integrate

Integrate Aquaculture: an eco-innovative solution to foster sustainability in the Atlantic Area

IMTA systems in the open sea

BARRIER-LOISEAU Chloé
GROSJEAN Camille
LACHERY Briac

AGROCAMPUS OUEST
20th December, 2019

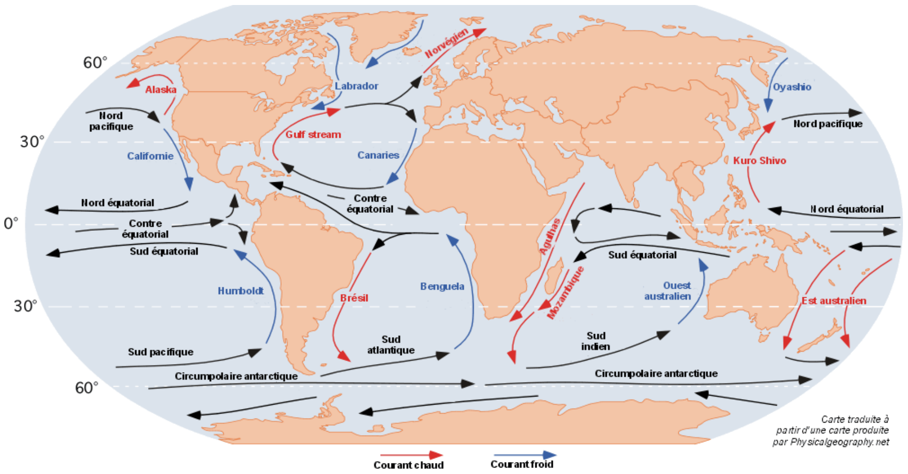
Interreg
Atlantic Area
European Regional Development Fund

EUROPEAN UNION

AGRO CAMPUS OUEST
Pôle halieutique

IMTA systems in the open sea

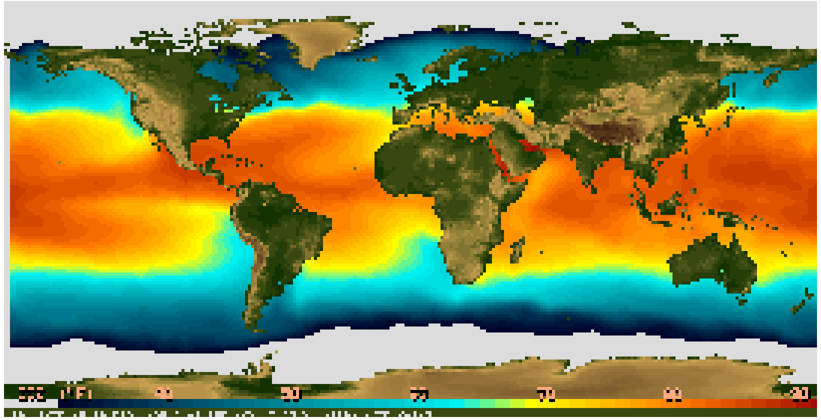
Open ocean → more parameters to consider compared to other IMTA systems (hydrography, currents …)



Carte traduite à partir d'une carte produite par Physicalgeography.net

Tidal Currents

7ème Continent - E-monsite



Oceanography and hydrology of the habitat

lecalve.univ-tln.fr

Temperate climate : latitude between 23.5° and 66.5° for both hemispheres.

Water temperature between 7 and 25°C.

Particularity of IMTA systems in the open sea

The physical and chemical parameters of the environment cannot be as controlled as in the others IMTA land-based systems.

As a consequence, the whole point is to develop production units adapted to local conditions

≠ considering species separately.

