CHAPTER - 8

Integrated Multi-Trophic Aquaculture (IMTA) Technology for Augmenting Production

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Introduction

Aquaculture contributes to global food security, and fish and seafood play an important role in healthy human diets, expansion and intensification of the sector are not without consequences and is associated with several ecological concerns. Aquaculture relies on natural resources, like water, energy, raw materials, space and expansion of the sector will inevitably put more pressure on these resources. The increase of the aquaculture sector also contributes to the growing demand for high-quality feed, as 50% of the global aquaculture production concerns fed species. Ingredients traditionally used in aquafeeds, like fishmeal and fish oil, are unsustainable, as the majority of global fishmeal and fish-oil production consists of food-grade fish, resulting in feed-food competition. An increase in aquaculture production will also increase waste production, with potentially detrimental effects on the environment due to the discharge of metabolic waste, uneaten feed and feces. In land-based systems, water purification techniques can be used to convert waste into less hazardous forms. This includes the conversion of ammonia into nitrate and the capture and conversion of solid waste into a novel resource like a fertilizer. Nevertheless, a large fraction of these (valuable) waste nutrients nowadays end up in the environment, resulting in adverse effects. This highlights the need for the development of sustainable aquaculture approaches, which allow us to keep up with the growing demand for food and resources with no or minimal adverse impacts on the environment. At this juncture, the concept of Integrated Multi-Tropic Aquaculture addresses the issues of increasing food demand, followed by increasing in waste production by the aquaculture practices.

Basics of IMTA

IMTA (Integrated Multi-Tropic Aquaculture) is a practice in which the by-products (wastes) from one species are recycled to become inputs (fertilizers, food and energy) for another. Fed aquaculture species (e.g. finfish/shrimps) are combined, in the appropriate proportions, with organic extractive aquaculture species (e.g. suspension feeders/deposit feeders/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweeds), for a balanced ecosystem management approach that takes into consideration site specificity, operational limits, and food safety guidelines and regulations. The goals are to achieve environmental sustainability through biomitigation, economic stability through product diversification and risk reduction, and social acceptability through better management practices.

IMTA refers to the more intensive cultivation of the different species in proximity of each other (but not necessarily right at the same location), connected by nutrient and energy transfer through water. Multi-trophic refers to the incorporation of species from different trophic or nutritional levels in the same system. This is one potential distinction from the age-old practice of aquatic polyculture, which could simply be the co-culture of different fish species from the same trophic level. In this case, these organisms may all share the same biological and chemical processes, with few synergistic benefits, which could potentially lead to significant shifts in the ecosystem. Some traditional polyculture systems may, in fact, incorporate a greater diversity of species, occupying several niches, as extensive cultures (low intensity, low management) within the same culture system. The integration can be of freshwater recirculating aquaculture systems (RAS) with horticulture (aquaponics) or Freshwater Integrated Multi-Trophic Aquaculture (FIMTA) or for marine systems the term integrated mariculture has been used or IMTA, which can refer to land-based systems or systems at sea. Even though diverse names have been proposed, all rely on the same concept: the recycling of waste nutrients by combing different species, with the overall aim to transform linear monocultures into more circular farming systems, producing additional valuable crops that benefit from the waste nutrients**.** Some IMTA systems have included such combinations as shellfish/shrimp, fish/seaweed/shellfish, fish/shrimp and seaweed/shrimp. Finally, a working IMTA system should result in greater production for the overall system, based on mutual benefits to the co-cultured species and improved ecosystem health, even if the individual production of some of the species is lower compared to what could be reached in monoculture practices over a short term period.

Concept of IMTA

It was chosen to focus on fish as fed species, but it should be noted that invertebrates, like shrimp is also a major group of fed species. To estimate retention efficiencies, we first qualify and quantify fish waste. Nutrient retention by the fed species is influenced by species, feeding level and management, diet composition, temperature and fish size. Retention efficiencies reported for marine fish species range between 13-43% for N, 18-36% for P and 14-38% for C. Fed nutrients that are not retained by the fed species become input for the extractive species. Three groups of extractive species are recommended, each taking up a different fraction of the waste released by the fed fish: (1) an autotrophic species, which takes up inorganic nutrients; (2) a filter-feeder, which consumes particulate organic matter (POM) suspended in the water column; and (3) a deposit-feeder, which scavenges on POM that settles on the bottom (Soto 2009).

