IDREEM - Increasing Industrial Resource Efficiency In European Aquaculture

BEYOND FISH MONOCULTURE

Developing Integrated Multi-trophic Aquaculture in Europe

INTRODUCTION

Aquaculture is the fastest growing animal food producing sector in the world and is an increasingly important contributor to global food supply and economic growth. The European aquaculture industry covers the production of finfish, shellfish and other aquatic species, including algae, in both freshwater and marine conditions. Currently in the EU the demand for seafood is increasing while the amount caught from wild fisheries is decreasing and the European Commission calls for this gap to be partly filled with environmentally responsible aquaculture. Moreover, the EU's Strategy for Blue Growth identifies aquaculture as a sector which could boost economic growth and bring social benefits through new jobs. There are over 14 000 aquaculture enterprises in the EU, directly employing 85 000 people in total, but in contrast with other regions of the world, aquaculture production is stagnating in the EU, while imports are rising.

In this context, Integrated Multi-Trophic Aquaculture (IMTA) can be used as a valuable tool towards building a sustainable aquaculture industry. IMTA systems can be environmentally responsible, diverse, profitable and a source of employment in coastal regions. IMTA has been practiced for centuries in Asia, but has yet to become established in Europe.

This report outlines the activities and main results from the EU framework 7 project IDREEM, a collaborative research project launched in 2012 with 15 partners, to move IMTA beyond the current state of the art and to demonstrate its viability for the European aquaculture sector.

EU Seventh Framework Programme funding provided time and money that allowed seven companies across Europe to invest in IMTA that would otherwise have not done so. Each has gained an insight into the infrastructure needed, the time and dedication needed, the learning of new skills and techniques, most of whom were entirely unfamiliar with aquaculture production of seaweeds, bivalves and other species. Having undergone a huge learning experience, they remain committed to developing IMTA to the next level through increased, more commercial scale implementation of IMTA, as a lasting legacy from the funding provided by the EU Seventh Framework Programme.

Photo courtesy: MER Lab

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IMTA for a more sustainable European aquaculture

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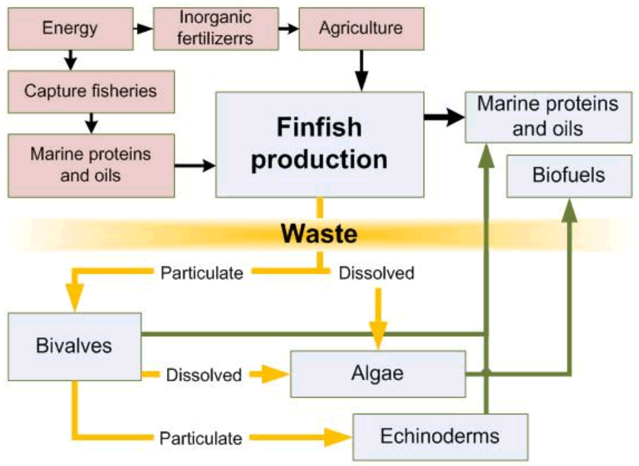
Integrated Multi-trophic Aquaculture is a win-win concept but is not widely adopted in Europe. The IDREEM project examined barriers that limit the uptake of IMTA; combining research with implementation at seven pilot sites across Europe, it demonstrated the benefits and opportunities IMTA can offer the European aquaculture sector.

Currently, aquaculture supplies over 50% of fin- and shellfish consumed worldwide. This represents a paradigm shift in our exploitation of the sea that for centuries was dominated by capture fisheries. With global population growing and the European population expected to rise to 520 million by 2030 (currently 499 million), the demand for aquaculture products is expected to expand. In fact, the demand for aquaculture products will probably be disproportionally large because global fisheries have generally been stagnant or in decline since the mid 1980's and aquaculture will fill the widening gap between demand for marine products and ability of traditional fisheries to satisfy it.

In addition, a shift to healthier food will increase the consumption of aquatic products. Notwithstanding these trends, there are serious questions over the environmental and economic sustainability of Europe's current aquaculture industry. The potential for aquaculture to reduce pressure on stressed wild-stocks depends on the extent to which fish farming relies on wild-stocks for manufactured fish feed. The European aquaculture industry is dominated by monoculture of carnivorous finfish and has therefore contributed to aquaculture's doubled share of fish oil and fishmeal demand over the last decade despite a growing trend in substitution of marine with terrestrially derived proteins and lipids. Moreover, all waste by-products of monoculture are discharged directly into aquatic ecosystems.

To overcome these issues the IDREEM project worked towards the rapid development of alternative Integrated Multi-Trophic Aquaculture (IMTA) production technology in Europe. This technology is based on the principle of eco-efficiency – turning waste streams into secondary raw materials for further production. The concept of Integrated Multi-Trophic Aquaculture (IMTA) is simple; utilise the waste products from fed species (mainly fish) and co-produce other species lower down the food chain that will use this waste stream to grow; waste nutrients and energy converted to other products for harvest including shellfish, seaweeds and other species and supporting a reduction in the overall environmental impact from aquaculture activity. In marine aquaculture systems the production of fish, shellfish or algae is undertaken using a variety of production methods (cages, longlines, rafts) but generally produced alone in monoculture, where each species is grown separately. IMTA is different.

In an IMTA system the layout of the IMTA site is such that species are grown in proximity, in both space and timing of culture, in such a way that the shellfish and/or plants and other species, can recycle the nutrients that are lost from the fed culture of finfish. A fish farmer who adds fish feed to his cages, knows that a proportion of the feed, and a large proportion of the nutrients in that feed, will not end up in the fish but will be lost to the environment. If the farmer adds a bivalve culture operation near the fish farm, then these filter-feeders might benefit by consuming some of the particles of waste, allowing the shellfish to grow faster or bigger than they might otherwise have done. Additionally, the farmer might elect to grow some seaweed near



A diagram of the IMTA concept.

the fish farm. These plants can utilise the dissolved nutrients excreted by the fish and the bivalves to enhance their growth. This is IMTA in operation. These additional products provide a valuable economic resource for the aquaculture operation, to harvest, market and sell and increase overall aquaculture production in line with European goals. This is combined with a net reduction of losses to the environment improving overall aquaculture sustainability.

This approach is not new, IMTA has been practised by default in Asia for thousands of years and has been studied in Europe and elsewhere for 40 to 50 years. It is only recently, however, that our understanding of IMTA has been developed more fully, through research projects in Asia, Canada and Europe. The concept is gaining traction and the potential benefits of this system are better understood, but to date IMTA is only practiced in the EU by a few specialist companies.

The idea behind the European research project IDREEM (Increasing Industrial Resource Efficiency in European Mariculture) was to understand some of the bottlenecks and barriers that prevent the industrial uptake of this production system, and to better understand the economic, social and biological benefits of IMTA in a European context.

Launched in 2012, IDREEM was a four-year programme with a budget of €5.7 million funded by the 7th EU Framework Programme. Investigation of IMTA was carried out by fourteen partners, the majority of whom were aquaculture production companies or SMEs, and the remainder were research organisations; coming from six countries across Europe: Cyprus, Ireland, Israel, Italy, Norway and UK.

Industry at centre stage

A focus for the IDREEM project has been putting industry at the centre of the project, with all partners supporting the practical implementation of IMTA at aquaculture sites.

The consortium included finfish producers wishing to develop IMTA, and on-shore marine hatchery facilities, who were paired in each country by a supporting research organisation. Other SMEs provided value added services to the project. Through the close collaboration among partners and fish farmers, seven pilot scale IMTA operations were developed across Europe – four in the Atlantic region and three in the Mediterranean. The process of development and the practicalities in co-producing species provided invaluable information on the long term prospects for IMTA in Europe. The project funding allowed farmers to test alternative species, to develop best practices for growing animals and algae, allowed them to develop their infrastructure requirements and to grow their aquaculture products to harvestable size.

Multi-disciplinary approach

In addition to a better practical understanding, project partners investigated the regulatory and policy constraints, economic benefits, social understanding and acceptance of IMTA products.

Direct measurements at sites enabled an understanding of environmental consequences of the IMTA system, supported by Life Cycle Analysis, species growth and environmental modelling.

The overall concept was to study IMTA using a multi-disciplinary team and approach, benefitting from the experience of a range or producers, research organisations and SME's; and covering social, economic and scientific disciplines.

In an IMTA system the shellfish and or plants or other species can recycle the nutrients that are lost from the fed culture of finfish.

Chapter 1 – IMTA for a more sustainable European aquaculture

Learning from experience and observations-disciplinary approach

The pilot scale IMTA projects have all been successful in their own terms but with a range of different implementations. Some producers have found a lot of bottlenecks, while some have found it much more logistically easy. Farmers were able to gain an insight into the practicalities of growing additional species, and for many this was a lesson in new techniques.

The environmental interaction of fish farms and IMTA was monitored, in terms of effect both on the water column and at benthic level. This highlighted the environmental sustainability of each monoculture operation, and some of the difficulties in directly measuring and seeing environmental benefit of IMTA in the field.

Assessment of regulatory controls and surveys on public understanding and acceptance of IMTA were conducted, and revealed that even though the average consumer has no idea what IMTA is, once this is explained, there is a good social acceptance and a general consensus that IMTA will help produce a sustainable industry, help produce food, produce rural employment and help generate income for local communities.

This also translated into a general willingness to pay a premium for a more sustainable aquaculture production.

A Life Cycle Assessment was conducted for each farm company, with a comparison of the new IMTA system with fish monoculture, which highlighted a number of technical and methodological trade-offs between systems. Market and financial aspects of Integrated Multi-Trophic Aquaculture were assessed focused on translating environmental and social impacts of IMTA into economic and financial values with direct relevance to the IMTA investor or operator, and showed, even at the small scale that certain economic benefits are gained. Evaluation of the potential for Integrated Multi-Trophic Aquaculture (IMTA) was in part established through modelling and development of the Farm Aquaculture Resource Management (FARM) model, that allowed assessment of species growth in monoculture and IMTA scenarios and assessment of the environmental consequences. This decision tool offers farmers the ability to assess growth of each species individually and when grown in combinations of species, what the benefits are from any additional growth we get from the IMTA, what that converts into in terms of reduced environmental impact.

IDREEM has placed the cornerstones for a wider adoption of IMTA in Europe

After four years of hands-on practical experience, research, dedication and a better understanding of aquaculture producers, sufficient evidence has been gained to show that, even though the conditions are not yet fully in place in Europe for the wide scale adoption of IMTA, there is a growing commercial interest, consumer interest, an economic and environment case for adoption of IMTA, as well as clear policy drivers for its future development.

Overall, the work carried out by partners in the IDREEM project has gone a long way to develop IMTA into a practical development for European aquaculture. Through the life of the project and with no IMTA in Europe at the start there are now seven IMTA operations in place, and the first IMTA products have been brought to market and sold.

In Norway the first IMTA licence has been approved for a fish/algae facility. In Scotland adoption of a fish/shellfish/algal facility at one site will see this expanded to several other locations in the near future. Also in Scotland a land-based hatchery facility is using a tank-based IMTA system to produce algae as food for other more commercially viable species and with bivalves to improve water quality in outflows. Previous outline approval for algal culture has now been extended to a 5 hectare algae growing site next to salmon production in Ireland. In Cyprus the fish farmer has evaluated a range of species options and is continuing to develop a suitable system. In Israel a practical solution for growing algae next to fish cages has been developed and expanded, and in Italy growth of oysters next to fish cages has been successful and increases in production of oyster is planned.