Technical characterisation

FISH

e.g.: Atlantic Salmon (*Salmo salar)*, Sablefish (*Anoplopoma fimbria*)

→ fed

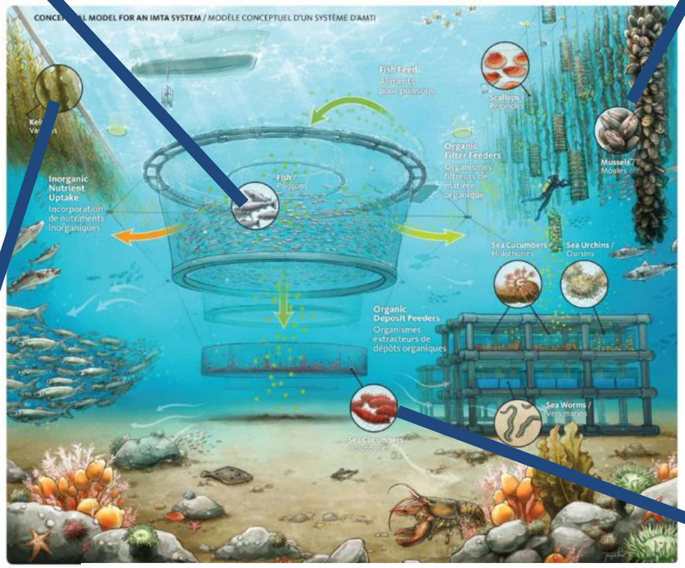
→ produce organic and inorganic waste

SEAWEEDS

e.g.: Sugar Kelp (*Saccharina latissima*), Winged Kelp (*Alaria esculenta*)

→ extract dissolved inorganic nutrients

→ must be placed a little further away to better capture the inorganic dissolved nutrients



©Pêche et Océans Canada

FILTER FEEDERS

e.g.: Blue Mussel (*Mytilus edulis*), Japanese Scallop (*Mizuhopecten yessoensis*)

→ reduce the level of finer organic particles

→ ingest substantial amounts of organic wastes from the surface layer of bottom sediments

DEPOSIT FEEDERS

e.g.: Green Sea Urchin (*Strongylocentrotus droebachiensis*), California Sea Cucumber (*Parastichopus californicus*)

→ recycle the larger organic particles (uneaten feed, faeces)

Open sea IMTA system

Environmental analysis - Nitrogen

Measurements are not easy to obtain in open-water studies. These deal mostly with uptake rates which are based on nutrients contained in seaweed proteins (Troell et al., 2003).

Datas in an open-water IMTA system:

2.3–4.4 kg of dissolved nitrogen removed **per kg of kelps** (*Alaria esculenta* and *Saccharina latissima)* near a fish farm of Atlantic salmon (*Salmo salar*) (Reid et al., 2013)

80% of nitrogen (produced by a 1500T salmon farm) can be removed by a 100 ha *Gracilaria* farm (Buschmann et al., 2008)

4.3% of particulate nitrogen removed by deposit feeders co-cultured with Chanos (Watanabe et al., 2015)

1.4% of solid nitrogen removed by deposit feeders (Chary et al., 2020)

Environmental analysis - Phosphorus

Fish farm cages release phosphorus → increase phosphate concentrations in water, which is the right form of phosphorus for growth of seaweed (Lobban and Harrison, 1994; Neori, 1996; Chopin and Wagey, 1999 in Troell et al, 2003)

Datas in an open-water IMTA system:

70.4% of phosphorus removed from water by *Gracilaria lemaneiformis* (Mao et al., 2009).
1.5% of solid phosphorus removed by deposit feeders (Chary et al., 2020).

Environmental analysis - Organic matter

The **concentration of surface phytoplankton** is correlated to the amount of organic matter in water.
Suspension feeders are able to exploit **suspended organic matter**.

Datas in an open-water IMTA system:

