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A review of IMTA practices in India: Potential, challenges, and future directions

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Abstract
Integrated Multi-Trophic Aquaculture (IMTA) represents a sustainable approach to aquaculture that promotes the co-cultivation of multiple species to enhance ecosystem efficiency and productivity. This paper provides a comprehensive review of IMTA practices in India, examining their potential benefits, encountered challenges, and outlining future directions for development. India's diverse aquatic ecosystems offer ample opportunities for IMTA implementation, with various species combinations including finfish, shellfish, and seaweeds being explored. Despite its potential, IMTA faces numerous challenges in India, ranging from regulatory hurdles and technical constraints to socio-economic factors and environmental concerns. The review synthesizes existing research and industry experiences to assess the current status of IMTA in India, highlighting successful case studies and identifying areas for improvement. Additionally, the paper discusses potential strategies for overcoming barriers to IMTA adoption and suggests avenues for future research and policy interventions to promote its widespread implementation. By addressing these issues, India can harness the full potential of IMTA to enhance sustainable aquaculture practices and contribute to food security, economic development, and environmental conservation.

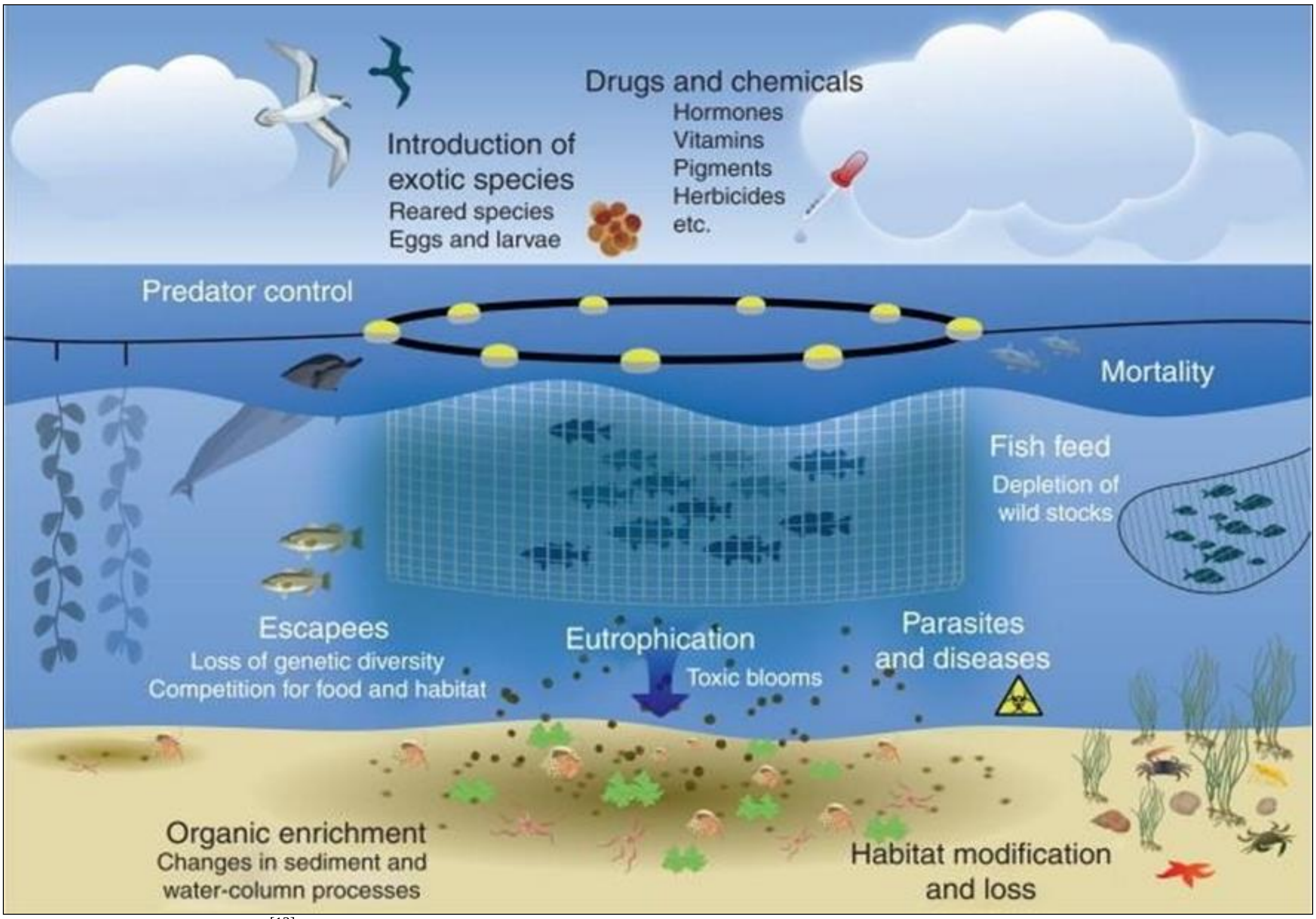
Keywords: Integrated multi-trophic aquaculture (IMTA), India, sustainable aquaculture, co-cultivation, ecosystem efficiency, food security, environmental conservation