Thus, the project has made real steps towards the development of IMTA through improved scientific and economic understanding, and practical adoption. With the adoption of appropriate measures and conditions (see chapter 9), IMTA can really become an important tool for the economic development and environmental sustainability of the European aquaculture industry.

Developing IMTA across Europe

Daryl Gunning, Julie Maguire: Daithi O'Murchu Marine Research Station, Ireland

The IDREEM project consisted of seven pilot-scale Integrated Multi-Trophic Aquaculture sites in three Northern European and three Mediterranean locations. This chapter details the experience that each IDREEM SME partner had in implementing new IMTA crops into their existing monoculture operations.

Development of IMTA systems was undertaken at four sites in Northern Europe, with its colder and more nutrient rich water; and at three sites in the warmer and less nutrient rich waters of the Mediterranean. The following is a synopsis of each company's activity in growing extractive species next to their more usual finfish aquaculture.

Ireland – *Fish cultivated: Organic salmon*

Research organisation Daithi O' Murchu Marine Research Station (DOMMRS) and production company Murphy's Irish Seafood collaborated to introduce the production of seaweed grown on longlines, alongside Murphy's organic Atlantic salmon facility on the west coast of Ireland.

Throughout the project longlines of seaweed were deployed over 2013 and 2014, typically comprising of 200m long surface lines deployed 50m from fish cages, to grow the brown seaweeds *Alaria esculenta* (also called winged kelp). Kelp does not seed naturally, and required the local collection of fertile specimens which were spawned in the laboratory to produce sporophytes that were sprayed onto the thin ropes, before being deployed for on-growing at sea.

In June 2013, the final harvest resulted in an average biomass of between 17.2 and 18.1 kg wet weight per metre of line. This represented better growth than the average achieved at other locations in Ireland (approximately 10kg/m), although there was little difference between the control site, some 1km from the fish cages and those grown next to the cages. It was unfortunate, but storm damage in 2014 resulted in no harvest.

In 2015, the trials were increased slightly in size, consisting of a 300m IMTA line (80m *Alaria sp.* and 220m of *Saccharina latissima* – also called the sugar kelp) adjacent to the cages, and a 100m control line approximately 1km downstream of the cages. The distance between fish farm and seaweed longline was increased to 150m to facilitate the implementation of new anchorage lines at the salmon farm and for the longlines themselves, required for reinforcement following winter storm damage.

Deploying seaweed longlines in Ireland (top); harvesting (bottom left) and drying (bottom right).

Upon harvesting in June 2015, *Alaria* had grown to an average of 11.9 kg/m ww and the sugar kelp to an average of 6 kg/m ww, marginally higher and lower than the control site respectively. Also this lowering of growth compared with the previous year provided a valuable lesson in trying to determine and control growth in seaweeds, something that has become customary in fish production.

The production of seaweeds in the IMTA system has not gone unused. In 2013 and 2015 seaweed harvested was sent to an Irish horse feed company as a health supplement and used within the Marine Station's own facility to feed sea urchins. In 2015, the sugar kelp harvested was sent to the Environmental Research Institute of University College Cork for use in biogas research.

DOMMRS and Murphy's have learnt a lot about the development, benefits, and potential of IMTA through the IDREEM project. There are current plans for expansion, when in July 2014, after a four-year wait, DOMMRS was awarded their requested seaweed licence, which will allow deployment of seaweed longlines over an area of 6 hectares approximately 200-300m from the salmon site. It is estimated that approximately 16 longlines of 200m in length could be deployed at a site of this size with seaweed production expected to reach 30 tonnes per annum.

Scotland Offshore – *Fish cultivated: Atlantic salmon*

In Scotland, the Scottish Salmon Company and Loch Fyne Oysters, along with their research partner the Scottish Association of Marine Science, collaborated to introduce an IMTA system comprising of Atlantic salmon, and 10 x 200 metre longlines growing mussels (*Mytilus edulis*) on "New Zealand" continuous rope, seaweed (*A. esculenta & S. latissima*) on seaweed strings, oysters (*Crassostrea gigas*) in SEAPA baskets, queen scallops (*Chlamys opercularis*) on collectors and pearl and lantern nets, and sea urchins (*Echinus esculenta*) in pots and oyster baskets.

Although only a pilot scale operation the company harvested a total of 2,500 kg wet weight (ww) *A. esculenta* in May 2013 and 2015 and 1,000 kg ww of *S. latissima* in May 2015, and sold the seaweeds to a Scottish company, who dried, diced and milled the seaweed for use as a food condiment. 60,000 kg of mussels were also harvested as spat, that were then deployed at other locations around Scot-

Some of the species grown at the IMTA site in Loch Fyne: the salmon cages (top), scallops (bottom left), oysters (bottom right).

land for on-growing. The site also has produced over 250,000 queen scallops, which are currently being harvested, individually quick frozen and are entering the market as a high value niche product. The company's IMTA system provided the opportunity to invest in other niche requirements, such as for research and broodstock development, provision of much needed mussel spat that could be on-grown within the company, as well harvestable stock for direct sale.

Following their experience with the IDREEM project, the SSC plan to expand their IMTA production at their project site and other sites around Scotland. As part of this development they are also considering other species such as the native oyster (*Ostrea edulis*), dog whelks (*Nucella lapillus*), and other gastropods, as they provide the opportunity to develop both traditional and niche markets.

Scotland Onshore – *Fish cultivated: Turbot, cod, sea bass*

Ardtoe on Scotland's west coast provided the only land-based pilot IMTA system in the IDREEM project. A collaboration between FIA Aquaculture Ltd and the Scottish Association of Marine Science, saw three trials carried out in raceways, with *Ulva* sp (commonly called sea lettuce) grown on nutrient rich water coming from tanks containing turbot (*Psetta maxima*), cod (*Gadus morhua*) and sea bass (*Dicentrarchus labrax*). The harvest of sea lettuce was used to feed much more valuable species such as sea urchins (*Paracentrotus lividus*) and oyster spat, also placed in the IMTA raceways.

The results of the first trials indicated that the increase in biomass of sea lettuce was stronger in the raceways fed with fish effluent water compared to control tanks containing only seawater. Sea urchins achieved similar levels of growth in all raceways and unfortunately the oyster spat did not grow well.

In a second trial, *Himanthalia elongata* and *Laminaria digitata* were also tested in different raceways, in addition to *Ulva spp.*, but did not perform well.

The system was further modified so that all *Ulva* raceways were fed with fish tank wastewater; raceway water inflow was increased and a more vigorous air system was introduced. Oyster spat was removed from the system and more sea urchins were added. The new aeration improved the growth and quality of the *Ulva sp.* allowing all sea urchins to be fed without losing seaweed biomass.

In 2016 a further improved design was adopted, along with the addition of other species. In the current configuration the fish tank wastewater passes through settlement tanks before arriving at the raceways, to remove detritus and uneaten feed. In the first section of each raceway, where the wastewater enters, there are sea urchins, and ragworms (*Nereis virens*) growing underneath a layer of sand at the bottom of the tank, surviving on the detritus from the urchin culture. The remainder of the raceways contain *Ulva* and amphipods. In this novel system sea urchins are fed with the *Ulva* growing in the second area of the raceways, this *Ulva* also absorbs the nutrients dissolved in the water coming from the fish production tanks, sea urchins, and worms.

Further validation is needed but the company plan to produce enough *Ulva* to support sea urchin growth at commercial production scales, with the potential to grow 100-200 adult individuals/m^2 to commercial size.

Raceways at Ardtoe Marine Lab (left), collecting samples of *Ulva spp.* (right).

Norway – *Fish cultivated:* Atlantic salmon

The Norwegian IMTA system developed by Gildeskål Aquaculture Research Station (GIFAS) in collaboration with the Norsk Institutt for bioøkonomi (NIBIO) is located at Oldervika, inside the Arctic circle.

The site consisted of Atlantic salmon and the cultivation of *Alaria esculenta* on two rafts (45x15m and 90x20m) located within the framework of the mooring system of salmon cages. Having never grown seaweeds before, initial delays resulted from: lengthy discussions with regulators, the need to determine a suitable local stock to use for cultivation, and learning the techniques required to harvest wild stock, mix sexes and grow sporophytes in the laboratory and seed lines.

Between May and July 2015, GIFAS harvested 2,200 kg wet weight of seaweed, which was subsequently air-dried on-site and sent to Ireland for use in fodder products. Some of the best quality material was used to test its suitability for human consumption; a collaboration with a local salt maker.

In late 2015 and early 2016 a larger scale seeding took place at the site, with 1.5 km of *A. esculenta* seeded string deployed in December 2015 and 1.5 km in February 2016. Soon after deployment the seed lines became contaminated with unwanted algal growth (called epiphytes) and this subsequently reduced the growth potential of the seaweeds. Rather than harvest a low biomass of seaweed GIFAS decided to leave the algae in the water, to observe and record the growth development over a much longer period in the hope of harvesting commercial scale biomass the following year. At the time of writing, the algae were continuing to grow.

GIFAS plan to continue with the cultivation of *A. esculenta* and development of their IMTA site, including a complete redesign of the fish and algae mooring system to allow each species to be grown in close proximity to each other. GIFAS are confident in the potential marketability of their IMTA seaweed, identifying a number of potential markets, including: food for human consumption, feed ingredients, development of bioactive compounds, as an additive to insect meal, and as a fertiliser.

Italy – *Fish cultivated:* European sea bass; gilt-head bream

In Italy, development of IMTA was a collaboration between sea bream and sea bass producer AQUA s.r.l. at their fish farm in the Ligurian Sea, and the University of Genoa. As the Mediterranean is oligotrophic, and lacking generally in nutrients, options for the IMTA setup were limited, but involved the deployment of the European Flat Oyster (*Ostrea edulis*) and Pacific Oyster (*Crassostrea gigas*) cultivated in lantern nets positioned 50m downstream from the fish cages.

At the beginning of the trial 2000 oysters were deployed in 3 lantern nets (containing 10-12 baskets in each). The stocking density was later modified to reduce the number of individual oysters per basket, to approximately 1000 oysters deployed in 5 lantern nets. These were harvested in November 2015 at a reasonable weight of approximately 60g (whole weight).

Despite low levels of microalgae and detritus in the water column, on which oyster feed, oyster

Algae rafts in Oldervika (left); monitoring seaweed growth in summmer 2016 (right). Photo: Erling Fløistad.

IDREEM IMTA Pilot sites across Europe

The IMTA site in Italy: offshore cages in front of Portofino Bay (top), underwater lantern nets (middle), harvest of oysterss (bottom).

growth performed sufficiently well, the pacific oyster performing better than the native European oyster. Based on the biomass achieved over the course of this project, it is estimated that potential production at the site could be in the range of 4-5 tonnes/annum, and taking 1 to 1.5 years to achieve harvest weight, before being transferred to another site for final growing, harvest and sale.

This latter point may change in the future. The site was given outline permission as a research project, and at the time of writing did not have graded shellfish water status that would allow direct harvest and sale from site. The work conducted on the feasibility of farming oysters alongside the fish, in terms of growth and survival of oysters in an oligotrophic environment, has been sufficient for the company to apply for this graded shellfish water status and work is on-going with the regulator to test the water and gain the necessary information and data to obtain this essential approval, so that the site can be a fully integrated IMTA site in the future. The company plans to scale-up to a commercial scale IMTA production facility, concentrating on pacific oysters along with their sea bass and sea bream, with planned deployment of oysters both north and south of the fish cages.

Since there is a lack of oyster production locally the plan for market into the future will be local distribution to retailers and restaurants.