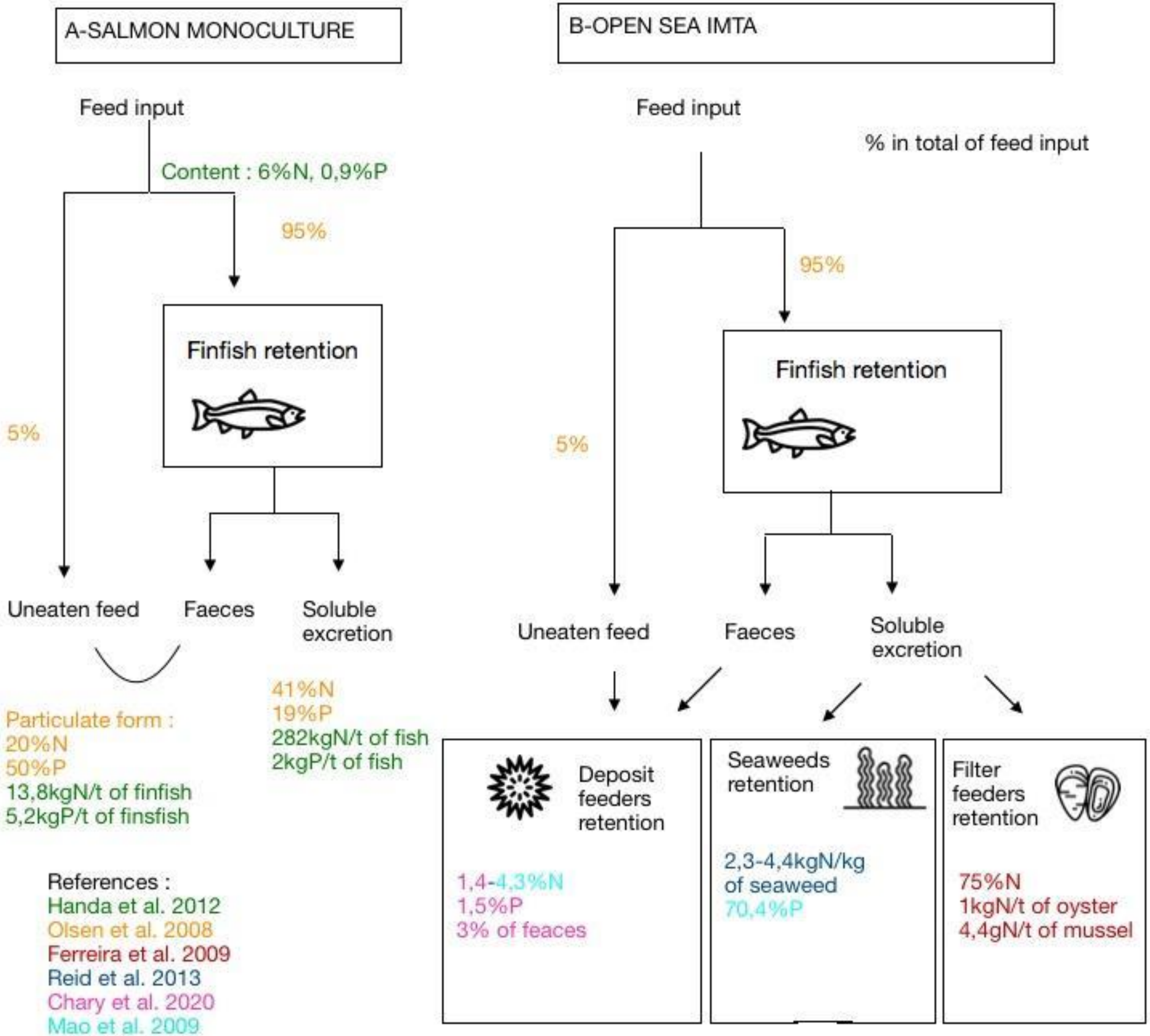
30% of the concentration of phytoplankton controlled by seaweeds (Zhang & Kitazawa, 2016).
3.1% of faeces removed by the co-culture of sea cucumber (Chary et al., 2020).
Up to 70% of particulate carbon removed by deposit feeders co-cultured with salmon (Cubillo et al., 2016).