Introduction

The world's population is booming, and with it comes a rising demand for seafood. Aquaculture, the farming of fish and other aquatic organisms, is expected to bridge the gap left by stagnant wild fish catches. However, intensive aquaculture methods, like open-water cage farms, can have negative environmental consequences. One major concern is nutrient pollution. Excess waste from these farms can lead to eutrophication, a process that disrupts the delicate balance of aquatic ecosystems. This can result in oxygen depletion, harming fish stocks and overall water quality. Additionally, disease outbreaks in these high-density environments can further damage surrounding ecosystems. Sustainable solutions are crucial. Engineering improvements can offer a path forward. Aquaculture systems need to become more environmentally friendly, cost-effective, and adaptable to cultivate diverse species while minimizing risks and gaining public acceptance. One promising approach is the Ecosystem Approach for Aquaculture (EAA). This method emphasizes efficient nutrient use and minimizes negative environmental impacts while maximizing production and benefits. Additionally, multispecies farming shows promise. By co-culturing different species, these systems can create a more balanced ecosystem, reduce waste generation, and enhance overall resilience.

While the notion and implementation of integrated aquaculture are widely known in inland environments, particularly in Asia, its prevalence in the marine environment has yet to be significantly less documented. Nonetheless, in recent times, the concept of integrated aquaculture has frequently been regarded as a strategy to mitigate the excessive nutrients and organic matter produced by intensive aquaculture practices, especially in marine waters. In this context, the emergence of integrated multi-trophic aquaculture (IMTA) has occurred, wherein the term multitrophic pertains to the deliberate inclusion of species from various trophic positions or nutritional levels within the same system. Integrated Multi-Trophic Aquaculture (IMTA) includes species from diverse trophic levels, in contrast to polycultures, which allow numerous species to be farmed together but all belong to the same trophic level. This approach could address environmental concerns associated with aquaculture and provide economic benefits. IMTA promotes an ecological and sustainable approach to the development of aquaculture. IMTA is a promising initiative that could sustainably expand aquaculture in coastal and marine habitats while fulfilling the world's demand for fish.

Need for adoption of IMTA



Source: Gasper *et al.*, 2012 [13]

Fig 1: Environmental risk associated with cage/ pen farming in open waters

Figure 1 illustrates the possible risk associated with the intensive cage or pen mariculture practices widely adopted in India and the world to meet the increased demand for seafood products. In India the species which is mostly cultured in cage farming is *Pangasianodon hypophthalmus* and Genetically Improved Farmed Tilapia (GIFT) while salmon, yellow tail, etc. are most preferred in other parts of the world. The culture of non- native and genetically modified organisms (GMO) could potentially lead to the introduction of the invasive species into the natural system by escape or during natural calamities like flood, thereby disrupting the natural fauna and its genetic diversity. The high stocking density can also result in introduction of new diseases and parasites into the culture water, reduces the dissolved oxygen concentration and apparently deteriorates the water quality. The intensification in aquaculture is often linked to a significant reliance on chemicals in this sector, as confined conditions and stress can make organisms more susceptible to disease, resulting in financial losses for the producers. Moreover, if farmers are not provided with sufficient knowledge, it might result in the irresponsible use of chemicals. Although parasitic diseases rarely cause the death of organisms, they can nonetheless lead to increased production expenses or a decline in the quality of the final product (Granada *et al.*, 2016) [14] and market rejection as an effect of nonconformity. Therefore, the management of this type of infestation frequently depends on the utilization of antiparasitic substances, which, despite being prescribed, typically result in being discharged into the adjacent ecosystem, consequently impacting other organisms that coexist within the identical framework. The use of hormones, antibiotics, hormones, drugs and algicides for disease treatment, algal control, etc. may also find its way into the culture system. Moreover, the uneaten feed and fish faeces results in nutrient loading and eutrophication in the surrounding areas. The release of deoxygenated water, which is highly rich in hydrogen sulphide, occurs due to the anaerobic degradation of fish wastes from years of intensive cage farming in these areas (Rosa *et al.*, 2020) [27].

Hence, the concept of Integrated Multi- Trophic Aquaculture (IMTA) found its successful expansion as a solution for environmental degradation and eutrophication in mariculture practices while providing improved environmental and economic sustainability, lowers production cost and increased profit from species diversification for local coastal community.