Cyprus - *Fish cultivated:* Gilt-head bream, sea bass, meagre

Off the southern coast of Cyprus, in the Vasiliko/Zygi region, Seawave Fisheries Limited has cages of gilt-head bream (*S. aurata*), sea bass (*D. labrax*), and meagre (*Argyrosomus regius*) and has been collaborating with a local research organisation, MER Lab, to bring IMTA to this part of the eastern Mediterranean.

The local environmental conditions in this part of the Mediterranean have proven to be a major barrier to IMTA development at Seawave. The temperature of the water is above the tolerance level of many species and the water is highly oligotrophic, with low concentrations of chlorophyll and other particulate matter, so essential for bivalve growth for example.

Despite this Seawave's selection for trial included filter feeders, detritivores, and herbivores native to the Mediterranean Sea that were either available from the wild and/or produced at European hatcheries. Trials will continue beyond the life of the IDREEM project but growth trials have been conducted using mussels (*Mytilus galloprovincialis*), sea urchins (*Paracentrotus lividus*), oysters (*Ostrea edulis*), abalone (*Haliotis tuberculata*) blue crabs (*Callinectes sapidus*) and sponges.

Mussels were cultured in longlines around and inside fin-fish cages and in empty cages available on-site for comparison. A small number of abalone and sea urchins were kept in Ortac baskets, hanging on lines adjacent to sea bass cages in order to monitor survival rates and growth parameters. Sea urchins were also trialled in cages and on the benthos. Blue crabs were grown in Seapa baskets for a short period while sponges were cultured using the mesh and kebab methods.

Some species displayed growth to marketable size (e.g. mussels), but in most cases growth has been very low. Abalone and sea urchins have displayed remarkable survival rates in the baskets but need macroalgae to achieve significant levels of growth and development of gonads respectively. Unfortunately, macroalgae are not readily abundant in the vicinity of the farm and it has proven prohibitively expensive to purchase artificial feed. No harvesting of products was achieved during the life of the project, which proves a point that although IMTA offers the opportunity to diversify and increase overall aquaculture production in Europe, at some sites IMTA development is more challenging and faces environmental and technical bottlenecks.

Not to be put off a further trial was undertaken growing sponges, trialling two different methods of cultivation, referred to as kebab-line and mesh. Both these methods displayed challenges; the fragile sponges broke apart using the kebab-line method and got heavily biofouled with the mesh method. Sponges in the mesh displayed growth but sponges are slow growers and should not be attached to the farm structure. Commercial sponges seem to be a potential IMTA candidate in these oligotrophic waters.

A small number of all the species cultivated were collected for scientific monitoring purposes.

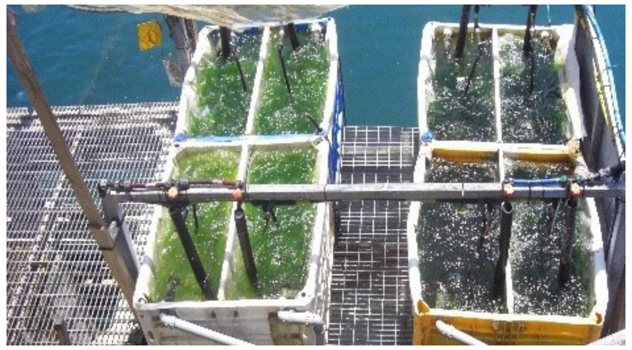
Cyprus: cultivation trials with sea urchins in benthic cages (top), sponges mesh method (bottom).

Israel - *Fish cultivated:* Sea bream

The IMTA system at Suf Fish farm, adjacent to the port of Ashdod in Israel, was developed in collaboration with Haifa University.

The Suf Fish farm consists of cages culturing sea bream. As part of IDREEM initial trials were conducted co-culturing grey mullet, a fish lower down the food chain, in mesh baskets underneath the main site (i.e. sea bream cages). Due to technical difficulties and inconsistencies in feed supply, the mullet experiment was terminated. What proved more successful was the cultivation of *Ulva spp.* (sea lettuce) in four containers located on the harbour sea wall, with seawater pumped from underneath seabream cages. Suf Fish harvested a total of 80 kg of *Ulva* between April 2015 and September 2015. The *Ulva* had to be harvested every 10 days during this period, such was the growth success. The *Ulva* was dried on site and used as an add-on feed for the fish farm. Although the IMTA operation is of a small scale, the growth of *Ulva* as an additional crop has been successful, achieving similar growth rates to those measured at commercial *Ulva* farms in Israel, but with the advantage of not specifically adding nutrients to maintain growth, as happens at these other commercial sites, and at the same time reducing the environmental load within the port area.

Following on from their IDREEM experience, SufFish plan to up-scale their IMTA *Ulva* production. The market potential is high, with an Israeli fish-feed production company expressing a strong interest in the crop.



Israel: fish cages at Suf-Fish (left) and the IMTA algae setup (right).

The IDREEM partners at the kick-off meeting in Oban, Scotland, October 2012.

The IDREEM special IMTA session at Aquaculture Europe 2014 in San Sebastian (Spain), in October 2014.

The first European Seaweed Production and Marketability Workshop, organized in May 2015 in Oban, Scotland, presented the activities of five different European projects,IDREEM, AT~SEA, EnAlgae, SeaBioPlas and Atlantic Blue Tech. It was organized in conjunction with the GlobalSeaweed network and the Biomarine International Clusters Association (BICA).

Learning from practical experience: the farmers insight

Karen Alexander, Adam Hughes: Centre for Aquaculture, Scottish Association of Marine Science, Scotland, UK

IDREEM focused on working with an informal "community of practitioners", to identify areas of shared experience, commonalities and lessons learnt, in relation to setting up and running an IMTA system in Europe[1]

In this work representatives from seven European companies across six countries were interviewed to gain an insight into their experience in developing their IMTA sites. The wide-ranging discussions included, for example, the processes involved in setting up an IMTA site, an evaluation of positive and negative experiences in producing products in an IMTA system, harvesting processes of IMTA products and difficulties relating to marketing and selling the products. Interviews were fully transcribed; the transcripts were then compiled, prepared and imported into a computer-assisted qualitative data analysis software which facilitates coding and retrieval, making the analysis process more efficient. This allowed large amounts of qualitative data to be reduced into smaller 'packages'. Data was then displayed in an organised and compressed format, allowing themes and patterns to be identified as well as comparisons and contrasts made, and thus conclusions drawn.

Shared experiences

This study revealed three main experiences shared between project partners:

The lack of an existing process for licensing of IMTA

It is unsurprising that most SME partners experienced issues relating to a lack of an existing process for licensing IMTA sites, given the novelty and early development stages of establishing the practice of IMTA within Europe. This certainly appears to have been the case in terms of the amount of time taken to obtain a permit in the majority countries included in this study, with one partner still not having received a full permit after three years as regulator and policy maker determine how this should be implemented.

Environmental constraints

Environmental constraints were an issue for some of the partners. One partner already operates in an exposed site with very dynamic conditions (where waves can be up to 6m), and for this reason had to create a custom-built structure to deal with the high hydrodynamics. Furthermore, several partners had to deal with destruction due to storm events. It should be noted however, that the partner already dealing with an exposed site did not suffer from problems due to storm events. This would suggest that when planning for an IMTA site, issues of exposure and hydrodynamics require in-depth consideration. In some cases, it may be as simple as placing the more fragile species on the inside and the more rugged species on the more exposed side, however decisions will likely depend on which species within the system are most valuable.

Drying and storing of algae

The drying of algae is perceived to be one of the main bottlenecks in algae culturing. Conventionally, algae drying is done by solar drying by hanging or spreading the algae over a net or tarpaulin; oven drying and freeze drying are also used, particularly in more temperate regions. However, as many of the Atlantic-based partners noted, access to driers was problematic. Either driers were not locally available, or not available at the time required. One of the partners suggested that freezing algae in a similar method to freezing other seafood could be a suitable way in which to deal with the drying and storing problem. Alternatively, another partner suggested establishing a joint platform within the industry to enable shared access to facilities.

[1] This is an abridged version of a longer publication: Alexander, K.A., Hughes, A.D. 2015, Teach a man to fish… technology transfer and development in European multi-trophic integrated aquaculture (IMTA), submitted to the Aquaculture Journal, pending publication.

Chapter 3 - Learning from practical experience – the farmers insight

Lessons learned

The partners also identified three key lessons learnt. Firstly, it is important to choose extractive IMTA species based on what is endemic to the area and grows well. Much research has been undertaken into candidate species for IMTA, in most cases experience suggested that growing species that were not only endemic to the general area, but actually found growing at the site, were likely to be the best option. The difficulty arises when determining if there is a market for such extractive species.

Secondly, simplicity is key in establishing the correct system design of IMTA. Sometimes, introducing IMTA in an existing farm requires to re-design the aquaculture site and its operational grid, in order to deal with physical conditions and constraints at the site but also to make the system easier for the farm employees to work with This may take a lot of trial and error, but that simplicity is crucial to the final design chosen.

Finally, most companies were 'learning by doing' and identified the need for a range of skills. Farm workers may be required to develop a variety of complex knowledge and know-how, and to manage a number of different species in a variety of system design. In the IDREEM project, the range of expertise required has been possible with the inclusion of the research partners, but yet it has still led to a "trial and error" type of learning approach.

One of the most successful developments of IMTA within the IDREEM project was where a fin-fish company bought in expertise directly from the shellfish industry. While this may be an option for a larger operator, for smaller SMEs it may not be practical. In such a case a partnership and co-location model of fin-fish and shellfish farmers may be more appropriate. However, when undertaking a commercial scale IMTA operation, obtaining the required skills will be a key consideration.

The IDREEM project has gone a long way in bridging the gap between laboratory research and commercial development. Nevertheless, no matter how much experimental research and advance preparation is undertaken prior to setting up an IMTA system, at this early stage there are still likely to be many problems identified and lessons learnt. In the move from a mono-culture to poly-culture system a number of issues must be considered, particularly relating to the initial set-up of the system.

These considerations will be indispensable when it comes to moving forward with commercial scale operations.

1. There is no existing process for licensing IMTA sites, when this comes into place in any specific case, this should be communicated across the EU through mechanisms such as the EU Aquaculture Advisory Council.
2. Storm events may be problematic in exposed areas, it may be prudent to consider placement of species on the site to reflect this prospect.
3. The drying of algae is a bottleneck in algae culturing, freezing may be a potential solution or alternatively establishing a joint industry platform to enable shared access to facilities.

When choosing which extractive species to culture, species which are not only endemic to the general area, but actually found growing at the site, are likely to be the best option.

A screenshot of the TV documentary about IDREEM. Image courtesy: Euronews.

Learn more

In July 2016 the IDREEM project was featured in the Euronews TV programme Futuris Watch this documentary at **goo.gl/lygvZH**

Assessing the environmental interactions of IMTA

Mariachiara Chiantore: DiSTAV - Department for Earth, Environment and Life Sciences , University of Genoa, Italy

A European scale comparison of off-shore mariculture farms shows good environmental sustainability and scope for growth.

Aquaculture, and marine aquaculture in particular, has often been associated with a perceived degradation in environmental quality, especially in the eye of public opinion. This perception, is a somewhat older view and often not substantiated by scientific data, but can create a bias in legislator and public bodies, that sometimes then opposes the development of new farms, or the enlargement of those that are already working, effectively reducing the scope for 'blue growth' in European coastal areas.

