Integrated Multitrophic Aquaculture (IMTA) – A Successful Diversified Farming System

Shoji Joseph, Boby Ignatius, Imelda Joseph and N. Rajesh

ICAR-Central Marine Fisheries Research Institute
shojicmfri@gmail.com

Aquaculture is one among the industries growing at the fastest rate in the world with an average rate of 5.8% in the last 15 years (Food and Agriculture Organization [FAO], 2018); due to the increased high demand of products and a way to a good steady income generation in the minimum time. Aquaculture is an old practice thought to have begun over two thousand years ago in China (Rabanal, 1988). However, it has only been in the last four to five decades that commercial production became widespread, moving from an annual output of 4.7 million tons in 1980 to 80 million tons in 2016 (Bacher, 2015). Aquaculture is currently the food production sector owing to an increasing food demand, combined with fish stock depletion, it is now recognized that fisheries will not be able to meet the projected global needs in high-quality protein. This sector is expected to supply 109 million tons of fish by 2030, with a growth of 37% in 2016 (Food and Agriculture Organization [FAO], 2018).

The growth of cage aquaculture industry; known as the technology of the millennium is again another very rapid growing sector during the past two decades due to the technological strength, easiness, and it is recognised as the most attracting technology for the large scale fish production and steady income generation. The technology is presently undergoing swift changes in response to increasing global demand for aquatic products around the world. Therefore the urgent need in this area is the sustainable development of the technology for long term usage of the natural resources. Thus the Integrated Multi-Trophic Aquaculture (IMTA) concept was developed as a way to increase the sustainability of intensive aquaculture systems, through an ecosystem based model. Integrated multi-trophic aquaculture (IMTA) borrows its concept from nature; namely, that in the food chain, one species always finds a feeding niche in the waste generated by another species. Integrated multi-trophic aquaculture, or IMTA, is similar to polyculture, where two or more organisms are farmed together. In IMTA, multiple aquatic species from different trophic levels are farmed in an integrated fashion to improve efficiency, reduce waste, and provide ecosystem services, such as bio-remediation. Species at the lower trophic level (usually plants or invertebrates) use waste products such as faeces and uneaten feed from the higher trophic species (typically finfish), as nutrients. The lower trophic species can then be harvested in addition to the fish to give the farmer more revenue, or even to be fed back to the fish. The Integrated Multi-Trophic Aquaculture (IMTA) aims to multiply the production and income by the increased resource use efficiency through linkage of trophic levels of the cocultured species to improve nutrient usage for environmental mitigation and to produce additional organisms (crops) in contrast to monoculture (Chopin *et al*. 2010). IMTA systems can be complex, diverse and affected by multiple drivers.

Researchers thus tested the theory that nutrients fed to finfish would generate high-quality organic and inorganic waste that shellfish and marine plants depend on to grow. IMTA is based on a very simple principle. “The solution to nutrification is not dilution, but extraction and conversion through diversification,” which is another way of expressing the principle of conservation of mass, as formulated by Antoine Lauren de Lavoisier in 1789. Over the past decade, scientists have studied ways to improve the productivity and environmental sustainability of marine aquaculture practices. This includes examining the economic and environmental benefits of growing finfish, shellfish and marine plants together – an idea now known as integrated multi-trophic aquaculture.

Integrated Multi-trophic aquaculture (IMTA) offers a new concept in aquaculture.