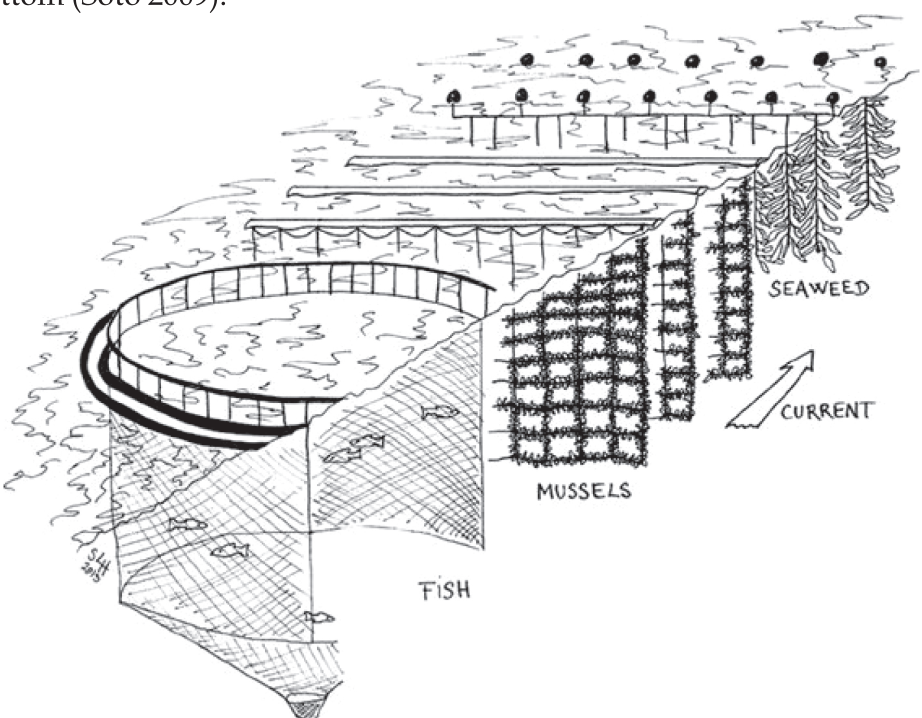

Fig.1: Schematic of an integrated multi-trophic aquaculture (IMTA) (Source: Maeve Edwards, 2014)

The bioremediation potential of IMTA is determined by the amount of waste nutrients retained and subsequently harvested in extractive species biomass. Non-retained nutrients by fed cultures can be categorized in inorganic and organic nutrients. The latter is subdivided into large organic particles that sink, and smaller organic particles that remain in the water column (Wang et al. 2013). Based on these waste flows three types of extractive species can be defined, each serving a different niche in the food web: (i) autotrophs that take up inorganic nutrients, (ii) filter feeders that consume organic particles suspended in the water column and (iii) deposit feeders that feed on organic particles that settle on the bottom.

Species selection for IMTA

When establishing the species to use in an IMTA system, one must carefully consider the suitability of the species in a particular habitat/culture unit. In order to ensure successful growth and economic value,

- Use local species that are well within their normal geographic range and for which technology is available. This will help to prevent the risk of invasive species causing harm to the local environment, and potentially harming other economic activities. These species have also evolved to be well adapted to the local conditions.
- Use species that will complement each other on different trophic levels. For example species must be able to feed on the other species waste in order for the newly integrated species to improve the quality of the water and grow efficiently. Not all species can be grown together efficiently. Particulate organic matter and dissolved inorganic nutrients should be both considered, as well as the size range of particles.
- Use species that are capable of growing to a significant biomass. This feature is important if the organisms are to act as a biofilter that captures many of the excess nutrients and that can be harvested from the water. The other alternative is to have a species with a very high value, in which case lesser volumes can be grown. However, with the latter, the biomitigating role is reduced.
- Use species that have an established or perceived market value. Farmers must be able to sell the alternative species in order to increase their economic input. Therefore, they should establish buyers in markets before investing too heavily.