While a large literature exists on negative environmental impacts of aquaculture farms, it mostly refers to farms within closed bays or those located in low current speed environments, where farm effluents tend to sink to the bottom before being washed away and diluted by the action of currents. More recent development of marine aquaculture includes consolidation in more exposed environments where conditions are better. Off-shore farms, also, sit in areas that are farther away from the coast subject to faster current and rougher conditions. While this makes for higher running and maintenance costs, it also provides ideal conditions for effluents dilution and better environmental conditions that could be used within a marketing strategy to help producers generate a higher income and more efficiently cover production costs.

The IDREEM project has addressed environmental interactions, investigating differences among farms and control sites at each of the partners' facilities, both under monoculture and IMTA, assessment covering the water column and sediment community. A good assessment of present possible impacts of the farms has been performed as well as a general environmental setting characterization in order to support choices for further development of farm activities in an IMTA perspective.

As part of this work an estimate of food health related aspects has been performed, assessing metal and organic pollutants levels on both main products (fish) and on the additional species added to each site (seaweeds and bivalves).

Farm activities, water column quality, sediments and macrobenthic communities

Water column features investigated were temperature, salinity, nutrients and chlorophyll concentrations, as well as currents. At all the farms investigated, changes in water quality were observed over time, depending on the time of year in which sampling was undertaken, but no significant differences were detected between farm sites and controls in terms of water column quality. Within the data collected there were times when higher nutrient concentrations were recorded, but not consistent over time and never obviously related to farm activities. Sediment organic matter, grain size and macrobenthic community structure were investigated at all relevant farms, at both farm and control locations.

The results highlighted an extremely limited impact of the farm activity on the sediments and benthic communities living there, with no significant differences at all between farm and control sites in organic matter concentration, for example, and only limited differences in the structure of benthic communities for most of the farms investigated.

By way of example Figures 1 and 2 show the plots of sediment organic matter and environmental quality based on benthic communities in three of the investigated farms, which, based on their current speed (referred to as hydrodynamics) were all characterised as high energy sites.

There was no significant difference found in the concentration of organic matter (Figure 1) at the sampling stations below the cages and those tested progressively farther away from the farm in the case of farm 2 and farm 3 at the chosen sampling

times. At Farm 1 the concentration of organic matter was significantly higher in the middle sampling station (Mid) compared to all other stations in July 2015, but it was not the case in November 2014, for example. Regarding the environmental quality assessment on benthic communities (Figure 2), two out of the three investigated farms seem to have no impact in the area they are located, as measured by macrobenthic community composition. Only Farm 1 has a very limited impact that quickly dissipates, and impacts are not measurable at the North and South stations which were placed just around 100 m far from the cages.

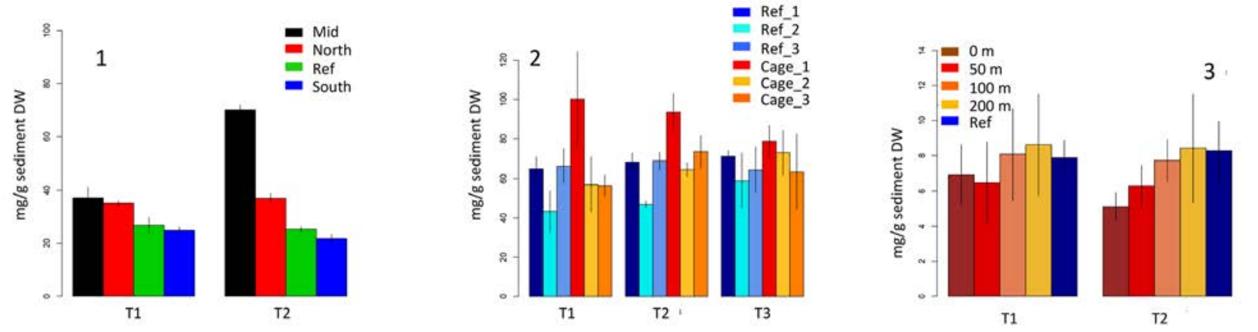


Fig. 1. Organic matter concentration (mg/g sediment dry weight) at different times in sediments below three of the farms of the project, located in North-Eastern Atlantic Ocean and Mediterranean Sea. Error bars are 1 standard deviation.

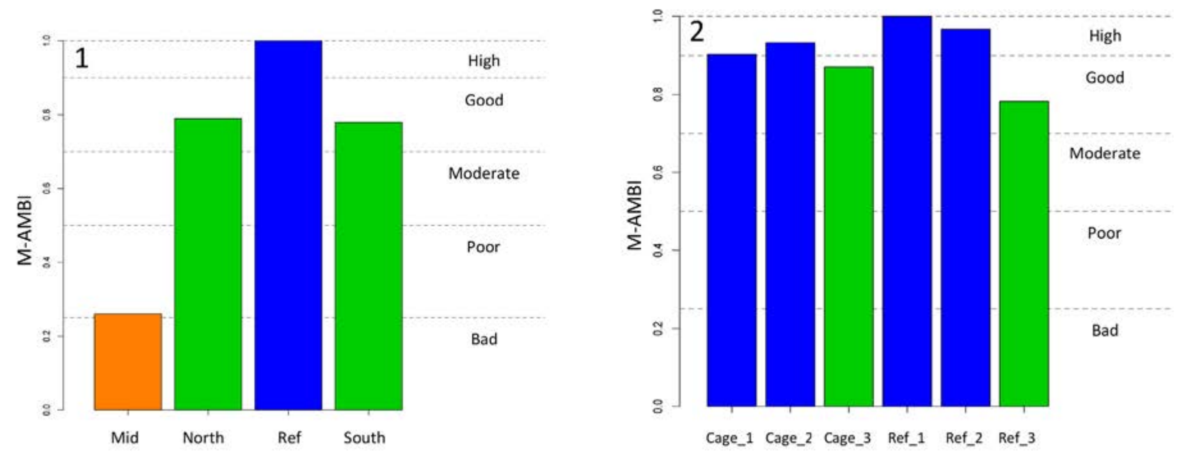


Fig. 2. Environmental quality assessment by means of M-AMBI benthic index in sediments below three of the farms of the project, located in North-Eastern Atlantic Ocean and Mediterranean Sea.

Food safety

Food safety aspects were investigated in relation to concerns that co-cultivation under IMTA of different species could affect their quality, because of the potential for bioaccumulation of some contaminants.

To assess this, fish, mollusc and seaweed samples from IMTA and control sites were collected from all the farms, and assessed for concentrations of relevant contaminants, including heavy metals, Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCB) and microbiological parameters), evaluating compliance with the limits set by the European legislation[1].

Results show that contaminants concentrations in all investigated species were well below the thresholds set by legislation, except for a few cases of seaweeds, where thresholds marginally exceeded legislated concentrations for some metals.

Despite this these excess concentrations were never related to the IMTA implementation and seem to be more related to species specific bioaccumulation or to higher background concentrations.

[1] In particular we referred to 2006/1881/EC (for human consumption), 2002/32/EC (for animal feed and feed materials) and 2005/2073/EC (on microbiological criteria for foodstuffs). National French regulations (inspired by EU laws) were also considered about seaweed for food consumption.

Implications for IMTA

Assessments made through the IDREEM project show that off-shore farms or those located in more dynamic environments in Europe, generate a low impact on water quality and the surrounding seabed. This contrasts with observations in some regionally enclosed coastal areas and indicates the possibility of pursuing a sustainable blue growth agenda, as pursued by the European Community, by fostering the development of off-shore farming activities.

There were no observed differences in water column and seabed impacts at sites that started as monoculture facilities and ended as IMTA sites, culturing a range of different species. This is perhaps not unexpected, given the relatively small scale of the IMTA experimental layouts that has not allowed for a more intensive assessment. Some of the farms had close proximity between fish and other species, whilst others had larger distances (up to 300m in one case) between the fish culture and culture of the bivalve and seaweed species. It has not been possible directly to test any possible mitigation of the environmental footprint of the farms through the introduction of IMTA. And because of the distance between fish and other species cultivation in some circumstance, it may be that assessment of water quality and sediment quality under IMTA needs to be carried out at a larger scale than a single site location.

The good growth performance of the co-cultured species (seaweeds and bivalves) in most of the sites, alongside the low contaminant contents, support further implementation and uptake of IMTA practices in European aquaculture.

Furthermore, these results showing performance of IMTA in off-shore conditions, reinforce the potential for decision-making in spatial planning, to select Allocated Zones for Aquaculture[3].

Finally, these results highlight the need to challenge the technical constraints related to operating in off-shore conditions in implementing IMTA as well as the legislative constraints related to licensing and permitting for IMTA operations.

The fish cages of AQUA srl are located in open waters, 2 km off the coast of Lavagna, in the Ligurian Sea, not far from the Portofino Bay.

[2] Resolution GFCM/36/2012/21

Life Cycle Assessment of Integrated Multi-Trophic Aquaculture in Europe

Angelica Mendoza Beltran, Jeroen Guinée: Institute of Environmental Sciences (CML), University of Leiden, Netherlands

The environmental impacts of fish production largely depends on the technologies and practices used at the farms. IDREEM has mapped and compared the environmental performance of monoculture and Integrated Multi-Trophic Aquaculture (IMTA) systems, using Life Cycle Assessment (LCA).

Improving the environmental performance of aquaculture in Europe is a central part of the sustainable development of the sector. Environmental impacts of fish production largely depend on the technologies and practices used at the farms. The dominant technology in Europe is monoculture in which a farmer specializes in the growth of one species. While "efficient", this practice can raise concerns with regards to several environmental issues such as excess nutrients in the water, especially in "enclosed" bays.

The IDREEM project evaluated an alternative way for aquaculture, Integrated Multi-Trophic Aquaculture (IMTA), that aims to alleviate some of the issues with excess nutrients. Unlike monoculture, IMTA produces more than one species thus increasing the production of the farm while managing some emissions originating from the cultivation of the monoculture species. For instance, co-production of fish with seaweed leads to less emissions of dissolved nitrogen and phosphorus to the sea water as the seaweed uptakes these nutrients emitted in the grow-out of fish.

In IDREEM, we have mapped and compared the environmental performance of monoculture and Integrated Multi-Trophic Aquaculture (IMTA) systems, using Life Cycle Assessment (LCA).

Environmental trade-offs in Life Cycle Assessment

Monoculture production of fish leads to emissions of nutrients that are expected to be reduced in the IMTA production. On the other hand, when IMTA production is introduced additional environmental impacts are expected due to the add-on infrastructure required, including ropes, buoys and extra diesel and so on. The balance between such dynamics leads to environmental trade-offs when comparing monoculture and IMTA production of fish. The comparison of the life cycle impacts of monoculture and IMTA production of fish for seven SMEs in the IDREEM project showed that environmental trade-offs largely depend on two factors: (i) technical parameters of the IMTA systems (ii), methodological parameters (Figure 1).

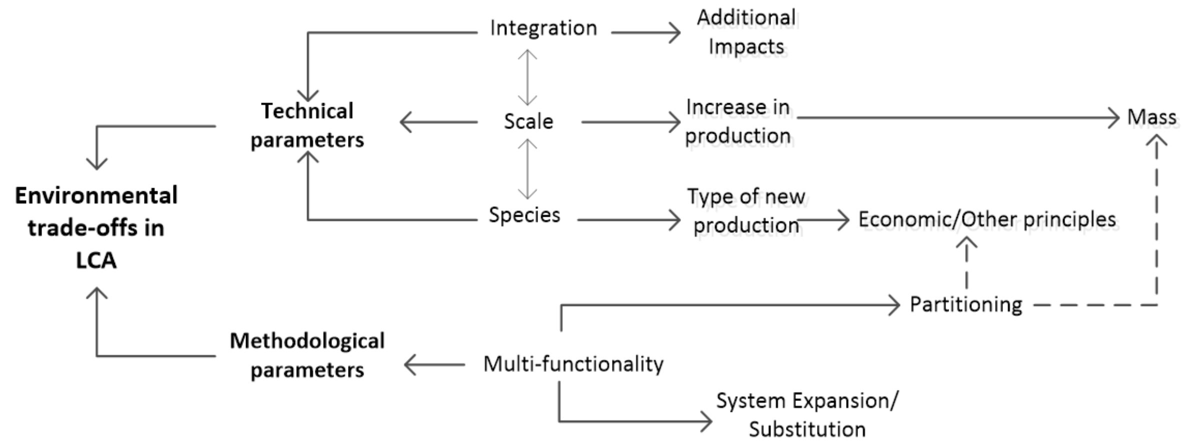


Figure 1. Key parameters determining the life cycle environmental trade-offs between IMTA and monoculture production of fish.