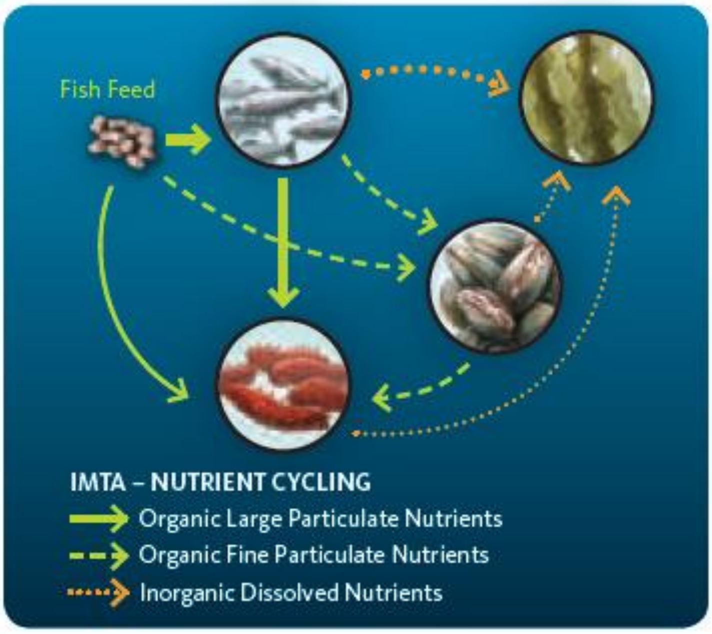
The FAO Aquaculture Glossary defines IMTAas the practice that combines, in the appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish/shrimp) with organic extractive aquaculture species (e.g. shellfish/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental sustainability (bio mitigation) economic stability (product diversification and risk reduction) and social acceptability (better management practices).

Designing an Effective IMTA System

An effective IMTA operation requires the selection of different species for farming, arrangement and placement of various components or species, so as to capture both particulate and dissolved waste materials generated by fish farms. The selected species and system design should be engineered to optimize the recapture of waste products. As larger organic particles, such as uneaten feed and faeces, settle below the cage system, they are eaten by deposit feeders, like sea cucumbers and sea urchins. At the same time, the fine suspended particles are filtered out of the water column by filter-feeding animals like mussels, oysters and scallops. The seaweeds are placed a little farther away from the site in the direction of water flow so they can remove some of the inorganic dissolved nutrients from the water, like nitrogen and phosphorus. IMTA species should be economically viable as aquaculture products, and cultured at densities that optimize the uptake and use of waste material throughout the production cycle.

IMTA involves farming organisms in a way that allows it should have a main fed farming species which is the main component of the system; the uneaten feed, wastes, nutrients and by-products of this to be recaptured and converted into feed, fertilizer and energy for the growth of other associated species so that the amount of ultimate output to the environment will be reduced maximum. Integrated multi-trophic aquaculture has additionally been recognized as a contributor to reducing public opposition toward intensive aquaculture (Ridler *et al*., 2007; Alexander *et al*., 2016b; Buck *et al*., 2018). The seaweeds extract the inorganic dissolved nutrients (such as nitrogen and phosphorus) that are produced by the other farmed species. Essentially, extractive species act as living filters. The natural ability of these species to recycle the nutrients (or wastes) that are present in and around fish farms can help growers improve the environmental performance of their aquaculture sites. In addition to their recycling abilities, the extractive species chosen for an IMTA system are also selected for their value as marketable products, providing extra economic benefits to farmers.

IMTA mimics a natural ecosystem by combining the farming of multiple, complementary species from different levels of the food chain.



