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Integrated Multi-Trophic Aquaculture in Europe: *will it work for us?*

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The idea behind integrated multitrophic aquaculture (IMTA) does on the face of it seem to be a bit of a 'no brainer'. The concept that you take waste products from one aquaculture operation, normally finfish, to use as nutrients and energy to grow another crop is beguilingly simple. And it is not really as if it is a new idea. In Asia the idea of integrated aquaculture where farmed animals such as ducks or pigs are grown together with aquaculture such as fish ponds has been around for centuries. It uses the same principle of one component, the ducks or pigs, fertilising or feeding another component, the finfish. There are also direct parallels in the ancient Chinese art of polyculture where five or more species of carp would be grown within the same pond, each feeding on different components of the ecosystem and each cycling nutrients or benefitting the other species. In a modern context an IMTA system is normally based on a fed component such as fin-fish or shrimp. From this fed component there are normally two waste streams; particulate waste (such as uneaten feed, feed fines, and faecal matter) and dissolved components (such as metabolic waste nitrogen). The particulate matter, which falls out of the water column first, can be a food source either for bivalves suspended in the water column or for detrivores, and the nitrogenous dissolved waste can be used as a nutrient for macroalgae production. This produces a classic win/win situation, where the extra nutrients increase the growth of the extractive crops such as shellfish and seaweed, and in doing so reduce the amount of waste material entering the wider environment. Within this basic concept there are normally two forms of IMTA, either land based or open water. In land based systems the water movement, and therefore the movement of nutrients is regulated by the flow of water from one pond or tank to another. In open water systems that movement of water is supplied by natural currents or tidal movements of water.

Given the appeal of the philosophy of IMTA and its long history in Asia, as well as almost forty years of scientific research in the western academic literature, there has been very little adoption of this technology in either Europe or north America. This is puzzling because the concept of IMTA is very much related to the concept of the circular economy where waste streams from one industry provide the raw materials for another which has gained ide acceptance across a range of European industriess. A good example of this would be Kalundborg Eco-industrial Park in Denmark, where waste material or heat from one industrial

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process such as gypsum from a power station gas scrubber is used as a raw material for another, such as plaster board manufacture.

It was to answer this quandary that the IDREEM project was set up (Increasing Industrial Resource Efficiency in European Mariculture) under the FP7 Resource Efficiency research theme. The idea was, over the course of the four years of the project, to follow seven finfish producers from across Europe as they developed pilot scale or commercial scale IMTA operations within their existing businesses and to support and document this process. In order to achieve this, three academic institutions and four aquaculture support industries were included in the project along with the seven finfish producers. The €5.7M project is being led by the Scottish Association for Marine Science and has received funding from the European Commission under grant agreement 308571. The project is currently in the final year of its four year course, and as such there is still more data and analysis to be done. However, the project has made significant advances into understanding why IMTA technology has not been more developed in Europe and the Americas and to understand how any bottlenecks can be overcome.

The concept of IMTA is often characterised as a win-win situation where the twin benefits of increased productivity and reduced environmental impact are coupled together. However, as with most things in life, it just isn't that simple and there is a cost to pay for the development of IMTA, and we are discovering that it isn't always those who pay the cost who reap the benefit. Through the process of the IDREEM project we have been able to systematically look at the process of technology adoption in aquaculture across Europe and that has allowed us to better understand the challenges aquaculture producers face when they try and adopt a production system such as IMTA. Although each company faced their own unique issues during this process, by looking across seven companies in six different countries it was possible to discern some common themes around the challenges of adopting IMTA. These challenges can really be broken down into three different organisational levels, those that concern regulation, those that impact investment decisions by companies, and those that effect the farm management.