Technical parameters of the IMTA systems

The IMTA systems are composed of the monoculture species (fish) and the co-cultured species. In all the pilot sites considered in IDREEM, additional infrastructure was needed to co-culture the IMTA species, which mostly consisted of new offshore infrastructure. This resulted in additional life cycle environmental impacts due to the production, use, maintenance and disposal of such add-on infrastructure. The integration of activities necessary to grow the IMTA species as part of the current fish grow-out activities determined other additional impacts, such as the use of additional fuel for boats, compared to that needed with just the monoculture site present.

The need for additional infrastructure is closely linked to the type of co-cultured species as well as to the scale of its production. At the same time, the choice of co-cultured species is largely determined by environmental variables such as temperature, photoperiod and nutrients content in the sea water, that will allow or halt their growth. Overall, technical parameters determined additional impacts of the IMTA system as compared to the monoculture.

Methodological parameters

In comparison to monocultures, IMTA systems produce more than one product, i.e. the fish plus the co-cultured species. Therefore, the products of IMTA and monoculture are not comparable unless impacts of the system can be allocated between species. We partition the impacts of the IMTA system in the impacts of fish and the co-cultured species using different partitioning principles (such as mass, economic value, protein content) and have calculated the LCA results using each method. Results showed that trade-offs between IMTA and monoculture impacts are influenced by this parameter. For instance, a "turning point" was observed for impacts that showed benefits under mass partitioning and detriments under economic partitioning. This was the case at very low prices and scales of production of co-cultured species compared to the fish price and scale.

IMTA vs. monoculture

IMTA systems reduced life cycle eutrophication impacts compared to monoculture systems. This is despite the fact that IMTA generates additional need for more infrastructure, fuel and other resources, and could therefore translate into marginal benefits in the life cycle impacts per unit of fish produced under IMTA compared to monoculture. The outcome depends on methodological choices made. Also, any impacts increasing in IMTA with respect to monoculture, depend on the final setup of the IMTA species and the material requirements and wastes generated to construct, operate and maintain it, as well as the integration of activities for managing the IMTA species into the current activities of the farm for fish grow-out.

At the scales of production and with the setups (and level of integration) of the IMTA systems considered in the IDREEM project, similar environmental performance (marginal benefits or drawbacks) was observed for the IMTA and monoculture production of fish in the IDREEM farms. The scales of production of the co-cultured species were marginal compared to the fish production and the integration level of new productive activities, for the co-cultured species, in the current production activities of the farms were also low.

There remains some uncertainty in the results of this Life Cycle Assessment. The analysis was based on discrete estimates for one cycle of fish production and the corresponding IMTA species cycles for the co-cultured species, based on projected inventories. Given this limitation the analysis is not sufficient to determine statistical significance of the outcomes.

It will be important that future studies deal with variability and uncertainty in production data, from production cycle to production cycle for all species in the IMTA set-up, as well as uncertainty introduced due to methodological choices. Importantly within the IDREEM project this anomaly lead to a methodological advancement dealing with choice uncertainty in LCA, and a new approach was developed using a pseudo-statistical method to simultaneously deal with data variability, which is available (see references).

Despite the uncertainty around IDREEM LCA results, we can expect that scaling-up of IMTA systems to industrial scales of production in combination with more economically valuable species and higher integration of activities to manage both the fish and the co-cultured species, so that they are technically and biologically integrated as much as possible, will lead to increased benefits in the environmental performance of IMTA with respect to monoculture production of fish, per unit of fish produced.

Right: Salmon cages at the Norwegian IMTA site. Photo: Erling Fløistad.

Social acceptance of IMTA and policy implications

Karen Alexander: Scottish Association of Marine Science, Scotland[1]

Stakeholder interviews and public questionnaires show that there is potential for IMTA in the public's mind. Nearly 70% of those surveyed recognised improving waste management, increasing food production and improving overall sustainability as key benefits of IMTA.

Societal acceptance is an important factor influencing the successful development and spread of new technologies. There are numerous examples around the world of societal opposition hindering or even stopping the implementation of projects, perhaps the most instantly recognisable case being that of wind energy technologies. In the case of aquaculture, societal opposition has, in some instances, led to lawsuits and even violence. For these reasons, it is vital that we understand societal perceptions of IMTA prior to attempting to set up full-scale commercial operations.

Societal perceptions are held by stakeholders (those who can affect or be affected by IMTA operations) and the lay public. The issues concerning IMTA are likely to be quite different for each group, largely because the former are prone to have a set of preferred policy objectives in mind or a defined agenda, whereas the latter are unlikely to have an a priori viewpoint. In the IDREEM project, we wanted to investigate the perceptions of both groups.

Stakeholder acceptance of IMTA

In-depth interviews with a variety of stakeholder groups including planners, farmers, retailers, and environmental and community organisations (amongst others) revealed that levels of knowledge of the concept of IMTA were mixed across different stakeholder groups and across countries. Unsurprisingly, those who were directly linked to the aquaculture industry were more familiar with IMTA. Stakeholders interviewed in Norway and Scotland were also generally more aware of IMTA. It may be that the longer history of commercial aquaculture means that they are storming ahead with more sustainable and/or profitable aquaculture production methods.

A variety of perceived positive and negative effects, as well as risks and potential mitigation, regarding IMTA practices were also identified during the interviews with stakeholders. Many of the anticipated negative effects, which included spatial and location issues; concerns regarding interactions between species, food safety, visual impact and interactions with other users; and the potentially high investment needs required, were not specific to IMTA but relate to traditional monoculture also. In fact, by amalgamating two or more monoculture aquaculture facilities which are currently remote from each other, spatial or locational problems may be alleviated. The positive effects identified by those interviewed were much more specific to IMTA and included environmental impact reduction, waste utilisation, resource efficiency and new income streams.

Similarly, the sources of risk raised by the stakeholders also focused very much on IMTA. Containment of species which are broadcast spawners (when animals release their eggs and sperm into the water and where fertilization occurs externally) such as urchins and oysters may be difficult and this may have an impact on native species. Very few risks actually related to the environment, but focused rather on the industry. Stakeholders believed that the biggest risk for the industry related to economics and the existence of markets. It was suggested that 'middle-class trendies' might be interested in buying some of the potential IMTA species such as sea urchins or sea cucumbers, but that most consumers are quite conservative regarding the seafood products that they are willing to buy. However, stakeholders also believed that many of these risks can be overcome by spatial planning, education and further research.

[1] Now at Centre for Marine Socioecology, University of Tasmania, Australia.

Public acceptance of IMTA

It has been suggested that public criticism based on suspected environmental impact may be holding back development of the aquaculture industry and that IMTA may be able to remedy this. In the IDREEM project we also undertook a multi-country internet-based survey of 2520 people to assess lay public attitudes towards aquaculture in general and IMTA more specifically.

A key finding of this survey was that the general public do not hold as negative perceptions of aquaculture as previously thought, in fact they often rank the benefits higher than the impacts. Over 50% of respondents ranked aquaculture as being important for improving health and nutrition and as being part of a reliable and affordable food source. Economic boosts and job creation were also ranked very highly. The main negative impact found was pollution, with approximately 50% of respondents expressing concern over this issue. Animal welfare and conflicts with other users were seen as moderate impacts and visual impacts, biohazards and risks to wild fish were not seen as major issues at all.

It is important to remember, however, that attitudes can vary widely from country to country due to different cultures as well as different social and economic factors.

Public awareness of IMTA was universally low, although people who were under 35 years old, more highly educated and had a higher than average income were more likely to have come across the term. Based on some of the perceptions of aquaculture in general, it is fairly safe to assume that the level of knowledge of aquaculture was not high to begin with. For example, only 25% of respondents regarded overfishing as a negative consequence of fish farming, and 60% of respondents viewed aquaculture as a means of preventing overfishing, whilst this is considered by experts to be one of the major negative impacts of aquaculture.

To assess lay public attitudes towards IMTA, we first had to provide an explanation of what an IMTA system entailed. Once the IMTA concept had been explained responses to questions about its potential reflect the potential benefits with reasonable accuracy. Nearly 70% of those surveyed recognised improving waste management, increasing food production and improving overall sustainability as key benefits of IMTA. Interestingly, this result mirrors the findings of a similar survey carried out in Canada.

Improving social acceptance of IMTA

So how can we improve societal acceptance of IMTA? The IDREEM project has identified two key ways in which this could be done:

The two societal groups addressed in the IDREEM project, stakeholders and the lay public, have quite different levels of knowledge. The former group can be split into those who are very aware (those linked to the industry) and those who are less so (those not linked to the industry), whereas the latter have very little understanding of the concept. Clear communication and education (using information from scientific, government and media institutions) will be key in leading to mainstream awareness and acceptance of IMTA, although this must be appropriately targeted for each group.

Standards for stakeholder acceptance of IMTA or any other new aquaculture developments are likely to be based on a mix of local and national social, economic and cultural factors. However, a number of issues were raised in this study that crossed the stakeholder groups and countries. To address these issues, it will be important to provide a definitive demonstration of the financial and environmental benefits of IMTA accruing for both the producer and the local environment. Furthermore, the issues raised should form priorities for research and reform. Indeed, many of these issues could be addressed at the European level.

To shepherd successful development and spread of IMTA, improving societal acceptance is likely to be crucial. Should this be achieved, IMTA may just become a common feature of an economically and environmentally sustainable European aquaculture industry.

David Attwood – Aquaculture director at Loch Fyne Oysters, interviewed by Mark Stephen for BBC Radio Scotland in January 2015.

Photo courtesy: BBC Radio Scotland

Market and financial assessment of IMTA

Shirra Freeman: Leon Recanati Institute for Maritime Studies (RIMS), University of Haifa, Israel.
Dror Angel: Department of Maritime Civilizations, Leon Charney School of Marine Sciences, and RIMS, University of Haifa

One of the major reasons for interest in promoting IMTA production systems is the double potential of improved profitability and environmental performance. In IDREEM the economic dimension of multiple IMTA production systems was analysed from the perspective of fish farmers, markets, consumers and environmental stakeholders.

In IDREEM, market and financial aspects of Integrated Multi-Trophic Aquaculture were assessed. The work focused on translating environmental and social impacts of IMTA into monetary values (€) of direct relevance to the IMTA investor/operator, in effect valuing the external effects of IMTA for the company undertaking it.

This assessment was based on the concept of Total Economic Value (TEV) of the transition from monoculture of fed finfish to an IMTA system incorporating the additional species. TEV measures the changes in economic benefits stemming from alterations in ecosystem services and environmental quality. In the case of IDREEM, the aquaculture-ecosystem was assessed within the context of changing the method of producing farmed fish. The benefits considered accrue to both private and public stakeholders.