Environmental analysis
Water and energy

Very few data

Water consumption: none (open system)

Energy : the percentage of energy of IMTA could be **lower** than those of the monocultures (Shi et al. 2013)



A-SALMON MONOCULTURE

Feed input

Content : 6%N, 0,9%P

95%

Finfish retention

5%

Uneaten feed

Faeces

Soluble excretion

Particulate form :
20%N
50%P
13,8kgN/t of finfish
5,2kgP/t of finsfish

41%N
19%P
282kgN/t of fish
2kgP/t of fish

B-OPEN SEA IMTA

Feed input

% in total of feed input

95%

Finfish retention

5%

Uneaten feed

Faeces

Soluble excretion

Deposit feeders retention

1,4-4,3%N
1,5%P
3% of feaces

Seaweeds retention

2,3-4,4kgN/kg of seaweed
70,4%P

Filter feeders retention

75%N
1kgN/t of oyster
4,4gN/t of mussel

References :
Handa et al. 2012
Olsen et al. 2008
Ferreira et al. 2009
Reid et al. 2013
Chary et al. 2020
Mao et al. 2009

Open sea IMTA system

Productivity gains

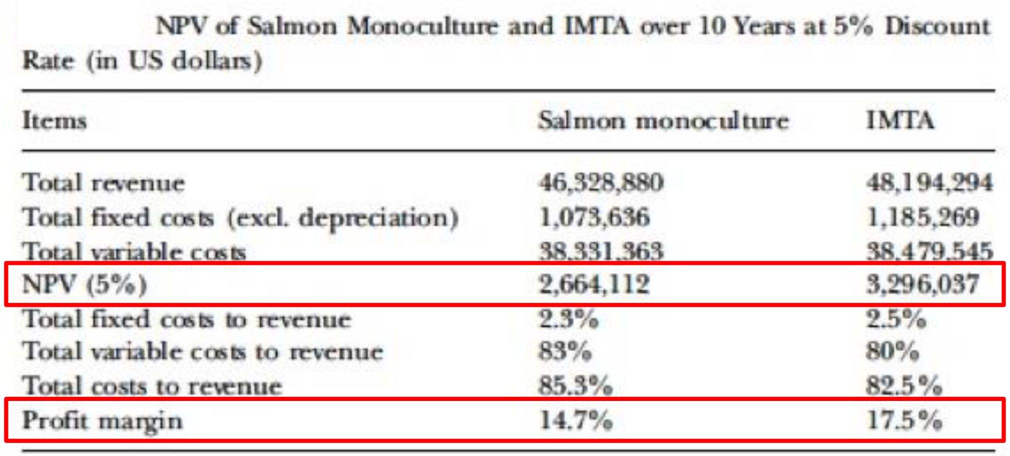
It has been demonstrated that combining salmon cages and seaweeds can increase their **growth** rate by **26%** in Scotland and **46%** in Canada for example (Ben Ari et al., 2014).

Moreover, growing **fish** with blue mussels or kelps increase the growth rate of the **bivalves** and **seaweed** respectively by **50%** and **46%**. For example, G*racilaria chilensis* grows 30% faster with salmon and produces **agar** of better **quality** compared to its monoculture (Barrington et al., 2009).

Economical analysis

Only few studies with economic calculation about IMTA systems in open ocean.

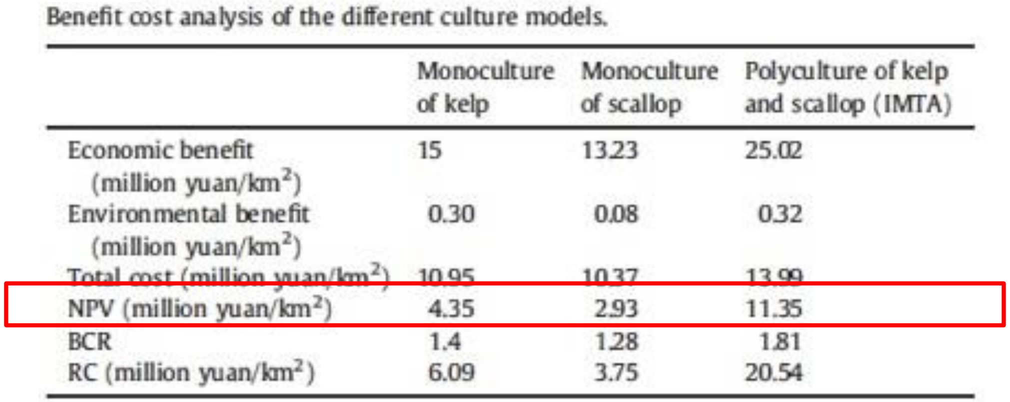
NPV (Net Present Value) is higher in IMTA systems => 5.7-38.6% higher (Carras et al., 2019; Ridler et al., 2007).