THE GAP BETWEEN POLICY AND REGULATION

One of the first challenges facing a company who want to develop an IMTA system is that of regulation, or rather lack of it, specific to IMTA. The IDREEM project found that across Europe the regulatory framework is complex and far from unified. There is a lot of policy within Europe that supports the development of more sustainable forms of aquaculture, and as such would support the development of IMTA. However the IDREEM project found that there was a gap between policy and regulation in a number of countries, and that while obtaining permission for small scale experimental IMTA is possible, the regulatory framework in some countries represents a significant barrier to the development of commercial scale IMTA operations in a number of countries. Even where the regulation is in place, early adopters of IMTA may find a lack of experience or clarity amongst the regulators is a considerable hindrance leading to lengthy delays as they go through the process of licencing an IMTA farm for the first time. This lack of clarity at the first step of IMTA may be enough of a barrier to halt a company's plans to develop IMTA, especially if the company is small and has limited resources to dedicate to working through the process with the regulators. Part of this policy gap may be as a result of the regulators' feeling that they do not have enough evidence on which to base the development of new regulations. Although there are a large number of scientific studies looking at different components of IMTA, the lack of commercial scale trials means there is a lack of evidence of the impacts of IMTA at a commercial scale. When we are discussing impacts in this context, we are not only discussing the environmental impacts (which are fairly well demonstrated for the different IMTA components) but broader impacts such as the effect on bio security and disease management, or the impact on the visual amenity associated with more aquaculture infrastructure. In the realm of early technology adoption, this policy/regulation gap is a common phenomenon, as technology will always develop faster than regulation. However to ensure that it does not stall the development of IMTA there is a clear need for close collaboration between the technology adopters and regulators, with research playing a crucial role in providing the evidence needed to fill the policy gap with evidence based management.

GETTING THE BUSINESS MODEL RIGHT

Once permissions have been granted then the next set of challenges really operate at the level of the company. The biggest barrier to a fin-fish company adopting IMTA is a simple matter of the scale of investment and uncertainty over the level of return that investment will realise. One reason to invest might be that the sale of the additional products (the extractive products) will increase the profits of the company. While it is true that there are valuable markets for shellfish products in Europe there is little evidence to suggest that the returns in the shellfish industry are higher than for the fin-fish industry, and when we look at the seaweed industry, aquaculture production is still in its infancy with very uncertain level of returns. This begs the question, why make a decision to invest in IMTA when it may be easier at an organisational/operational level to invest in more fin-fish production? This leads to the second reason why a company may choose to invest in IMTA, that there is limited space available to increase the fin-fish production. It is generally accepted that site availability is one of the limiters on traditional aquaculture expansion. There are three ways in which IMTA may allow a company to increase production capacity:

Firstly the inclusion of extractive organisms at an existing site simply increases the biomass of total product that can be produced at any one site (as long as the regulation allows for this) and therefore if a company is site limited then these additional products may allow an increase in turnover and perhaps profit. There have been academic studies to show that increasing

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IMTA mussel cultivation in Cyprus

IMTA scallops being produced in Scotland

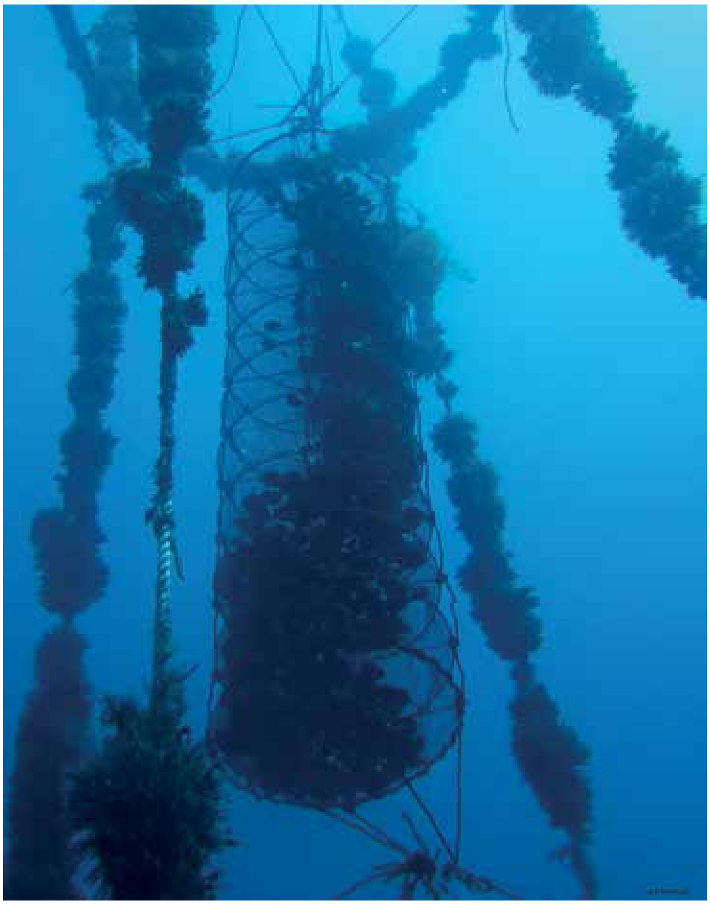
IMTA *Crassostrea gigas* produced in Italy

