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

Integrated multi-trophic aquaculture: open sea IMTA analysis

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1. Technical characterization of the system

Open sea IMTA systems have specific characteristics compared to land-based ones. Indeed, those systems are influenced by tidal currents, oceanography and hydrography characteristics of the location. These parameters must be clearly considered as they can strongly influence yields and economic results. Consequently, producers have to think in terms of unit of production, without considering each species independently, in order to build systems adapted to local conditions.

An Integrated Multi-Trophic Aquaculture (IMTA) farming system combines organisms from different levels of the food chain that normally share the environment. In open sea IMTA, the system is often composed by the following compartments (Government of Canada, 2013).

Fish (e.g. Atlantic Salmon, *Salmo salar*) are fed and produce organic and inorganic wastes.

Seaweeds (e.g. Sugar Kelp, *Saccharina latissima*; Winged Kelp, *Alaria esculenta*) extract dissolved inorganic nutrients (e.g., Nitrogen and Phosphorus) and must be placed at a certain distance in order to better capture these nutrients that are lighter and travel longer distances than the organic ones.

Filter feeders (e.g. Blue Mussel, *Mytilus edulis*; Japanese Scallop, *Mizuhopecten yessoensis*) reduce the level of finer organic particles by ingesting substantial amounts of organic wastes from the surface layer of bottom sediments, thereby reducing the content of organic wastes in sediments (Zhang and Kitazawa, 2016).

Deposit feeders (e.g. Green Sea Urchin, *Strongylocentrotus droebachiensis*; California Sea Cucumber, *Parastichopus californicus*) recycle the larger organic particles (uneaten feed, faeces …).

2. Environmental analysis

Several chemical elements have an impact on the environment around fish cages, we consider here the Nitrogen, Phosphorus and the carbon/organic matter.

It has been shown that in a traditional finfish farm, a ton of fish release 282 kg of dissolved Nitrogen, 2 kg of dissolved Phosphorus, 13.8 kg of particulate nitrogen and 5.2 kg of particulate Phosphorus in the water around (Handå *et al*., 2012). Another released form of nutrients in the environment is contained in the food which is not used by fish (5% of the feed input) (Olsen et al., 2008).

In an IMTA system in open sea, the nutrients released by fish are used by other organisms associated with this production. The filter feeders (such as mussels or oysters) are able to remove 75% of the dissolved Nitrogen, with a better efficiency for oysters (Ferreira *et al.,* 2009). Seaweeds co-cultured with an average production of finfish can remove 70.4% of the dissolved Phosphorus (Mao et al. 2009). For dissolved nitrogen, up to 4.4 kg can be consumed by seaweeds (Reid et al. 2013).

Then, the solid and particulate part of nutrients can be removed from the environment by a co-culture of deposit feeders (such as sea cucumber). This co-culture decreases the production of fish faeces by 3%, consumes 1.5% of the particulate Phosphorus and 1.4% to 4.3% of the particulate nitrogen (Mao *et al*., 2009; Chary *et al*., 2020). For the particulate carbon (contained in the organic matter), it seems like up to 70% could be removed thanks to a co-culture of deposit feeders (sea cucumbers) (Cubillo *et al*., 2016). Seaweeds have an impact on the concentration of organic matter as they control 30% of the concentration of phytoplankton (which is correlated with the organic matter rate in the environment) (Zhang et Kitazawa 2016).

The water use is not different from another monoculture system as the IMTA open sea system is an open water system.

Very few data are listed for the waste of energy that takes place in such a system but this could be lower than the energy needed for a traditional monoculture system (Shi et al. 2013).

Thanks to those several studies, often based on models, we can see that environmental impacts of an IMTA system are meant to be lower than those recorded for a monoculture system. They depend on the co-cultured species and on the way of managing the systems too (feed input and waste of fish feeding).

3. Productivity gains

It has been demonstrated that the growth rate of filter feeders is higher with IMTA systems compared to monocultures. Indeed, the growth rate of seaweeds, when cultivated close to salmon cages, is increased by 46% (Ben-Ari *et al*., 2014). Finally, combining fish and blue mussels cultures can increase the growth rate of mussels up to 50% (Barrington *et al*., 2009).

4. Economic analysis

Only few studies about IMTA present any economic calculation. Indeed, in his review, Troell *et al.* (2003), economic data appeared in only 7% of the IMTA studies. Economic feasibility studies on open sea IMTA are rare and are often based on hypothetical data with little allowance for risks and their management (Chopin *et al.*, 2013).