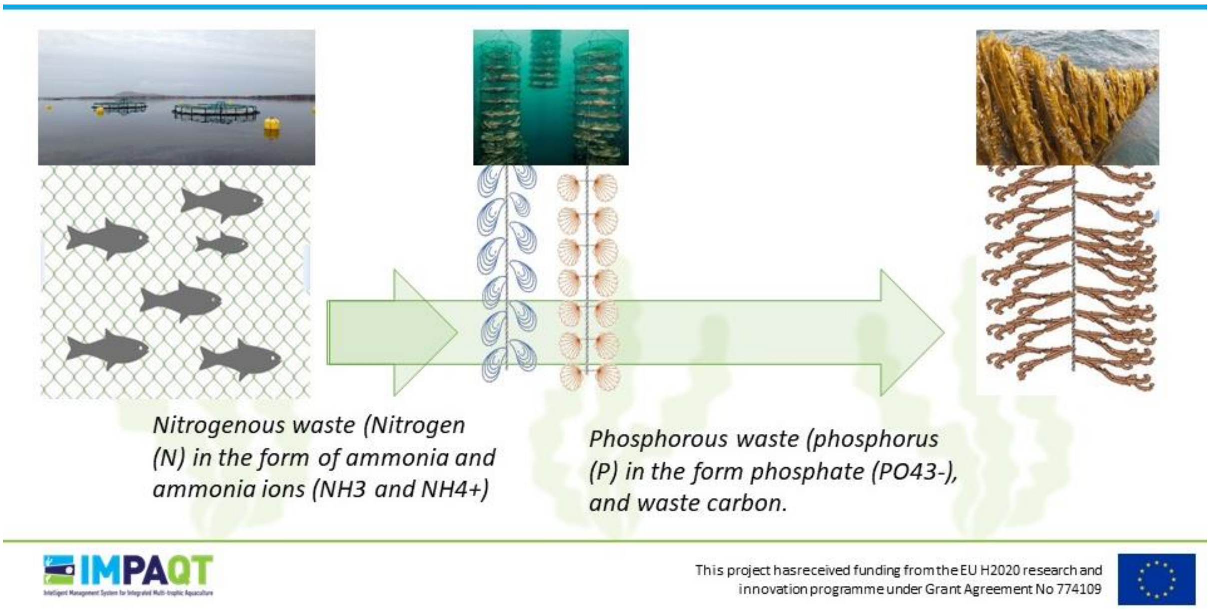
This simple illustration depicts the Integrated Multi-Trophic Aquaculture (IMTA) nutrient cycling. The organic particulate nutrients coming from finfish feed and by-products are shown flowing from the fish food and fish (represented by green arrows) towards Sea Cucumbers (IMTA deposit feeder component) and Blue Mussels (IMTA filter feeder component) who ingest and convert those nutrients. Green arrows also point from the Blue Mussels and the fish food towards the Sea Cucumbers for nutrient extraction. The inorganic dissolved nutrients coming primarily from the finfish are represented by dotted orange arrows towards seaweeds (IMTA seaweed component) for nutrient uptake.

Components of IMTA systems

Major Fed System: Usually the farming of fishes or shrimps will be the major Fed system in the IMTA; which will be in the open ponds, closed systems like pens and or Cages where the animals farming by feeding are stocked. The fish species to be cultivated in the cages to be of high commercial value, with a high market demand, consists largely of carnivorous fishes in intensive farming practices. They have to be fed regularly based on the species and the quantity of the organism stocked. Recently the cage culture of fishes has increased tremendously; in the coastal waters it forms the major fed systems. In cages there is no other natural feeds the feeding of pelleted feeds is major activity. This is the major input to the system and the dissemination of the other energy system start from this. The design of cages, its feeding systems, feeding behaviours, species-specific feed formulations and food conversion ratios, water movements etc have roles in the feeding efficiency and wastage of feeds. The quantity and form of nutrient input is dependent on species, its feeding behaviour, size and finally composition of the feeds used.

Intensive open water finfish farms in the long term can cause a significant loss of benthic biodiversity due to the formation of anoxic sediments, from the deposited feed wastes and faecal matters. This can reduce the production potential by around 33%. If the oxygen level does not come back; again the production must reduce and different types of anoxic and other harmful organisms will accumulate there and finally leads to problems for the farmed fishes and activities which may lead to closing of the entire farming. Cages are usually intensive aquaculture systems and it requires large quantity of feeds for the fishes. The composition of the pellet feed again influence the nature of the bottom. So the selection of fish/shellfish species to be done very carefully to minimise the deleterious effects.

In offshore IMTA systems some changes can be expected as it is very large and extensive systems.