Integrated Multi-Trophic Aquaculture System (IMTA)

Integrated multitrophic aquaculture may be characterized as a method wherein the by-products of one species are repurposed as resources for another species (FAO, 2014) IMTA, Integrated multi-trophic aquaculture, encompasses cultivating fed species alongside extractive species. These extractive species can utilise the inorganic and organic wastes produced by aquaculture to facilitate their own growth. According to Barrington (2009) [1], IMTA is a technique that combines the production of feed aquaculture species—such as shrimp and finfish—with inorganic extractive species—like seaweed—and organic extractive species—like herbivorous fish and shellfish. These combinations aim to create well-balanced systems that improve social acceptability via improved management techniques, economic stability through product diversification and risk reduction, and environmental sustainability through biomitigation. Throughout the past decade, integrated aquaculture has been employed to reduce the excessive nutrient and organic loading that intensive aquacultures create (Neori *et al.*, 2004) [24]. A community that includes filter and deposit feeders in addition to a principal species (shrimp or finfish) with its unique diet is essential for optimizing the performance of an IMTA. Due to their capacity to benefit from a wider variety of organic particle sizes, these secondary species can increase productivity by expanding their product line and less the organic load's ecological effects.

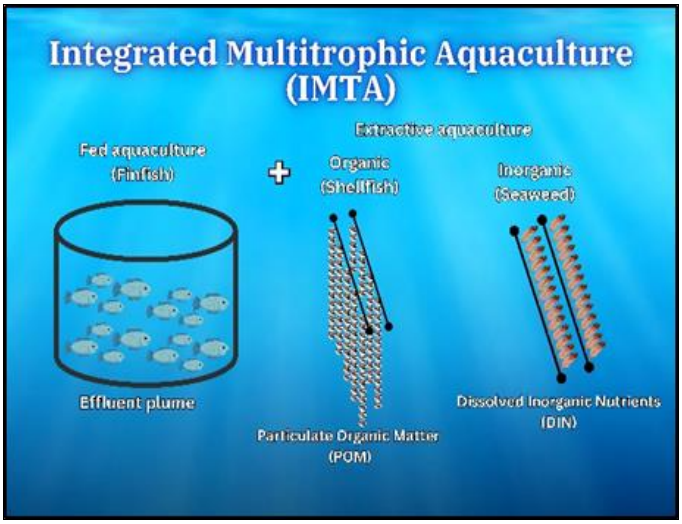
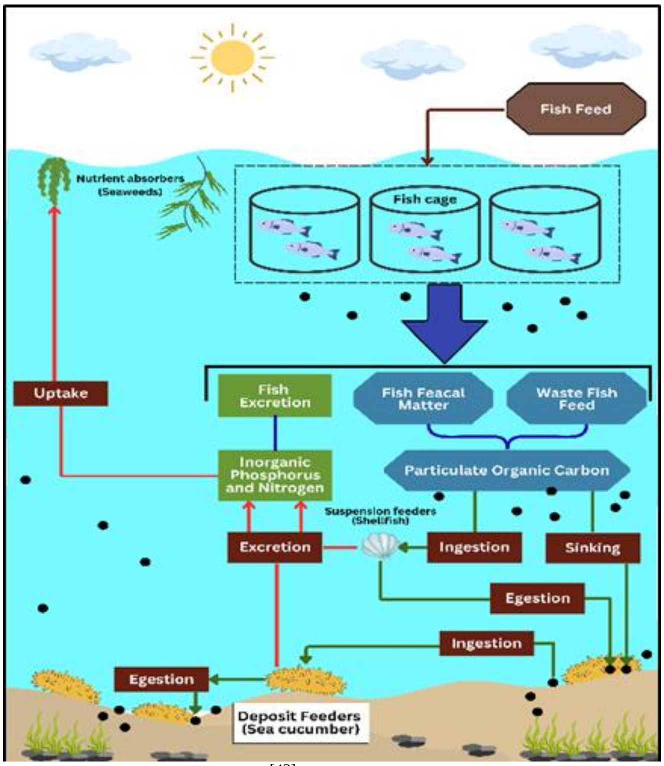


Fig 2: Representation of a possible IMTA system, with fed species and both organic and inorganic extractive species

Figure 2 represents the common IMTA system which is widely practiced in various parts of the world in both freshwater and coastal waters. The interdependence between different trophic levels begins at the nutrient zone, where nourished species are raised, adding nutrients to the water in solid and liquid forms. Subsequently, this enriched water cascades towards the regions harboring extractive species Particulate organic matter (POM) contains nutrients filtered by invertebrate species. Lastly, primary producers, mostly seaweeds, eliminate dissolved inorganic nutrients, such as phosphate and ammonium (Chopin, 2006; Barrington *et al.*, 2009) [3, 1]. Seaweeds and shellfish are examples of extractive species that may be found in organic and inorganic forms. These species are important because they efficiently reduce the waste released from the fed aquaculture component of integrated multi-trophic aquaculture (IMTA). By retaining and consuming suspended tiny particle organic matter, this ecological function—known as extraction—helps to reduce nutrient loading (POM). The key element lies in selecting appropriate organisms based on their ecological functions within the ecosystem. The basic idea underlying IMTAs is that they may offer economic diversification and environmental sustainability. Each single species contributes to the total value of aquaculture by performing as a built-in biofilter and having economic worth of its own.