Alaria esculenta *Photo by F.O'Mahony*

Organic salmon cages with Mytilus edulis lines in the background

IMTA oysters being produced in Scotland

Lantern nets used to grow osters next to seabream in Italy



IMTA oysters growing in Italy

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the range of products a company produces increases the resilience of the company to economic or environmental shocks.

The second mechanism may be through the regulators allowing additional biomass of fin-fish to be produced on the condition that this extra production is to be balanced against the reduction in nutrient emissions to the environment associated with the IMTA production. This idea is similar to what is reportedly occurring in Denmark. The Danish government have stipulated that the nitrogen emissions per kg of fish must be reduced by 40% and the legislative body have recognised the bioremediation potential of mussels and seaweed in relation to their ability to uptake nitrogen. As such, additional biomass of fish production and the nutrient output from that additional biomass has to be balanced by nutrient reduction measures such as those offered by IMTA. This is a good example of where regulation could drive the adoption of IMTA.

The third mechanism is where the existence of IMTA operations adopted by a company adds value to the fin-fish production through the selling of the fin-fish at a premium. It is known that organic and sustainability labelling adds value to retailed fin-fish products and work undertaken in the IDREEM project suggests that there is a willingness within the general public to pay a premium for IMTA-produced fish. However for this potential to be realised there is a need to be able to certify IMTA products in a similar way to current sustainability standards in aquaculture. For this to happen a much clearer definition of IMTA is required, and an understanding of what does and what does not constitute IMTA. This definition and certification needs to be suitably robust to allow an aquaculture company to make the considerable investment that is required for a meaningful IMTA operation to be set up.

AN INDUSTRY DEFINITION OF IMTA

Though the concept of IMTA is relatively simple, its definition is far from simple. From an industry point of view, it might be best to define IMTA in terms of its environmental performance, given that this is the criteria that the company want to differentiate their products by. There are a large number of ways in which the environmental performance of an IMTA system could be classified or measured. A starting point for an industry definition might be how effective the IMTA system is at removing excess nutrients from the environment, and maybe more specifically how effective a system is at removing nitrogen from the environment.

The IDREEM consortium

This is in line with the approach taken by the Danish government. So if it is decided that nitrogen reduction is going to be the metric against which IMTA is to be measured, we then need to set levels to allow certification, and this begs the question, what percentage reduction constitutes an effective IMTA system. Setting this figure correctly is crucial to the success of any IMTA certification. If it is set too low, then the certification becomes meaningless; set it too high and IMTA becomes too difficult to implement. This idea of certification based on a percentage reduction in nitrogen emissions raises two crucial issues to the future development of IMTA and relates directly to company level decisions on adopting IMTA. The first is scale and the second is of integration.

THE ISSUE OF SCALE

Let us look at the issue of scale first. Fin-fish production in Europe is an intensive industry with large biomasses produced per m^2 of surface area. The cultivation of extractive organisms such as mussels and seaweeds is much more extensive, with much lower production densities per m2. As such there is a mis-match between the scales of production between fin-fish and extractive organisms in terms of the space required to make a meaningful reduction in the nitrogen emissions. Modelling studies suggest that to remove 10% of the nitrogen from a 1000 tonne salmon farm would require approximately 10 hectares of seaweed. This obviously represents a significant space requirement, and operational input. It is interesting to note that initial modelling work carried out in Canada suggests that benthic IMTA may be far more efficient in terms of space requirements. This type of IMTA involves the use of detritivores underneath the fin-fish cage within the benthic foot print of the cage, which can consume the large particulate waste which falls directly to the bottom. Species such as sea urchins and sea cucumbers have been piloted for this type of IMTA, although there are still considerable technical barriers to the commercial development of these systems.

