responsible Aquaculture

To Recap…

Studies show the negative impacts of nutrient pollution from open-ocean fish farming.

IMTA makes use of Marketable Extractive Species (MES) that impart SUSTAINABILITY into Aquaculture

Now we know the inherent value of imparting the use of MES in virtually any aquacultural technique…
These are:

- Seaweeds (halophytes, kelps and other macroalgae),
- Vegetables, Fruits, Tubers, Herbs, Flowers & Ornamentals
- Microalgae (*Spirulina sp.*)
- Suspension feeders (mussels, clams, and oysters),
- Deposit feeders (sea worms, lobsters, crayfish, shrimps, crabs, sea cucumbers, and sea urchins)

These are cultured in proximity of fish cages or downstream from culture tanks in an attempt to recycle the byproducts of each segment

The dissolved nutrients from the fish and shellfish are used by the macroalgae, while the solid particulate wastes serve as food for the shellfish and other invertebrates.

WASTES ARE RECYCLED ONCE SYSTEM MATURES

STILL, THERE IS MUCH TO BE LEARNED …



Economically Efficient Aquaculture

Monoculture is very <u>INEFFICIENT</u>!!!

- Aquaculture is invariably hard to make money, to be competitive and profitable, and to employ any measure of sustainability
- With high input costs and typically low return, it has never been more important to ensure procedural and economic efficiency is inherent in the business model
- Due to excessively high start-up, maintenance & input costs, RAS is even more so inefficient and any failure on any level can lead to financial ruin
- AS ANY GOOD ECONOMIST WOULD TELL YOU: THIS IS ESSENTIALLY A WAY YOU CAN DIVERSIFY YOUR AQUACULTURAL PORTFOLIO

→ Such a system can help limit the impacts of nutrient loading on a farm's surrounding ecosystem (or within RAS), while also offering economic stability and supplemental income from the sale of multiple products raised on (*or in proximity of*) the farm.

→ Potentiating the ability to offset the overall financial impact of monoculture, many benefits are evident to justify the use of IMTA

THANK YOU AQUAPONICS!!







Aquaculture Comes Full-Circle!

- Farming operations are notorious for using large quantities of wild fish to produce food.
- Today, grains and waste from fish processing plants have drastically reduced the amount of wild fish needed to feed farmed fish
- Sale of the fish, shellfish, sea urchins, lobsters, crab, sea cucumber…..
- The seaweed can be harvested and sold for food and cosmetic products
- Other than the high-value human food species, detritus-eating species such as sea-worms, can be used to formulate sustainable animal protein sources for fish feed
- Researchers are are also exploring whether the protein from seaweed can be used as a partial alternative to fish feed

Thus <u>CLOSING THE LOOP</u> in the farm system

Aquaculture Comes Full-Circle!

1. **Feed Alternatives -** Nutrient-extractive aquaculture appears to be a viable ecological engineering option for managing/internalizing some of the externalities generated by aquaculture operations. Moreover, **IMTA**, while not entering directly the debate regarding the inclusion of fishmeal and fish oil in commercial fish feeds, could provide a partial solution.

2. Modern commercial salmon diets contain much less fishmeal (15 to 25%) and fish oil (15 to 20%) than they did less than 10 years ago (40 to 60%). By-products such as trimmings and offal from wild catch fisheries are now used to supply a major portion of the fishmeal ingredients. Some non-governmental organizations arguing for fishmeal and fish oil replacement have also voiced concerns that, after all, marine fish should eat marine ingredients.

Obviously, one cannot have it both ways!

Aquaculture Comes Full-Circle!

3. **<u>Turning toward land plant proteins is not without its impacts</u>**. Extra farmland area would be required, which would likely increase deforestation and need to be irrigated on a planet already suffering from water availability problems. The price of some staple food crops like corn and soya used in traditional agriculture would rise considerably due to competition for their uses, as recently seen when they were sought as energy crops for the production of biofuels.

   - Notwithstanding there are potential **<u>negative impacts using soybean meal</u>** in salmonid diets → Soybean meal-induced intestinal changes (SBMIIC)
   - Several major findings prove that there is extensive cellular damage to the intestinal mucosa, compromised intestinal function and digestion, elevated mucosal IgM levels, impaired growth-rate, death, and an overall sense of malaise

4. **Partial substitution with organisms already living in water, such as seaweeds, could, in fact, be a very interesting option and fit well within the sustainability and management concept of IMTA.**




Is IMTA/IMRAS the Solution?

Is IMTA the "SOLUTION" that will consume all the anthropogenic wastes caused by fish farming?

No --- IMTA should be employed to gain efficiency in a system that did not have this beforehand
No --- IMTA is a way to employ justification for culturing seafood species

The invariable and sheer immensity of the ocean makes it difficult to account for IMTA's positive impact to down stream trophic levels and such…

On an immediate level, you can see that there are some reductions in waste … and by simple nature of the ecosystems approach we can rather easily see benefits multilaterally

~~~ MORE RESEARCH NEEDED ~~~
~~~

Final Thoughts

IMTA Systems are designed in order to:

1. Decrease the dependence of external inputs
2. Optimise the use of nutrients and energy in the production loop, in order to increase the system efficiency
3. Decrease the waste effluent and bio-deposit impacts by limiting the loss of nutrients (in water, sediments, and air)
4. Diversify farm-products and generate more robust sources of income (less dependent on mono-product markets)
5. Generate and use different types and levels of ecosystem functions and services

** The development of IMTA requires the identification of environmental and economic risks and benefits of such large-scale systems, compared with similarly-scaled monocultures of high trophic-level finfish in systems.

** The internalizing of economic, societal and environmental costs of finfish monoculture production by the bioremediative services of extractive species in IMTA offshore systems continually needs to be examined and analyzed.

** The results of such investigations will help determine the practical value of adopting the IMTA approach as a strategy for the development of offshore aquaculture.



* Aquaculture Projects *

* Superior-Quality Seafood Imports *

* Business Development *

* Consulting Services *

* Product Sales *

* Installation *

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FAIT AU CANADA

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