Extractive species in IMTA

The extractive species in the IMTA systems provide many advantages for the sustainability of the of the systems in addition to the income from other products . The species coming in this groups are primarily lower trophic species occupying lower trophic levels. They are referred to as extractive species, as they remove particulate matter from the environment and metabolise it into biomass that can be used for a range of applications on land such as food, feed or biomaterials. Extractive aquaculture performs very important regulating services. Seaweed and shellfish take up nutrients from the water column. Particularly in areas impacted by eutrophication, the removal of nutrients is valuable for general water quality. In areas where the extension of fish farming is restricted because of nutrient input, extractive aquaculture can provide the space in terms of nutrient budget for extension. Conversely in oligotrophic areas, where mussel and seaweed production is limited by nutrient availability, nearby fish farms may boost production. In that situation, the fish farms are providing a supporting service for extractive aquaculture.

This leads to ideas like nutrient trading, which could be explored through IMTA – this can be used to push nutrient load reduction or nutrient recovery. The concept of nitrogen credits or carbon credits for IMTA production could be explored. An IMTA set-up with the appropriate species can be used to reduce the overall nitrogenous, carbon, or phosphorous levels. Regulation needs to consider the values of the services to society provided by removing these minerals, versus water treatment. The IMTA concept works on the bay or management area level and regulation must be able to facilitate this. Integration should be understood as cultivation in proximity, meaning not just absolute distances between species but connectivity in terms of ecosystem functionalities. The 'integrated' element involves to connectivity within water bodies, rather than within absolute distances or spaces. The IMTA concept can be extended within very large ecosystems.

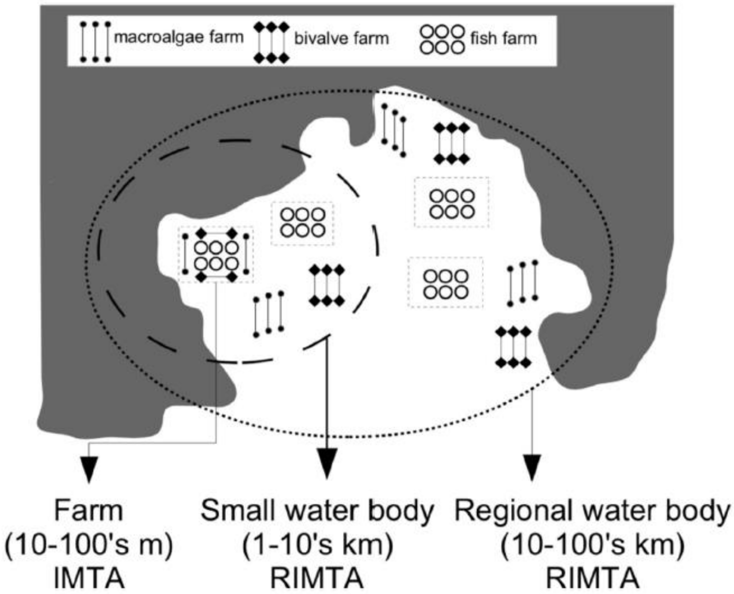


Fig. 2. Spatial scales of integrated multitrophic aquaculture (IMTA) and regional integrated multitrophic aquaculture (RIMTA).

Their role in IMTA scenarios can be as follows:

- A circular system - the extractive species utilise the waste from the fed species as well as any excess nutrients that enter the marine ecosystem from the land.
- Environmental benefits – the utilisation of waste which would previously have entered the environment is now remediated by the extractive species.
- More resilient ecosystem that may prevent disease, pests and parasite load for the system as a whole.
- Additional biomass and economic products from a farm.
- More optimised use of licenced aquaculture space.