INTEGRATION

Recent studies have shown that both the dissolved and particulate nutrient plumes from fin-fish farms are very hard to detect at distances of more than a couple of hundred meters away from the farm. If you think about some of the scales that were discussed earlier, then even if the culture area of the extractive organisms is directly adjacent to the fin-fish cage, a large percentage of the extractive organisms will be outside the measurable plume of waste nutrients. So it will be essentially impossible to prove that the nitrogen taken up by the extractive organism originated from the fin-fish cage. But does this matter? Is there a need to prove that there is direct transfer of nutrients from fin-fish to the extractive organisms for it to be classified as IMTA? Not if we are using the definition of IMTA we discussed earlier (a nitrogen-reduction of some predetermined percentage). In that case is it better to look at the scale of a water body, bay, loch or fiord? If we consider IMTA at the wider scale and not the farm scale, then the twin issues of integration and spatial scale are easier to manage. There is an increasing drive to manage disease and parasites at the loch or fjord scale in the salmon industry, so why not nutrients? This way of thinking about IMTA is very much in line with taking an ecosystem approach to aquaculture, where consideration is given for managing the whole water body. For a company to develop an IMTA system, where the integration occurs at a broader geographic scale may be a more attractive proposition. In addition to allowing much more effective disease and parasite control through their management at the level of the water body as opposed to the level of an individual site, this broader scale would allow much more effective biomass and emissions control. The locations and set up of farms could be planned and modelled to ensure that they are placed to balance maximised nutrient recovery while allowing the optimal biomass for the ecological limits of the system to be achieved. This type of area management may also be a valuable tool to increase the social licence for aquaculture companies to operate within the locality. Social licence is a concept that has come principally from the mining industry, and can be roughly defined as the on-going approval or acceptance of a project or operation within a community. As discussed earlier,

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availability of sites is becoming an increasing issue for the aquaculture industry, and applications for new sites are often slowed by objections from sectors of the local community. By using IMTA as a tool to create an ecosystem approach to aquaculture management, with such a management framework including a large component of bio mitigation in the form of extractive aquaculture integrated into the management of the fin-fish cultivation, you create a platform that can be used to build a social licence to operate for the aquaculture industry. This social licence is generated in a number of ways; firstly through increased employment in the local area from an increase in aquaculture activities, primarily through an increase in extractive aquaculture. The second mechanism is through an understanding that the aquaculture industry is acting in a responsible manner towards the environment and is taking actions to mitigate its environmental impact, and thirdly through better community engagement across the whole water body area and not just for a specific site.

FARM OPERATIONS

The final set of challenges is very much focussed at the level of the farm management and operation. Probably the largest challenge faced by the companies in the IDREEM project was a short fall in 'know how'. Fish farming is a technically and knowledge intensive industry, as is shellfish farming, and as is seaweed farming. For a fin-fish farm to start farming extractive species such as mussels or shellfish requires that the knowledge or know how to do this becomes in bedded within the organisation. There are a number of ways that this can happen. The knowledge can be brought in from outside the company through hiring the suitable technical expertise. This represents a significant investment which may be beyond a small fin-fish farmer. Another route is through 'learning by doing'. Though the initial investment is smaller, the potential for significant loss is not small whilst staff become proficient in the new production systems. In fact, set backs during this learning by doing period has the potential to stop the development of IMTA for a small firm. There is a hybrid option where a fin-fish farming company and a shellfish or seaweed company chose to develop a site together as a joint venture. While there are obvious advantages to this approach, there is a need to ensure there is integration between the separate companies at an operational level as well as at a biological level. This operational integration is another area that has been highlighted by the IDREEM project as another potential barrier to the successful implementation of IMTA. The level of organisational integration will depend on the nature of the IMTA operation, but there will be multiple aspects to consider. For example the layout of the farm, as the fin fish industry becomes more technical and specialised: there is less flexibility in how the cages are laid out or in the grid which is used to moor them. This is particularly the case for the salmon industry which is reliant on well boats of increasing size. These well boats require considerable sea room to operate, and as such their operation may limit how close the other components of the IMTA system can be to the fin-fish cages. However if IMTA is fully operationally integrated, then the mooring grids of the cages can be designed to incorporate the IMTA components within the grid while retaining full access to the outside of the cages, but this level of integration can only be achieved if IMTA is considered to be fundamental to the farm design and its operation and is included in the planning stage of infrastructure development. The issue of bio security was highlighted as one of the challenging aspects of organisational integration. This was perceived as a risk by most of the fin-fish producers prior to the start of the IDREEM project. The concerns centred around issues of disease management and different production cycles and whether the IMTA products would act as a potential reservoir for pathogens. Although highlighted as a perceived risk, there have been no reported issues of biosecurity within the project to date.