NPV of Salmon Monoculture and IMTA over 10 Years at 5% Discount Rate (in US dollars)

Items	Salmon monoculture	IMTA
Total revenue	46,328,880	48,194,294
Total fixed costs (excl. depreciation)	1,073,636	1,185,269
Total variable costs	38,331,363	38,479,545
NPV (5%)	2,664,112	3,296,037
Total fixed costs to revenue	2.3%	2.5%
Total variable costs to revenue	83%	80%
Total costs to revenue	85.3%	82.5%
Profit margin	14.7%	17.5%

(Ridler et al., 2007)



Benefit cost analysis of the different culture models.

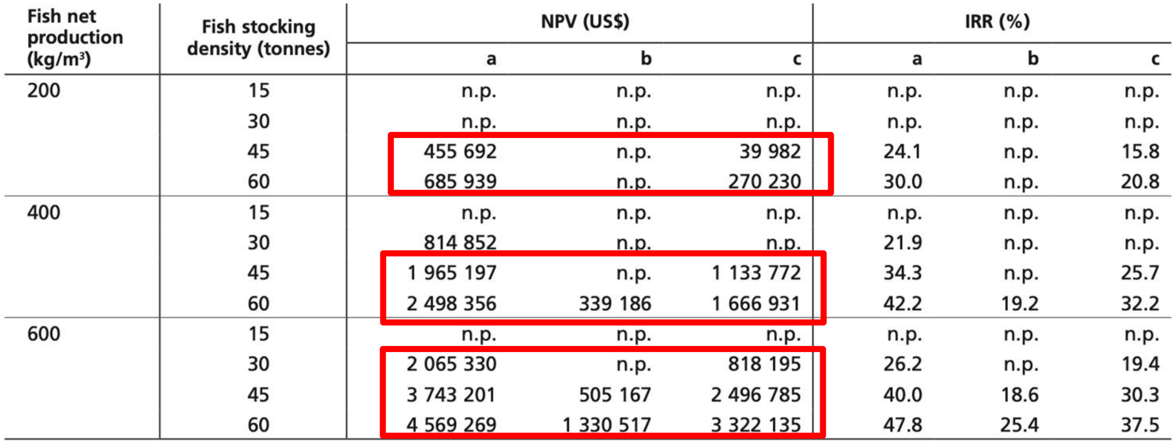
	Monoculture of kelp	Monoculture of scallop	Polyculture of kelp and scallop (IMTA)
Economic benefit (million yuan/km^2)	15	13.23	25.02
Environmental benefit (million yuan/km^2)	0.30	0.08	0.32
Total cost (million yuan/km^2)	10.95	10.37	13.99
NPV (million yuan/km^2)	4.35	2.93	11.35
BCR	1.4	1.28	1.81
RC (million yuan/km^2)	6.09	3.75	20.54

(Shi et al., 2013)

Economical analysis

3 scenarios:

- a) Salmon culture without internalization of the environmental costs
- b) Salmon culture with internalization of the environmental costs
- c) Salmon culture with internalization of the environmental costs + profit from seaweed Culture



Fish net production (kg/m³)	Fish stocking density (tonnes)	NPV (US$)			IRR (%)		
		a	b	c	a	b	c
200	15	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
	30	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
	45	455 692	n.p.	39 982	24.1	n.p.	15.8
	60	685 939	n.p.	270 230	30.0	n.p.	20.8
400	15	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
	30	814 852	n.p.	n.p.	21.9	n.p.	n.p.
	45	1 965 197	n.p.	1 133 772	34.3	n.p.	25.7
	60	2 498 356	339 186	1 666 931	42.2	19.2	32.2
600	15	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
	30	2 065 330	n.p.	818 195	26.2	n.p.	19.4
	45	3 743 201	505 167	2 496 785	40.0	18.6	30.3
	60	4 569 269	1 330 517	3 322 135	47.8	25.4	37.5

Source: Chopin *et al*. (2001).