The private good benefits are those that accrue directly to the fish farmers undertaking the investment in IMTA. Monetary metrics were readily available for these and the analysis included a comparison of the profitability of monoculture and IMTA; an assessment of consumers' willingness to pay a premium for IMTA products; price time series analyses and projections for all the main species produced by IDREEM's SME partners, and an assessment of the major risks they faced.

The public good benefits are those that accrue to a wide variety of stakeholders who may use the services from the aquaculture-ecosystem directly or indirectly. The benefits of interest are those that result from the external effects from the transition to IMTA. Two main assessments were conducted, an ecosystem service mapping and a viewshed analysis of each site. In addition, the consumer-choice survey results were used to obtain an indication of the value that fish consumers place on products from aquaculture systems that may produce lower waste discharges.

As with all environmental economic and bioeconomic modelling, analyses relied on identification of production, environmental and social variables as well as on conventional economic variables such as prices, revenues and interest rates.

This work resulted in two fully elaborated empirical models of financial performance from the SME partners that successfully implemented commercial scale IMTA. One model for a single farm implementing IMTA and the second for two farms cooperating in implementation. Time series models were also developed, for the price of farmed Atlantic salmon, gilthead sea bream, mussels, oysters and scallops in domestic and export markets for the IDREEM partner countries in which each species is produced. The models include test, training and projection components.

An analysis of risks for the implementation of IMTA was also carried out, including two workshops, in order to assess both stakeholders' risk perceptions and insurance behaviours. A decision model for the investment in IMTA was developed, including characterization of different types of risks facing prospective producers and solved drift control models based on the econometric price models. A review of markets for the products of IMTA was compiled. A choice survey and model for the preferences of consumers for IMTA products was conducted. A mapping of the ecosystem service for the six IDREEM coastal sites was done, focusing on recreation and tourism; education; amenity and biodiversity. This included viewshed analyses demonstrating how the implementation of IMTA may alter visual amenity of the areas surrounding the sites.

What we learned

The results of the work indicate that for the single farm model, Salmon-Seaweed culture is profitable, although slightly less profitable than monoculture of salmon. Nevertheless, IMTA generates enhanced biodiversity services, for example by providing habitat for lumpsuckers in the seaweed lines which could provide a resource for these important species in the fight against sea lice, through lower biomass loss. The additional structures were also seen to be useful nursery areas for local species (see page 32).

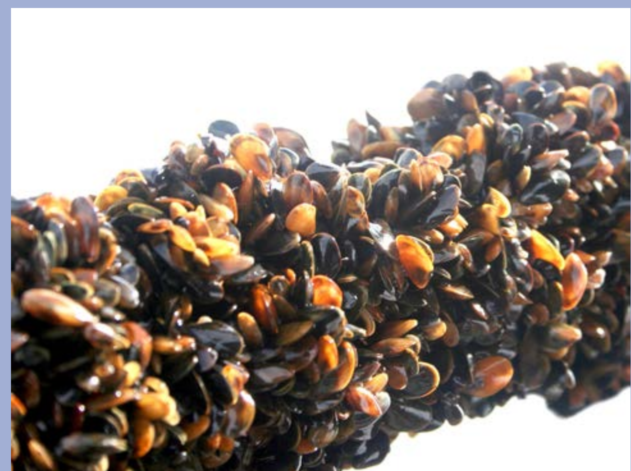
Willingness to pay a premium for sustainably produced salmon and sea bream exists in each market examined, indicating that if a farm can successfully position its IMTA products within the market, it stands to earn a higher return from the investment needed to set up the IMTA system.

With respect to the major risks facing SME IMTA producers, there is a gap between the perceptions held by producers and the actual experience of risk. This is especially true of market risks and insurable risks.

The result is that producers face greater losses than they would if these risks were more efficiently managed.

Changes in visual amenity can be rigorously analysed using viewshed models. The models produced measure the extent to which visual amenity is impacted by the presence of fish farms. These provide a powerful tool for planners concerned with changes in ES. They are also relevant for resolving stakeholder conflicts surrounding visual amenity.


Some examples of high value species that can be farmed with IMTA: sea urchins (left), queen scallops (right).




Some examples of high value species that can be farmed with IMTA: mussels (left), oysters (right).

A CASE STUDY

Adding algae to a salmon farm brings positive changes in ecosystem services provision

Céline Rebours, NIBIO, Norway; Julie Stamenic, Cranfield Univeristy, UK);
Tomas Bjørnå, Akva Artic,Norway; Johan Johansen, GIFAS, Norway
Shirra Freeman, Leon Recanati Intitute for Maritime Studies, University of Haifa, Israel.

Atlantic salmon represents a major industry in Norway and the country and is the dominant exporter and producer of Atlantic salmon worldwide. In 2014, 378.4 million salmon were farmed. Owing to expansion, the industry is facing a range of challenges, resulting in a call for more sustainable solutions. Integrated multi-trophic aquaculture appears as an appropriate answer, able to help social, economic and environmental dimensions to work together.

In the IDREEM project, the Norwegian partner NIBIO conducted research to highlight changes in ecosystem services provision and the potential economic value of growing seaweeds in proximity of a salmon farm located at Oldervika (Nordland), an open fjord above the Arctic Circle in Norway. The site owned by GIFAS was the first one in the country to obtain a license for integrated algae culture on a salmon farm.

During the winter 2014-2015, two rafts were added to a structure placed inside the existing fish farm mooring system and 3 km of lines containing seed of the algae *Alaria esculenta* were deployed on the rafts. At the end of May 2015 a first harvest was undertaken with a further harvest early June. On removal from the sea, algae ropes were hung in air to dry, algae removed from the rope and further air dried for processing into a food product, or air dried and then sun dried for a feed product. By mid July 2015, approximately 2 tons (wet weight) of fresh *Alaria* were harvested.

In addition to a product for sale and the extra growth brought about by being near to the fish cages, the algae provided other services that are worthy of mention.

Having the algae on site increased the observation of local species, such as the lumpfish (*Cyclopterus lumpus*). Lumpfish are avid eaters of sea lice, and could provide a source of this fish as an alternative to chemical use on site. The presence of algae also played an educational role, familiarizing students and visitors with the aquaculture industry, with the technology required to implement IMTA, and in spreading the word that the aquaculture industry takes its obligations to reduce impacts seriously. The combination of positive effects highlighted by the research demonstrates that IMTA can help the aquaculture sector to deal with its current challenges and allow for a more sustainable and socially acceptable industrial growth.


The site in Oldervika.


Algae rafts at the IMTA site.


Lumpfish found in the seaweeds at harvest.

What are the impacts of IMTA: Modelling tools for IMTA

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Proof of the impact of IMTA, on growth and on environmental loading, is limited; except through modelling that can help identify changes in species growth when species are grown individually in monoculture and combined in the IMTA system, and net contributions in terms of environmental loading and removal.

In IDREEM, modelling has played a significant part in understanding growth of each species in the Integrated Multi-Trophic Aquaculture (IMTA) system; assessing the environmental consequences, and the potential to reduce both particulate and dissolved wastes from the fish culture element, one of the key propositions for IMTA.

The context

In Northern Europe measuring water quality changes brought about by fish farms is not possible due to high dissipation and significantly larger fluxes due to tidal exchange and water currents. In the Mediterranean, being oligotrophic, means added nutrients are often quickly mopped up by microalgae and other fish, so again not measurable directly. Modelling therefore enables estimation of environmental changes under IMTA that could not otherwise be articulated.

The use of computer models increasingly plays an integral part in the development of aquaculture, to understand growth and environmental impacts, to evaluate overall carrying capacity, and to improve selection of aquaculture sites. Using the models developed in IDREEM it has been possible to assess the environmental impacts for a range of species, both as monoculture and in combination in IMTA.

Modelling in IDREEM has been undertaken in two stages: 1) simulation of growth of individuals, calibrated and validated through on-site measurements of species growth; and 2) advancement of the FARM (Farm Aquaculture Resource Model) population model (see further reading for more information) to assess farm scale production, harvest activity and environmental change brought about by monoculture of finfish, and then multiple species under IMTA.

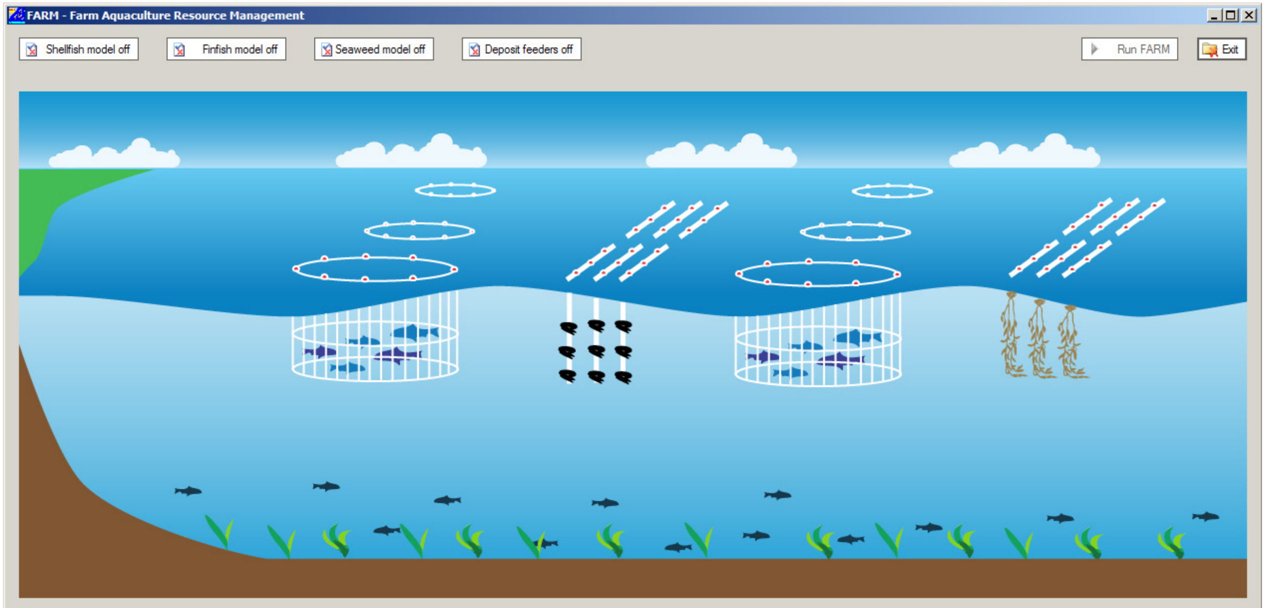
The FARM model uses state-of-the-art equations to describe the growth of each species over time, accounts for the inputs, such as feed, outputs such as dissolved and particulate waste, and resolves the culture practices to evaluate overall production of each species and the environmental consequences.