Organic extractives of the IMTA systems: IMTA farmers combine species that need supplemental feed such as fish, with "extractive" species that receives the primary outcomes from the fishes. Extractive species can include filter feeders (E.g. mussels) and deposit feeders (E.g. sea cucumbers, sea urchins), and seaweeds (E.g. Gracilaria, Kapaphycus). The filter feeders and deposit feeders use the organic particulate nutrients (uneaten feed and faeces) for nourishment. Species extracting the organic matter may be mussels, oysters, clams, sea urchins or polychaetes. These species feed on organic waste, such as uneaten food and faeces. Mussels and oysters are excellent filter feeders and they can filter large quantities of surrounding water for their feeds and grow well in the IMTA systems (Wallace, 1980, Lander er al., 2004 and Chopin *et al*., 2008). The particulate organic waste materials and phytoplankton that grows in the fish-excreted nutrients are suitable food for filter feeders. They can filtered out the uneaten dissolved and small particulate feeds and faecal matters of the fishes along with the phytoplankton from the water and assimilate the same for their nutritional purposes. Under IMTA production, the uneaten feed and wastes of fed animals are to be recaptured and converted into feed, fertilizers, and energy to another species. Thus the uneaten feeds are neither deposited to the bottom for adding up wates and create water quality problems and biodiversity changes nor the nutrients or the high energy from the feeds are wasted. Instead they are converted to the highly nutritious mussel meat; which is again a very good protein source for human consumption. The excess nutrients from the faecal matters and feed wastes causes nutrient release and that lead to increased phytoplankton production which is again become the feed for these mussels and they will be nutritionally rich. Very few have reported insignificant growth of the filter feeders in the IMTA systems may be due to different environmental conditions and cultivation system designs. The ambient concentration of particulate organic matter is the single most important factor determining the growth rate of mussels.

Advantage of mussels over oysters is they can be cultivated in the cat walks of the cages without much additional structures and efforts and it will not destroy the nets as they are attaching to the substrates by the byssus threads. If oyster is cultivated there is every possibility to attach the same to the nets and the nets will be teared. Another advantage of mussels is that as it is a stenohaline species it can not a permanent component in the system and causes problems. Mussels can be added to the system in the proper time and can be harvested and avoided during the other periods. They will be getting enough food materials in the new farming sites and they can be grown very easily and low costs. Only thing the stocking density of the mussels have to be standardised for better results.

Apart from these other extractive species used are scallops, other bivalves, sea cucumbers, sea urchins and polychaete worms.

Inorganic extractives of the IMTA systems

Investigations into the bioremediation potential of seaweed species showed that they can effectively remove enriched nitrogen and phosphorous from fish tank effluent and are suitable for integrated aquaculture and bioremediation. Seaweeds remove nutrients (nitrogen, phosphorous, and carbon), and can be farmed without fertilizer in an IMTA system. Seaweeds are most suitable for bio-filtration because they probably have the highest productivity of all plants and can be economically cultured. Seaweeds have a large market for human consumption as phycocolloids, feed supplements, agrichemicals, nutraceuticals and pharmaceuticals. Seaweed farming has long been promoted in China in areas of marine cage culture for bio-extraction of nutrients in the seawater. FAO aquaculture statistics record 37 separate seaweed species groups with dominance of Eucheuma seaweeds (8.44 million tonnes) *Kappaphycus alvarezii* and Eucheuma spp. farmed in tropical and subtropical seawater followed by Japanese kelp (5.94 million tonnes).

A good example of how IMTA is more sustainable is the inclusion of seaweed among the species farmed. Seaweeds remove nutrients (nitrogen, phosphorous, and carbon), and can be farmed without fertilizer in an IMTA system. As seaweeds are farmed in the water, there is no demand for scarce land and water resources. Moreover, seaweeds provide oxygen to the water column when photosynthesising. They 'sequester' carbon thus slowing down global warming and reducing coastal acidification, but the carbon sequestration is short-term as the seaweed is used and the carbon is released again. The '**Multi-Trophic**' element means that the species must come from different levels of the food chain. In a simple food chain, the base of the chain is plants that use sunlight to create energy so that they grow —seaweeds and algae are examples. The animals that feed on these primary producers, such as shellfish, mussels, and oysters, would be the next trophic level up —these grow by eating the primary producers, the plants, or micro-algae. Then the energy passes up the chain as animals eat each other. Fish are higher up the food chain again. This is what we mean by trophic levels. So the Multi-trophic element means that the organisms should come from different trophic levels - at least 2 trophic levels.