This table shows the **effects** of the internalization of the **environmental costs in the profitability** analysis. In most cases the production does not make profits (n.p.) if the environmental costs are taken into account or are fallen sharply (column b of NPV). However, the column c of NPV shows a well better profit if this from *Gracilaria chilensis* production is taken into account whatever the scenario considered (Barrington et al., 2009).

Economical analysis

ASSETS

IMTA systems are **more resilient** to natural causes (i.e. mass mortality).

Risk is reduced because of **diversification** + additional income stream.

Administrative and operational expenses are spread over a wider range of products (Carras et al., 2019 ; Chopin et al., 2013 ; Ridler et al., 2007)

The percentages of salary and wages, energy, and maintenance of IMTA could be lower than those of the monocultures (Shi et al. 2013).

LIMITS

IMTA **profitability can be influenced by price trends**

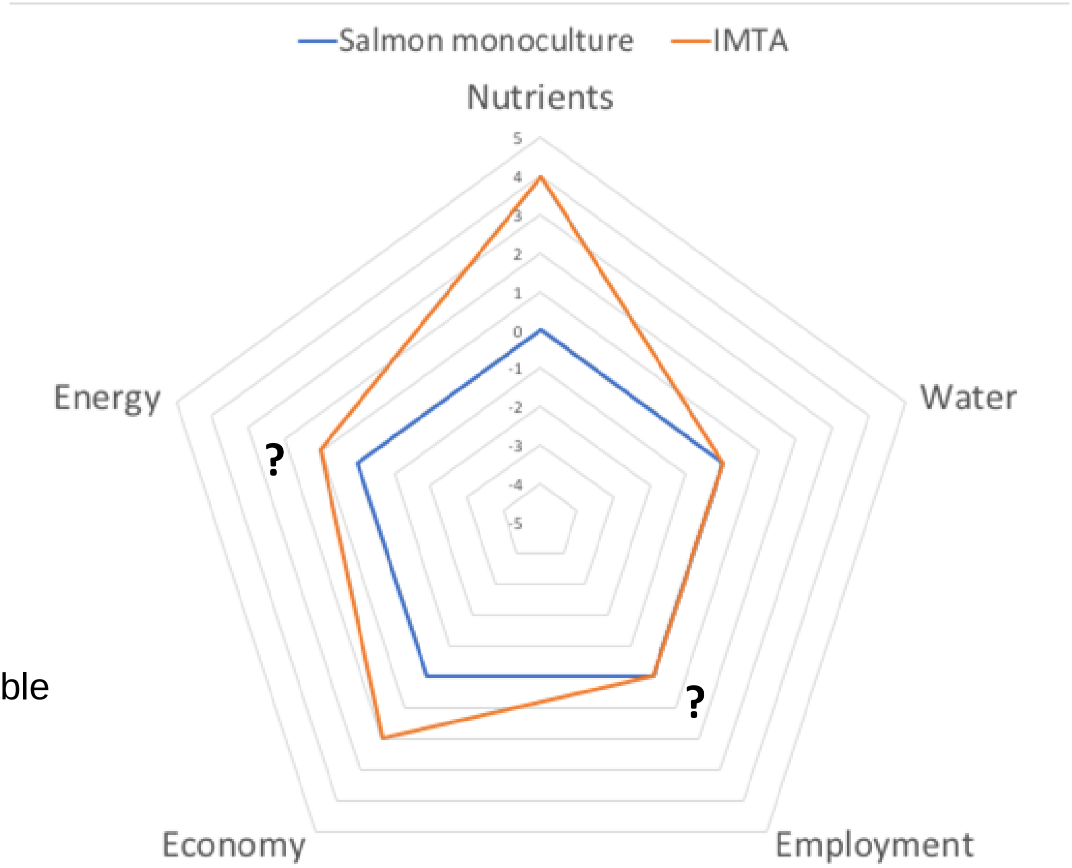
The cost of IMTA and capital investment requirements are higher than those of the monocultures, with added operational complexity (Carras et al., 2019 ; Shi et al., 2013).