The model works by accounting for the overall IMTA site layout, the distance between species and estimates, among other things, the environmental

Output	Model Application
Production Analysis	· Simulation of potential harvest · Optimisation of harvest timingChanges in Stocking density, mortality · Optimum profit structure with repect to stocking density, mortality and food supply · Calculation of optimum proit output (Average and Marginal Physical Product)
Environmental effects	· Deposition analysis · Dissolved oxygen and sediment oxygen demand analysis · Effects of the farm on water quality · Assessment of nutrient input/removal (monoculture) · IMTA simulation on water/sediment quality (Fish/Shellfish/Algae/Deposit feeders)
Mass balance analysis	· Mass balance analysis for offshore farms · Environmental footprint for offshore farms · Production analysis, fish/shellfish/algae/deposit feeder growth calculations using particulate and dissolved nutrent analysis and other water quality aspects · Nutrient outputs for finfish farms · Nutrient reduction for algal culture · Nutrient reduction for shellfish culture · Nutrient uptake in deposit feeders
Farm footprint	· Determination of Nitrogen and carbon footprint · Farm value for nutrient credit trading
Shellfish	· Pacific oyster - *Crassostrea gigas* · American oyster - *Crassostrea virginica* · Blue mussel - *Mytilus edulis* · Mediterranean mussel - *Mytilus galloprovincialis*
Finfish	· Atlantic salmon - *Salmo salar* · Gilthead seabream - *Sparus aurata*
Algae	· Sugar kelp - *Saccharina latissima* · Winged kelp - *Alaria esculenta* · Sea lettuce - *Ulva lactuca*
Deposit feeders	· California sea cucumber - *Parastichopus californicus*

Figure: FARM model applications

loads created by farming fish species alongside the potential reduction in loading through IMTA and the co-production of different species with different feeding habits. Such estimates can be used to consider environmental loads, costs of production, and be used to optimise production, through an analysis of growth performance at different times of the year for example. As well as providing producers with valuable information that can support the sustainable development of their business, environmental estimates from the modelling frameworks were also used to contribute to Life Cycle Assessment (LCA) of farming activities.



Screenshot of the Farm Aquaculture Resource Model (FARM).

What do the models show

Using information provided by the aquaculture farmers, including environmental data and culture practice information, modelling of finfish in monoculture and multiple species in an IMTA configuration produced a number key observations.

The first is that finfish cage culture generates significant quantities of feed, faecal and dissolved wastes that enter the environment. This is already well known. However, a new development for the project is that waste streams are now clearly defined, which enables traceability of the waste streams through the system and into the environment, which was not available previously.

Secondly adding other culture groups, such as shellfish and algae to a site, did not affect the growth of finfish species or the total harvestable production of fish. This is not surprising, but important to state, because fish farmers need to know definitively that adding other species on site, will not affect the growth and harvest potential of their primary stock.

In comparing the growth of the added species in the IMTA system, the model showed that growing shellfish and algae side-by-side and near to finfish cage culture increases the growth of both the shellfish and algae, compared against the growth achieved with no fish present. This increase in growth of shellfish and algae removes an increased level of nutrients from the environment, offsetting some of the outputs from the finfish culture.

At the pilot scale used in the IDREEM project the level of production of added species, the spatial layout of the site and the temporal overlap in the production cycles for each species play a significant role in determining the changes in growth under IMTA compared with monoculture of each species.

At the scale used in the project the additional growth (size and harvest weight) generated in the shellfish and algae when co-located as part of an IMTA system, is small.

To give 2 examples:

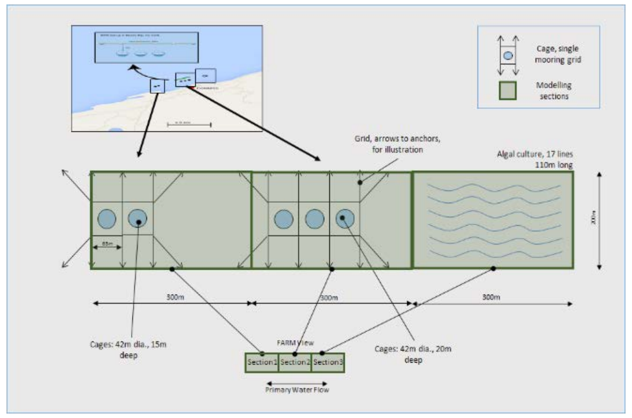
- Modelled outputs for the Norwegian system, with algae growing within the mooring system for the fish cages, produced additional growth in the algae of 4-6cm in length and an additional 600kg of algal product that would be harvestable.
- Modelled outputs for Italy, with oysters grown parallel to the fish cages, showed little interaction between the two due to poor positioning relative to the water currents at the site. The additional growth in the oysters predicted by the model was <1g over a 12-month oyster growth cycle. However, growth could be improved by revising the layout, shifting the oysters to north and south of the fish farm, which, based on the current flows, would bring the oysters into contact with more of the organic matter from the fish culture.

The impact of layout is important and best illustrated using diagrams of the sites.

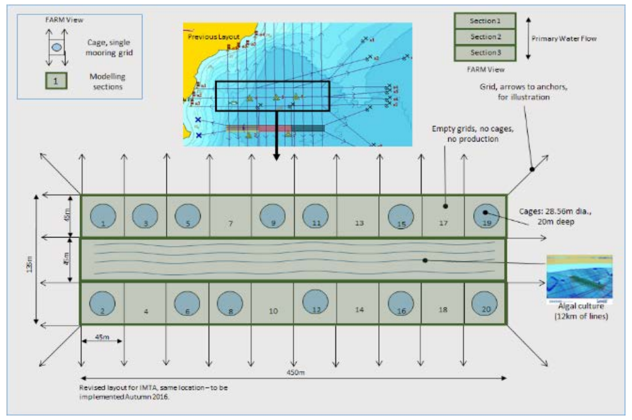
At the Irish farm, the algal culture is approximately 500m from the fish cages which diminished the chances for water flows, containing nutrients generated by the fish farm to then be utilized by the algal culture, in the model. If there is some means to bring the algae closer to the fish cages, then growth in the algae would be improved according to the modelling done.

At the Norwegian farm, the algal culture was integrated within the finfish farm, between 2 rows of fish cages, which allows water containing dissolved nutrients to flow more actively through the algal culture. Algal growth predicted by the model was larger at the Norwegian site than at the Irish site, for example.

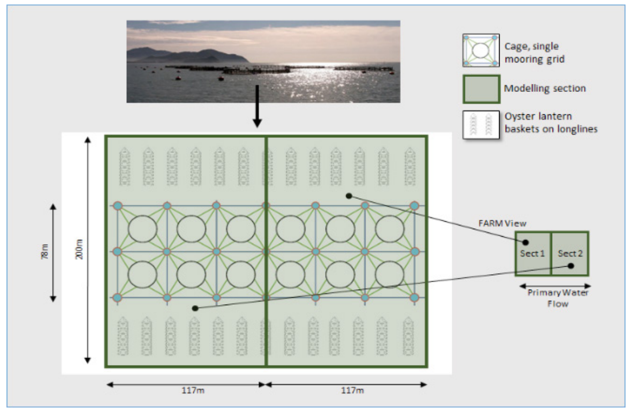
At the Italian site, oysters were grown running parallel to fish growth (see main current flow arrow) which may have limited interaction of the particulate wastes produced by the finfish and shellfish. A change in layout (not possible during this project) could improve this interaction and improve the growth of the oysters.



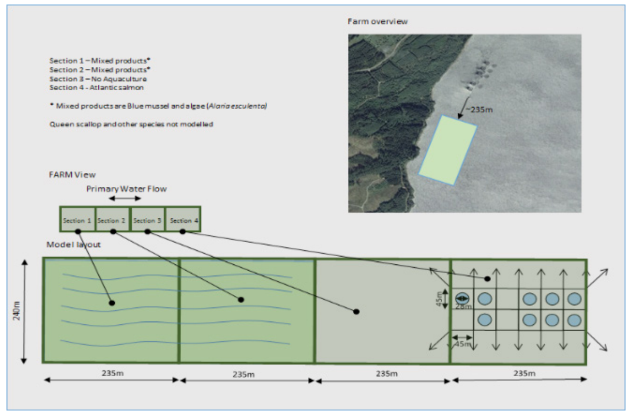
IMTA setup at the Irish site.



IMTA setup at the Norwegian site.



IMTA setup at the Italian site.



IMTA setup at the Scottish site.

At the Scottish marine site, the mixed system of additional extractive species included mussels and algae, both modelled in the IDREEM project, as well other species including scallops and oyster broodstock, which were not modelled. Presently there is some distance between the finfish site and the other species, possibly limiting the interaction between finfish wastes and the capture of this waste by these other species, potentially limiting the additional growth in shellfish and algae that is attributable to fish farm waste uptake.

The impact of timing in culture cycles of the different species used in the IMTA systems can also be illustrated graphically. Temporal overlap is important in IMTA, because uptake of nutrients from fish, by the added species can only occur when both are in the water. If fish are not present, algae and shellfish (and any other species in the IMTA system), are effectively being produced as monoculture. Similarly, when the additional species are not present but fish is, then there is also no IMTA in operation. Total production of each species is not the only consideration, timing of the culture cycles and the overlap of these, along with layout, are critical.

To give two examples:

In Scotland, mussel growth relies on natural settlement of spat, with settlement coinciding reasonably well with the addition of finfish, so that the mussels natural process meant a good overlap in production between fish and mussels. Conversely the seaweeds' natural reproductive cycle and reliance on using local collected stock to process and seed the algal lines meant just a single deployment of algae per year, in the first month of each year, so the overlap in production between finfish and algae was relatively poor.

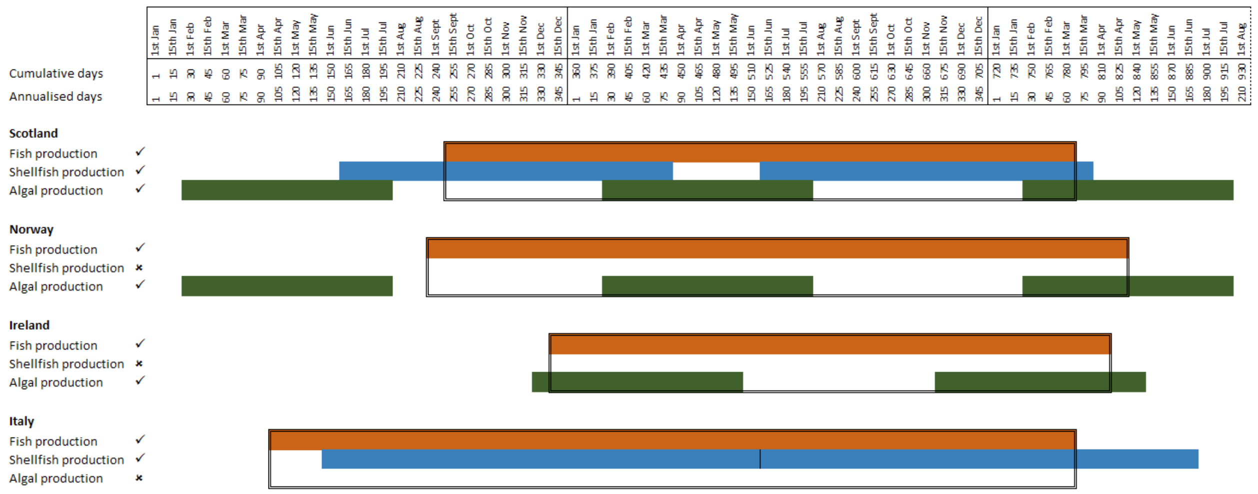
In the case of Italy, oyster production was able to be conducted over the same growth cycle as the finfish, which meant nutrients from finfish culture were available to the shellfish during their whole growth cycle. An important point is that oyster spat come from hatcheries, not from natural settlement, so the fish farmer had the option to deploy oysters at the same time as fish deployment. The production cycle for oysters at this site was 12 months, which enabled almost 2 complete cycles of oyster production for every 1 cycle of finfish.

In the IDREEM project, species choices among SME partners reflect a number of environmental, physical and practical limitations on what can be grown at each of their respective sites. Many European countries also have regulatory restrictions in place which currently limit species combinations and by inference the implementation of IMTA. Through the project these have mostly been overcome through applications for dispensation for research purposes in each of the countries this is necessary, which allowed growth under limited circumstances for the purposes of the project.