- Use species for which regulators and policy makers will facilitate the exploration of new markets, not impose new regulatory impediments to commercialization.
- Contribution to improved environmental performance.
- Compatibility with a variety of social and political issues.

Species/genera commonly considered for IMTA

Seaweeds	*Laminaria, Saccharina, Sacchoriza, Undaria, Alaria, Ecklonia, Lessonia, Durvillaea, Macrocystis, Gigartina, Sarcothalia, Chondracanthus, Callophyllis, Gracilaria, Gracilariopsis, Porphyra, Chondrus, Palmaria, Asparagopsis*and *Ulva*
Molluscs	*Haliotis, Crassostrea, Pecten, Argopecten, Placopecten, Mytilus, Choromytilus*and *Tapes*
Echinoderms	*Strongylocentrotus, Paracentrotus, Psammechinus, Loxechinus, Cucumaria,* and *Tapes*
Fish	*Salmo, Oncorhynchus, Scophthalmus, Dicentrarchus, Gadus, Anoplopoma, Hippoglossus, Melanogrammus, Paralichthys, Pseudopleuronectes*and *Mugil.*
Crustaceans	Penaeus and Homarus
Polychaetes	*Nereis, Arenicola, Glycera*and*Sabella*

Benefits of IMTA

The common benefits of IMTA includes

- The mitigation of effluents through the use of biofilters (e.g. seaweeds and invertebrates), which are suited to the ecological niche of the farm - Effluentbiomitigation.
- Prevention or reduction of disease among farmed fish can be provided by certain seaweeds due to their antibacterial activity against fish pathogenic bacteria, or by shellfish reducing the virulence of ISAV - Disease control.
- Increased overall economic value of an operation from the commercial by-products that are cultivated and sold - Increased profits through diversification.

- Potential for differentiation of the IMTA products through eco-labelling or organic certification programmes - Increased profits through obtaining premium prices.
- Economic growth through employment (both direct and indirect) and product processing and distribution - Improving local economy.
- Product diversification may offer financial protection and decrease economic risks when price fluctuations occur, or if one of the crops is lost to disease or inclement weather. - Form of 'natural' crop insurance.

Status of IMTA

The IMTA technology has been very well adopted in different countries for augmenting marine finfish production, but the level of adoption varies in different ranges. Details of IMTA activity in different countries are follows.

- In temperate waters Canada, Chile, China, Ireland, South Africa, the United Kingdom of Great\ Britain and Northern Ireland (mostly Scotland) and the United States of America are the only countries to have IMTA systems near commercial scale.
- France, Portugal and Spain have ongoing research projects related to the development of IMTA. The countries of Scandinavia, especially Norway, have made some individual groundwork towards the development of IMTA, despite possessing a large finfish aquaculture network.
- Studies have focused on the integration of seaweeds with marine fish culturing for the past fifteen years in Canada, Japan, Chile, New Zealand, Scotland and the USA.
- The integration of mussels and oysters as bio-filters in fish farming has also been studied in a number of countries, including Australia, USA, Canada, France, Chile, and Spain.
- IMTA in Asian countries including India has been performed with candidate marine fin species with mussels and oysters.

IMTA initiative in India by ICAR- CMFRI

IMTA activities initiated by ICAR –CMFRI in different places, where integration of seaweed with marine finfish in sea cages, and mussel culture with marine finfish in sea cages. Seaweed culture in raft (16 rafts of 12ft x 12ft size installed around a 6m dia. cage) has proven to double the yield in one cycle (45 days) of seaweed farming (additional 176 kg per cycle/raft of 12ft x 12 ft size) with commensurate income enhancement. The technology is currently adopted by more than 150 farmers in the Palk Bay region with the support of CMFRI.