Some studies show that open sea IMTA can increase profitability, showing that the NPV (Net Present Value) is higher in salmon IMTA system with salmon/mussel polyculture (Whitmarsh *et al.*, 2006), salmon/mussel/kelp (Carras *et al*., 2020; Ridler *et al*., 2007) or scallop/kelp (Shi *et al*., 2013) than in salmon monoculture, kelp or scallop monocultures (Carras *et al.*, 2020; Chary *et al*., 2020; Ridler *et al*., 2007; Shi *et al*., 2013; Whitmarsh *et al*., 2006), assuming that the quantity of salmon produced remains unchanged between monoculture and IMTA. For instance, in an Atlantic salmon, blue mussel and sugar kelp IMTA system, the NPV could be 5.7–38.6% higher (Carras *et al.*, 2020; Ridler *et al*., 2007).

Moreover, according to Ridler and al., IMTA systems are more resilient to natural causes. In addition to this, risk is reduced because of diversification (Carras *et al*., 2020; Chopin et al. 2013; Ridler *et al*., 2007). Carras *et al*. (2020) suggest that price premiums must be applied on IMTA products, in order that IMTA has significantly higher profits than salmon monoculture. Different elements can explain a The higher profitability of IMTA systems. First, growth rates of co-cultured extractive IMTA species are higher, IMTA's administrative and operational expenses are spread over a wider range of products (e.g. marketing and sales costs, salaries and wages, utilities). IMTA also provides access to additional income streams. Moreover, the percentages of salary and wages, energy, and maintenance of IMTA could be lower than those of the monocultures. However, the cost of IMTA and capital investment requirements are higher than those of the monocultures, with added operational complexity (Carras *et al.*, 2020; Shi *et al*., 2013).

To compensate for the higher costs of cultivating extractive species within high-tech open ocean infrastructures, their use and applications in high valued-added market (i.e. in human food consumption, nutraceuticals, cosmetics, bioactive compound) will be preferred (Chopin *et al*., 2013). If the costs of environmental degradation could be recognized and quantified or if there were limitations to nutrients emission, the interest of IMTA systems would be even more increased. In fact, IMTA systems and extractive species provide "environmental and societal services" that are not taken into account in the economic studies (Chopin *et al.*, 2013).

5. Balance sheet

Open sea IMTA (Figure 1) is here compared to that has 0 as score awarded for every issue (Nutrients, Energy, Economy, Employment and Water).

The water use is not different from another monoculture system as the IMTA open sea system is an open water system. We found no data about employment in open sea IMTA systems. In terms of economy, the NPV is 5.7-38.6% higher in IMTA (Carras et *al.*, 2019; Ridler *et al*., 2007): we consider a mean of 20%. Energy is almost not mentioned in studies about open sea IMTA except in one study from Shi *et al.* (2013) indicating that "the percentages of salary and wages, energy, and maintenance of IMTA could be lower than those of monocultures".

The filter feeders (such as mussels or oysters) are able to remove 75% of the dissolved nitrogen, with a better efficiency for oysters (Ferreira *et al.*, 2009) and seaweeds can remove 70.4% of the dissolved Phosphorus. Therefore, open sea IMTA systems are far better than salmon monocultures in terms of nutrients recycling.

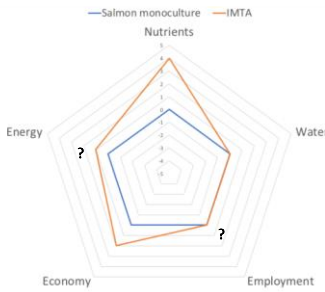

Figure 1. Radar diagram on environmental, social and economic aspects of the Open Sea IMTA system compared to the salmon monoculture system in open sea ("?" symbolises the lack of data)

6. Conclusion

Open-sea IMTA systems allow faster production cycles but some concerns exist about food safety (antibio-resistance and elements of feed such as supplements/copper by extractive species (filter feeders).

They also provide additional operational complexity and technical uncertainty remains (Alexander *et al*., 2016; Carras *et al*., 2020; Crampton 2016). Therefore, they have less impacts to the benthos. They permit to clean water and increase oxygen levels in the bottom sediments. Mussels can also be used as a pollution indicator. Moreover, those systems allow waste utilization: waste effluents are reduced by species at lower trophic levels (Alexander et al., 2016).

IMTA could provide financial benefits and increase profitability via product diversification, price premiums and the creation of new income streams. However, market may be a limiting factor: some extractive species (e.g. mussels) may have a lower market price than fish species, especially in western-type aquaculture which favour carnivorous fish (Chopin *et al*., 2013). Those systems also require higher capital investment and higher costs than monocultures (Carras *et al.*, 2020; Shi *et al.*, 2013).

Finally, IMTA increases social acceptability, "greening" the aquaculture industry image (Alexander *et al.*, 2016; Carras *et al.*, 2020; Ridler *et al.*, 2007; Whitmarsh *et al*., 2006).

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