Companies have combined their existing monoculture of fish, with extractive species such as shellfish and algae, to create their integrated sites, with small scale production of additional species alongside the primary fish species. The modelling undertaken reflects this, but has nonetheless advanced our understanding of the importance of culture practices, timing and layout on the potential for a European style of IMTA system. Modelling has shown that species being grown with finfish offer enhanced growth potential, and results have allowed a re-consideration by farmer partners of culture practices, layouts and timing for their specific sites.

European production of aquaculture products is currently dependent on monoculture of single species, grown for the most part using large scale intensive monoculture production systems.

Aquaculture production has stagnated or reduced in most EU countries over the last 10 years and there is a need to increase production of a variety of aquaculture products. Development of Integrated Multi-Trophic Aquaculture serves a number of purposes, including the potential for the European aquaculture sector to grow in line with EU strategy, diversification within companies into new species, and increase in saleable products to generate additional income. Modelling activity has served to provide evidence of that potential.



Representation of the overlap in production cycles between species groups at four IDREEM sites.

Key take-home messages

The FARM model has been developed during the IDREEM project to include finfish, shellfish, algal and deposit feeder species; which can be modelled independently as monoculture, or in any combination under IMTA. Given the farm layouts possible during the project, and the small levels of production allowed through regulatory and practical restrictions, modelling has nonetheless shown that additional growth is possible in shellfish, algae and deposit feeders when grown in combination with finfish, and that this additional growth increases the removal of nutrients generated by the fish farm, as part of European style IMTA system.

Modelling has enabled an assessment of growth, nutrient transfer between species and evaluation of the IMTA systems, that would otherwise not have been possible through field measurement techniques alone.

Seaweed rafts at the Norwegian IMTA site. Photo: Erling Fløistad.

Moving forward with commercial IMTA

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Seven companies in six countries across Europe – a lot has been learnt. Challenges in adopting commercial levels of IMTA can really be broken down under three themes : policy and regulation, company's investment decisions and effects on farm management.

The concept of IMTA is characterised as win-win, where the twin benefits of increased aquaculture production and reduced environmental impact are coupled together, through a mix of fed and extractive species being grown together in a single site. Obviously there is a cost to pay for the development of IMTA, alongside the benefits.

The IDREEM project has provided the opportunity to systematically evaluate the adoption of IMTA, through deployment at seven sites across Europe, and through an assessment of impacts - economic, social and environmental; using a number of techniques, including direct measurement, Life Cycle Analysis, economic forecasting, socio-economic evaluation and growth and environmental modelling. This has been carried out against the backdrop of stagnating aquaculture production in Europe, and determining whether IMTA offers one solution to increasing overall production, in line with European scale and national aquaculture plans.

The evaluation has allowed a better understanding of the challenges faced by aquaculture producers when adopting an IMTA production system and some of the scientific analysis has allowed a more thorough assessment of what IMTA means for Europe, in terms of potential for species growth and environmental impacts, and economic development.

Each company and research group faced their own unique issues during the process of setting up, analysing and evaluating the IMTA systems. Nonetheless it was possible to discern some common themes on the challenges of adopting IMTA, which fall into four broad categories.

Policy and regulation

Across Europe the regulatory framework for IMTA is complex, sometimes not available at all and is not harmonized. While obtaining permission for small scale experimental IMTA has been possible within the project, the regulatory framework in some countries represents a significant barrier to the development of commercial IMTA. One IDREEM partner spending four years to achieve an algal facility, and another spending three years of the project to gain shellfish water status, and not yet gaining approval are testament to the difficulties and where the lack of clarity in regulations can lead to lengthy delays in licencing. A lack of understanding in what IMTA is at all social levels, and what the issues are in terms of policy development are an active discouragement to companies, preventing them from developing their own IMTA projects. To address this problem, a stronger and closer collaboration between the technology adopters and regulators is necessary. There must also be public awareness campaigns, especially as the research in IDREEM showed people were positive towards IMTA, and indeed were prepared to pay a premium for the final product.

While research should continue to provide evidence of both the impacts and benefits of IMTA at both pilot and commercial scale, dialogue is required with regulatory bodies to improve their education and understanding, with all parties working towards closing this policy and licencing gap.

Drivers for investing in IMTA

The aquaculture industry in Europe is mostly represented by small and medium size companies, although this is changing. For SMEs the scale of investment and the uncertainty over the level of return of an IMTA project can represent a significant barrier to its implementation.

A major driver for a company deciding to invest in IMTA is of course represented by the possibility to increase its revenues and to generate more profits. This, however, can be true also in the case of a farm deciding to simply invest in more finfish production, so why should a farmer decide to invest in IMTA instead of scaling-up its monoculture?

One reason could be that it is increasingly difficult to find suitable space to increase finfish production, especially where this is limited by social acceptance at a local level, or competing uses for the same space. In those cases, the inclusion of species that will extract nutrients at an existing site has the combined effect of increasing the total production, increasing turnover, while providing diversification and reducing risk potential, such as complete loss of all stock in a disease outbreak.

A second reason is the prospect of reducing emissions. At the pilot scale it has been difficult to prove definitively that co-production through IMTA has had the desired effect of reducing nutrients in the water column and on the seabed, though the research carried out suggests larger scale production through IMTA would indeed reduce overall emissions of particulate and dissolved wastes.

In such cases, regulators may allow for additional finfish to be produced at an existing farm, where the scale of production in other species means that the overall net impact is no worse than is currently experienced at monoculture sites. Additional biomass of fish production and the off-setting gained by nutrient reduction measures such as those offered by IMTA through the use of filter feeders, seaweeds, or deposit feeders for example, offers potential to overcome the stagnation in European aquaculture. Such would need to be agreed with regulators of course, but could be a good example of regulation driving the adoption of IMTA, whilst not increasing the overall impacts from aquaculture development and expansion.

Fish cages in Oban, Scotland.

A further driver for IMTA investment is represented by the premium potential for products produced at a "greener site". Work undertaken in the IDREEM project suggests that there is a definitive willingness, within the general public, to pay a premium for IMTA-produced fish, for example, even where this does not translate into increased price for the other species. 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, and this requires a clearer understanding of IMTA and development of a set of appropriate standards to work to.

Perhaps the last major driver for investment in IMTA, is the ability to tap into non-traditional markets. Alga grown in this project was processed into a condiment for direct human food production and into fodder, or used as food source for other species within the IMTA system. Small amounts were also given to research for biofuel. Shellfish grown to 10g in weight were sent to other sites for on-growing within the same partner, but offers the potential for sale to other shellfish producers as well. Partner companies have also identified potential for bio-active compounds from algae, along with fertilisers and fish feed ingredients. These uses have potential, in addition to direct sale of aquaculture products into otherwise under supplied markets, or internal markets that rely on imports from outside the EU.

The practicalities of IMTA for Europe

Though the concept of IMTA is relatively easy to understand, its definition and application is far from simple. A starting point for an industry definition might be how effective the IMTA system is at removing excess nutrients from the environment, especially nitrogen. Developing standards and setting the right thresholds for nitrogen removal may be crucial to the success of a certification system for IMTA, but proving definitively that growth of the extractive species directly offsets nutrient load from fish is difficult to confirm directly. Changes in water quality have a wider variability than could be offset by the extractive species at scales that are liable to be implemented in a European IMTA system. Modelling outputs have shown that both shellfish and algae grow more when co-located with fish, than when they grow without fish, which is suggestive of offsetting taking place, but this could not be confirmed by measured water quality values, at least not at the production scales in the IDREEM project.

There is a mismatch 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. Work in Canada suggests that to remove 10% of the nitrogen from a 1000 tonne salmon farm would require approximately 10 hectares of seaweed. IDREEM data suggest the scales are liable to be larger than this. This obviously represents a significant space requirement, and operational input. A study by project partners suggest that benthic IMTA may be far more efficient in terms of space requirements. In this type of IMTA detritivores are grown underneath the fin-fish cage within the benthic foot print of the cage, feeding on 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.

Modelling has also shown that it is not as simple as having fed and extractive species on site. Spatial distribution and temporal overlap in production between the species added also impact the potential offsetting. In IDREEM algal species grown within the cage mooring system grew better than at other sites where the distance between the fish and the algae was only 200 – 300m where the impact on growth was marginal. So IMTA implementation suggests that it is not simply a matter of placing additional species at random around a fish site, and that a fundamental change in farm layout is necessary. Such layout must also take account of the currents present, such that the extractive species are located in line with the fish site to maximise the likelihood these other species will come into contact with fish wastes, which has implications for moorings and layout, but this in-line system may also affect water flows through the site and the level of oxygen reaching the fish may be compromised, although this was not experienced in IDREEM sites.

Temporal overlap in production is also important. Production of some of the species, especially algal species, relies on removing mature wild to produce sporophytes, and the temperature limitations means this can only happen over latter part of the year, and deployment generally in the early part of the following year for on-growing. This with the relatively short growth period meant the overlap in production of both fish and algae was relatively short, limited to 50% of the fish growth period, thus limiting offsetting potential. Timing between fish and shellfish production was generally better than with algae.

Within this context, and the limitations imposed, a useful approach for developing commercial IMTA in Europe could be by not considering the cultivation of multiple fully integrated species at the farm level but rather at the scale of a water body; bay, loch or fiord, allowing for example larger production of say algae slightly further away from the fish farm, without impacting water and oxygen exchange through the fish farm.

With this kind of ecosystem scale approach, species integration issues, spatial scale issues and some of the issues in temporal overlap of production could be easier to manage. IMTA is considered for the overall net reduction in nutrients, for example, without the need for specific sites to fully offset its own nutrient loading from the production of fish.

Moreover, a broader scale would allow much more effective biomass and emissions control. For regulators and planning authorities, the locations and set up of farms could be planned and modelled to ensure that they are placed to balance maximising nutrient recovery while allowing the optimal biomass for the ecological limits of the system to be achieved.

Meeting the challenge of commercial IMTA

IMTA has the potential to deliver greater productivity and reduced environmental impact for the European aquaculture industry. However, at the moment most of the costs of adopting IMTA (not just financial ones), and the effort to get the ball rolling are borne by the industry and benefits are not currently being accrued by industry. This limits the IMTA potential and reduces the interest in industry to invest in its development. The IDREEM project has identified a number of tools that would allow this mismatch to be realigned:

1. Development of standards for defining IMTA in a better way than is currently done, and development of appropriate standards and certification system, that the industry can adopt and that can be understood by consumers and industry alike.
2. Pursuing a water body approach to IMTA and to the management of aquaculture, that uses the IMTA approach as a means for aquaculture to be more balanced within a wider ecosystem and to manage the social and environmental impacts. This will require better development in policy and regulation but offers a policy led approach that could best drive the wider scale adoption of IMTA.
3. Need for a better understanding of technical and biological constraints of benthic IMTA, so that the largest deposition issue, waste feed and faeces, could be used to develop efficient turnover of sediments and growth of harvestable product. Marine aquaculture in Europe is mainly monitored through its impact on the seabed. Benthic species in an IMTA system appears to offer the best directly measurable change in nutrient loading and is therefore a promising target for an IMTA win/win. It is however, the least developed because it is the most technically challenging.
4. Developing a market for aquaculture seaweed in Europe. Seaweed is a crucial component of most IMTA systems and for it to make a significant contribution to nutrient reduction it needs to be grown in larger volumes than has been practiced to date.

Meeting these challenges will require a large and combined effort, through policy managers, regulators, industry and research. Once these conditions are in place, IMTA will increasingly become an important tool for the development of the economic and environmental sustainability of the European aquaculture industry.

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