Finally, an invertebrate -such as sea-cucumber, sea urchins or worm-, could be grown on the sea-bed, which would feed on the larger organic waste that falls to the sea-bed, from both the fed fish species and from the filter feeders. The bacterial component is also a factor but is less studied. This set-up can be run safely and efficiently together to reduce environmental impacts, to optimise the use of the space, to provide product diversity on the farm, and to provide alternative revenue streams for the farmer.

A typical IMTA set-up might include fed fish farmed in pens, tanks or cages, these fish release waste into the surrounding water. Filter feeders, such as mussels or other bivalves, can be grown adjacent to the pens to use this waste to grow, by filtering out the small particulate organic matter (POM). Seaweed could also be included and these absorb the dissolved inorganic nutrients, or minerals, from the water to grow. Thus IMTA can promote aquaculture sustainability, with environmental, economic, and social advantages. This can be achieved through nutrient cycling, increased economic resilience arising from increased production efficiency, product diversification, and potential price premiums (Chopin *et al*., 2012; Van Osch *et al*., 2019).

The benefits and challenges to IMTA

- It brings aquaculture from single species farming to multi-species, complementary, and integrated farming and this brings many benefits with it.
- It changes the linear production model of aquaculture to a more circular, whole eco-system approach is a key benefit. Farming fed species such as fish involves feeding of fishes which add fish feed to the ecosystem. The major inputs added to the ecosystem are the faeces and any uneaten food or particulate waste consists of dissolved waste and organic waste. These can be generally characterized as nitrogenous waste in the form of ammonia and ammonia ions (NH_3 and NH_{4+}), phosphorous waste and carbon waste.
- IMTA replaces the reduction of waste principle with the extraction and the conversion of these excess nutrients and energy into other **commercial crops**. The system copies the natural cycles in the ecosystem and allows the reuse of nutrients, reducing waste and environmental impacts. Thus the new system of IMTA provides a waste reduction service to the ecosystem as well as to the industry.
- This bioremediation element can contribute to meet the regulations and discharge limits of the farmers to a great extent; e.g. cleaning the water on the farm site so it can be discharged unspoiled, or to be reused.
- To increase circularity, the seaweed, plants or other species grown could be used as an ingredient in the fish food, creating a full circular system.
- The IMTA reduces the ecological impacts near the aquaculture operation while providing additional useful products. This reduction in ecological impacts and circularity is desirable from both a regulator and a consumer point of view, so IMTA can have the advantage of improving the societal perception of aquaculture.
- The IMTA grown products have an advantage in the marketplace by being more friendly to the environment, as well as making aquaculture a more acceptable activity amongst the general public, and politically.
- IMTA helps to decouple economic growth from resource use by reducing the volume of wasted resources and utilising by-products.
- IMTA also allows for the optimisation of the space available. It allows for numerous products to be produced within the same space, utilising the resource more effectively and efficiently.
- There is a commercial benefit to the farmer by growing other products on their site. Diversity provides alternative incomes and cash flows, increasing the resilience of the business.
- IMTA products provide a new market niche, of more circular and environmentally sustainable products, which could command a premium price.
- There is generally a difference between income from the fish produced compared to the other trophic layers – the shellfish, invertebrates, and seaweed or plants which are also have high market value – and this can encourage the adaption of the concept.

- Adding other trophic levels in an IMTA set-up adds complexity to the farm, it increases costs and effort on the farmers in the initial stages can be educated by supporting them in the initial phases.
- Farmers are familiar with their current systems and change is always a risk, and new skills need to be acquired. But as more and more begin to adapt IMTA practises and the expertise and technologies improve, this barrier will become less.

Anyway, while IMTA provides income and an alternative revenue stream, the economic element may not be the key reason for farms to adapt. There is an intrinsic benefit in being more sustainable and reducing your environmental impact, along with it offering desirable societal and regulatory benefits. These non-economic motivators can be powerful in a socially minded business environment, where corporate social responsibility is emphasised.

****