Seaweeds such as *Kappaphycus alvarezii*, *Gracilaria edulis*, *Gracilari averrucosa* and *Gelidiella acerosa* are farmed under IMTA, in India. Trials on seaweed *Kappaphycus* with finfish cobia (*Rachycentron canadum*) in floating cages in coastal Tamil Nadu resulted in increased production. Seaweed rafts integrated with cobia cage had a better average yield of 320 kg per raft while the same was 144 kg per raft in control. The total amount of carbon sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 357 kg and 161 kg respectively -an addition of 196 kg carbon credit. Trials on IMTA with bivalves and finfish (seabass) in the inshore waters of Karnataka demonstrated reduced risk of crop failure through diversification. Mortality loss of finfish (seabass) in the cages was compensated to a certain extent by bivalve production. Gross revenue realized was 5.34 lakhs of which 30% was contributed by mussel (1.6 lakhs). Seaweed, *K.alvarezii* in tegrated with Indian pompano cage in Visakhapatnam showed higher seaweed production.

Fig.2: Seaweed rafts integrated with marine finfish culture in cages (Indian pompano and cobia (Source: Johnson et al., 2019, Sekar et al., 2020)

Steps should be taken to ensure the expansion of IMTA

- Establishing the economic and environmental value of IMTA systems and their co-products – seaweeds and invertebrates can be very profitable cultured species, not only for their services as effluent biomitigators, but also as differentiated premium cash crops diversifying the aquaculture sector and reducing risks.
- Selecting species appropriate to the habitat and available technologies – native species should be used, to avoid problems with invasive, and potentially harmful, species.
- Selecting species according to the environmental and oceanographic conditions of the sites proposed for IMTA development, and also according to their complementary ecosystem functions.
- Selecting species that are capable of growing to significant biomass to capture many of the excess nutrients and remove them efficiently at harvesting time.
- Selecting species that have an established or perceived market value and for which the commercialization will not generate impossible regulatory hurdles.
- Promoting effective government legislation/regulations and incentives to facilitate the development of IMTA practices and the commercialization of IMTA products.
- Educating government/industry/academia and the general public about the benefits of IMTA. This can be done by disseminating knowledge through diverse media supports targeting diverse audiences.

Challenges

The following challenges are in front to effectively carry -out IMTA-related activities.

Higher investment - Integrated farming in the open sea requires a higher level of technological and engineering sophistication and up-front investment.

Difficulty in coordination - If practicedusing different operators (e.g. independent fish farmers and mussel farmers) working in concert, it would require close collaboration and coordination of management and production activities.

Increase requirement of farming area - While aquaculture has the potential to release pressure on fish resources and IMTA has specific potential benefits for the enterprises and the environment. Fish farming competes with other users for the scarce coastal and marine habitats. Stakeholder conflicts are common and range from concerns about pollution and impacts on wild fish populations to site allocation and local priorities. The challenges for expanding IMTA practice are therefore significant although it can offer a mitigation opportunity to those areas where mariculture has a poor public image and competes for space with other activities.

Difficulty in implementation without open water leasing policies- Few countries have national aquaculture plans or well developed integrated management of coastal zones. This means that decisions on site selection, licensing and regulation are often ad hoc and highly subject to political pressures and local priorities. Moreover, as congestion in the coastal zone increases, many mariculture sites are threatened by urban and industrial pollution and accidental damage.

Conclusion

IMTA can be used as a valuable tool for the establishment of a more sustainable aquaculture sector. IMTA systems can be environmentally responsible, profitable, and sources of employment in coastal regions for any country that develops them properly, especially when government, industry, academia, communities, and NGOs work in consultation with each other. It is highly recommended that IMTA systems be utilized wherever possible, and ultimately replace monoculture operations in regions where they can be developed. A successful IMTA operation must integrate all stakeholders into its development plan. Government, industry, academia, the general public and NGOs must work together. The role of IMTA in an integrated coastal zone management plan must be clearly defined. Beyond selecting the appropriate species for growth at a particular site, economics and social acceptability must also play a key role. Once these are established, a focused R&D&C programme will ensure efficiency and long-term sustainability for the aquaculture sector.

Suggested Readings

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