Economical analysis

→ **IMTA systems in the open ocean under offshore conditions has not yet been adopted at commercial scale**

- Price premium must be applied on IMTA products :
  In a survey : 50% of the consumers were willing to pay 10% more for these products if labelled as such (Barrington et al., 2010).
- Costs of environmental degradation could be recognized and quantified.
- IMTA systems and extractive species provide **"environmental and societal services"** that are not taken into account in the economic studies (Chopin et al., 2013).

Benchmark



?: No data available

Open sea IMTA system

	ASSETS	LIMITS
Technical	Faster production cycles	Additional operational complexity Insufficient organizational and managerial expertise Technical uncertainty
Environmental	Less impact on the benthos Waste utilisation (effluents) Sea lice larvae filtration Increasing oxygen level in the sediments Cleaning water	Risk of disease transmission between species Extractive species must be adapted to offshore conditions Great variability in hydrodynamic conditions, pelagic primary productivity...
Economic	Financial benefits/ increased profitability Creation of new income streams Best resilience to natural causes Increase social acceptability, “greening” the aquaculture industry image	Market must exist for all species, some extractive species may have lower market price Sensibility to salmon price trends Higher capital investment requirements, higher cost

Interreg Atlantic Area
European Regional Development Fund
EUROPEAN UNION
integrate

Open sea IMTA system

integrate

Integrate Aquaculture: an eco-innovative solution to foster sustainability in the Atlantic Area

MANY THANKS

BARRIER-LOISEAU Chloé
GROSJEAN Camille
LACHERY Briac

AGROCAMPUS OUEST

Interreg
Atlantic Area
European Regional Development Fund

EUROPEAN UNION

AGRO CAMPUS OUEST
Pôle halieutique

References

Alexander, K. A., Angel, D., Freeman, S., Israel, D., Johansen, J., Kletou, D., … Potts, T. (2016). Improving sustainability of aquaculture in Europe : Stakeholder dialogues on Integrated Multi-trophic Aquaculture (IMTA). *Environmental Science & Policy*, *55*, 96-106. https://doi.org/10.1016/j.envsci.2015.09.006

Barrington, K., Chopin, T., & Robinson, S. (2009). *Integrated multi-trophic aquaculture (IMTA) in marine temperate waters*. 4. in Integrated Mariculture: a Global review. Publisher: FAO, Editors: D. Soto

Ben-Ari, T., Neori, A., & Ben Ezra, D. (2014). Gestion d'Ulva lactuca en tant que biofiltre des effluents de mariculture dans le système IMTA. Aquaculture, 434, 493–498 | 10.1016 / j.aquaculture.2014.08.034.

Buschmann, A.H., Hernández-González, M.C., Aranda, C., Chopin, T., Neori, A., Halling,C., Troell, M. (2008). Mariculture waste management. In: Jørgensen, S.E., Fath, B.D.(Eds.), *Encyclopedia of Ecology*. Elsevier, Oxford, pp. 2211–2217. https://doi.org/10.1016/B978-008045405-4.00045-8.

Pearce, C. M., Hamer, A., Chopin, T., & Weaire, T. (2019). A discounted cash-flow analysis of salmon monoculture and Integrated Multi-Trophic Aquaculture in eastern Canada. *Aquaculture Economics & Management*, 1-21. https://doi.org/10.1080/13657305.2019.1641572

Chary, K., Aubin, J., Sadoul, B., Fiandrino, A., Covès, D., & Callier, M. D. (2020). Integrated multi-trophic aquaculture of red drum (*Sciaenops ocellatus*) and sea cucumber (*Holothuria scabra*): Assessing bioremediation and life-cycle impacts. *Aquaculture*, *516*, 734621. https://doi.org/10.1016/j.aquaculture.2019.734621

Chopin, T., Robinson, S., Reid, G., & Ridler, N. (2013). *Prospects for Integrated Multi-Trophic Aquaculture (IMTA) in the Open Ocean*. 8. Bull. Aquacul. Assoc. Canada 111 (2): 28-35.