Other operational challenges include processing the different components of the IMTA system. This has been especially true for the large amounts of seaweed cultivated during the project. Again the processing challenge relates to know how imbedded within the company but also to its available infrastructure. In the case of seaweed, drying is perhaps the most cost effective way to process the product, but this drying is space and energy intensive, and the large scale infrastructure required to deal with large volumes of seaweed are rare in Europe. The issue of processing is directly related to the issue of finding markets for the additional extractive organisms. For shellfish these markets are well developed and it may be a simple case of producers connecting directly to these distribution networks. However for products such as seaweeds these markets are poorly developed and this may act as a large disincentive to the development of IMTA.

WHAT DO WE NEED TO MOVE FORWARD?

As we said at the beginning, the IDREEM project was set up to understand some of the reasons as to why IMTA had not been more widely adopted, and we have gone through some of those reasons and the different operational levels at which they act. But the IDREEM project was also about finding tools to allow that benefit of the win/win to be enjoyed by the European aquaculture industry and by the wider European society. Although we have extensively listed challenges and bottle necks it does not mean that benefits of IMTA are not obtainable. IMTA has the potential to deliver greater productivity and reduced environmental impact; it also has the potential to decouple economic growth in the European aquaculture industry from resource depletion. However at the moment there is a mismatch in who bears the cost and who receives the benefits of IMTA. Most of the costs of adopting IMTA (and not just financial ones) are borne by the industry and yet their benefits are not being accrued by the industry. As such there is relatively little incentive for the industry to invest in its development.

However the IDREEM project has identified a number of tools that would allow this mismatch to be re-aligned:

1. Firstly there needs to be a **definition of IMTA that the industry can adopt**, a definition that can be understood by consumers and industry alike. Following on from this definition there needs to be a

certification for IMTA, so that industries who invest in IMTA can protect their investment from cheaper copies who have the potential to devalue the IMTA 'brand'.

2. Secondly, industry needs to be given the **flexibility to deal with the spatial mismatch in scales** described earlier between the extractive components of IMTA and the fin-fish production. The only way to do this for the dissolved component of the farm wastes is to pursue a water body approach to IMTA and to the management of aquaculture. There are clear drivers as to why the management of aquaculture at the loch/fiord/bay level would be attractive to fin-fish companies. Using IMTA as a way to 'balance' aquaculture within a wider ecosystem and to manage the social and environmental impacts will require a change in policy and regulation but offers the best chance for wider scale adoption of IMTA.

3. Thirdly the **technical and biological constraints of benthic IMTA need to be overcome**. Aquaculture in Europe is mainly managed on its benthic impact and at the same time this is the most concentrated source of nutrients that leave fin-fish production sites. Therefor this is the most obvious target for the IMTA win/win, but conversely because it is the most technically challenging it is the least developed. There is a clear need for further research spanning the disciplines of engineering and biology in order to come up with a workable solution for benthic IMTA.

4. The fourth condition that needs to be in place is the development of a **market for aquacultured seaweed in Europe**. Globally the seaweed industry is worth approximately $7bn and Europe imports approximately 90,000 tonnes of seaweed annually but only produces a tiny amount of seaweed domestically through aquaculture. Seaweed is a crucial component of most IMTA systems and we know that for it to make a significant contribution to nutrient reduction it needs to be grown in large volumes. These volumes of seaweed, though they have a high intrinsic value as a raw product, have a very limited market in Europe. The development of processing plants and bio-refineries for seaweed would allow for the expansion of this important component of IMTA and for it to reach its true economic value.

So what is the future of IMTA in Europe? There is growing commercial interest in its development, as well as clear policy drivers for its further development. The economic and environmental win/win is achievable, but currently the conditions are not yet in place in Europe to allow for its wide scale adoption. If these could be developed, then IMTA could become an important tool for the development of the economic and environmental sustainability of the European aquaculture industry.


Queen scallops ready to go into net at IMTA site in Scotland


Queen scallops growing as part of IMTA in Scotland


Oysters harvested from IMTA site in Italy