Cubillo, A.M., J.G. Ferreira, S.M.C. Robinson, C.M. Pearce, R.A. Corner, et J. Johansen (2016). « Role of Deposit Feeders in Integrated Multi-Trophic Aquaculture — A Model Analysis ». *Aquaculture* 453 (février): 54-66. https://doi.org/10.1016/j.aquaculture.2015.11.031.

References

Crampton, S. (2016). *Assessing the Barriers and Incentives to the Adoption of Integrated Multi-Trophic Aquaculture in the Canadian Salmon Aquaculture Industry*. 141p. https://summit.sfu.ca/item/16161

Government of Canada, F. and O. C. (2013). Aquaculture in Canada : Integrated Multi-Trophic Aquaculture (IMTA). Consulté 25 novembre 2019, à l’adresse https://www.dfo-mpo.gc.ca/aquaculture/sci-res/imta-amti/imta-amti-eng.htm

Mao, Y., Yang, H., Zhou, Y., Ye, N., Fang, J. (2009). Potential of the seaweed *Gracilaria lemaneiformis* for integrated multi-trophic aquaculture with scallop *Chlamys farreri* in North China. *Journal of Applied Phycology. 21*, 649–656.

Olsen, L.M., Holmer, M., Olsen, Y. (2008). Perspectives of nutrient emission from fish aquaculture in coastal waters: literature review with evaluated state of knowledge. *The Fishery and Aquaculture Industry Research Fund (FHF)*. Final report. 87 pp.

Ridler, N., Wowchuk, M., Robinson, B., Barrington, K., Chopin, T., Robinson, S., … Boyne-Travis, S. (2007). INTEGRATED MULTI − TROPHIC AQUACULTURE (IMTA) : A POTENTIAL STRATEGIC CHOICE FOR FARMERS. *Aquaculture Economics & Management*, *11*(1), 99-110. https://doi.org/10.1080/13657300701202767

Reid, G.K., Chopin, T., Robinson, S.M.C., Azevedo, P., Quinton, M., Belyea, E. (2013). Weight ratios of the kelps, *Alaria esculenta* and *Saccharina latissima*, required to sequester dissolved inorganic nutrients and supply oxygen for Atlantic salmon, *Salmo salar*, in Integrated Multi-Trophic Aquaculture systems. *Aquaculture,* 408–409, 34–46 https://doi.org/10.1016/j.aquaculture.2013.05.004.

Shi, H., Zheng, W., Zhang, X., Zhu, M., & Ding, D. (2013). Ecological–economic assessment of monoculture and integrated multi-trophic aquaculture in Sanggou Bay of China. *Aquaculture*, *410-411*, 172-178. https://doi.org/10.1016/j.aquaculture.2013.06.033

References

Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A. H., Kautsky, N., & Yarish, C. (2003). Integrated mariculture : Asking the right questions. *Aquaculture*, *226*(1-4), 69-90. https://doi.org/10.1016/S0044-8486(03)00469-1

Watanabe, S., Kodama, M., Orozco, Z.G.A., Sumbing, J.G., Novilla, S.R.M., Lebata-Ramos, M.J.H., (2015). Estimation of energy budget of sea cucumber, *Holothuria scabra*, in integrated multi-trophic aquaculture. In: Romana-Eguia, M.R.R., Parado-Estepa, F.D.,Salayo, N.D., Lebata-Ramos, M.J.H. (Eds.), Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia: Challenges in Responsible Production of Aquatic Species: Proceedings of the Internation. Tigbauan, Iloilo, Philippines Aquaculture Department, Southeast Asian Fisheries Development Center, pp. 307–308.

Whitmarsh, D. J., Cook, E. J., & Black, K. D. (2006). Searching for sustainability in aquaculture : An investigation into the economic prospects for an integrated salmon–mussel production system. *Marine Policy*, *30*(3), 293-298. https://doi.org/10.1016/j.marpol.2005.01.004

Zhang, J., & Kitazawa, D. (2016). Assessing the bio-mitigation effect of integrated multi-trophic aquaculture on marine environment by a numerical approach. *Marine Pollution Bulletin*, *110*(1), 484-492. https://doi.org/10.1016/j.marpolbul.2016.06.005