In recent decades, the incorporation of deposit feeders such as sea cucumber, sea urchin, etc. in integrated multi- trophic aquaculture system particularly in the marine and coastal open waters (Figure 3). A commercial scale trial on inclusion of deposit feeder in IMTA was up taken by Chopin *et al.* (2012). The wastes produced by fish have the potential to serve as a source of sustenance for other species. Suspension feeders can utilize small organic particles that originate from fish cages or are stirred up from the sediment, while deposit feeders can consume larger particles that settle on the seafloor. Seaweeds can take up and retain dissolved nutrients produced by cultivated species or liberated from sediment through water flow exchange (Yokoyama & Ishihi, 2010; Yokoyama, 2013) [40, 41].



Source: Zhang *et al.*, 2016 [43]

Fig 3: Representation of IMTA system with inclusion of fed, extractive and deposit feeder

Brief History of IMTA		
2200-100 B.C.	*You Hou Bin* detailed integration of fish with aquatic plants and vegetable production in China.	
1975-780 B.C.	Fish culture in rice paddies in China.	
1550-070 B.C.	Earliest representations of tilapia grown in drainable agriculture-aquaculture ponds in Egypt.	
1330-100 B.C.	Development of polyculture in China.	
889-904	Lin Xun published *The Curious Lingbiao Region* in China. It described the theory of mutualism in grass carp/rice paddies culture and integration of fish and fruit production.	
1500	Pond culture in East Java.	
1600	Chateau de Fontainebleau in France, a self-sufficient castle with King Henri IV's royal carp pond.	
1639	Xu Guangqi published The Complete Book on Agriculture, describing irrigation rotation of fish and aquatic plant production and integration of fish with livestock.	
1975	John Ryther *et al.*	Integrated waste recycling marine polyculture systems.
1979	Marilyn Harlin *et al.*	Seaweeds in closed-system fish culture.
1987	M. E. McDonald	Biological removal of nutrients in algal-fish systems.
1991	Amir Neori	Seaweed biofilters for intensive mariculture.
1991	Muki Shpigel *et al.*	Oysters in fish aquaculture ponds.
1994	Alejandro Buschmann *et al.*	Seaweed cultivation with land-based salmon effluents.
1999	Max Troell *et al.*	Aquaculture ecological engineering
2004	Thierry Chopin, Jack Taylor	Integrated milti-tropic aquaculture.

Evolution of integrated multi- trophic aquaculture (IMTA)

The history of IMTA begins with the development of aquaculture. In China, fish were integrated with aquatic plants and vegetables, according to records in the You Hou Bin from between 2200 and 2100 B.C. The bas-reliefs on tombs constructed in Egypt during the New Kingdom era, roughly between 1550 and 1070 B.C., include evidence of tilapia cultivation in integrated agriculture-aquaculture drainable ponds. The implementation of royal Integrated Multi-Trophic Aquaculture (IMTA) was conducted at the Château de Fontainebleau during the era of the French Renaissance, as substantiated by the enduring functionality of the Etang aux Carpes (Carp Pond) structure. Notably, French King Henri IV decreed that the estate should possess self-sufficiency and abstain from reliance on provisions that could be plundered during the arduous 65-km voyage from Paris. Irrigation and the cyclic production of fish and aquatic plants were among the subjects included in the posthumous edition of Xu Guangqi's 1639 book Nong Zheng Quan Shu (The Complete Book on Agriculture), which he had written in conjunction with Jesuit missionaries. The discussion also encompassed the amalgamation of fish and livestock as well as the influence of manure on pond production. The combined cultivation of mulberry trees, rice paddies and fish ponds was also considered. In the 1970s, John Ryther played a pivotal role in reigniting interest in IMTA and can be acknowledged as the trailblazer of modern IMTA due to his pioneering research on what he termed as "integrated waste-recycling marine polyculture systems." This research was initially conducted at the Woods Hole Oceanographic Institution in Massachusetts, USA, and later at the Harbor Branch Oceanographic Institute in Florida, USA. Ryther's work paved the way for three fruitful decades in polyculture, integrated mariculture or aquaculture, ecologically engineered aquaculture, and ecological aquaculture. To establish harmony among these various terms, Thierry Chopin and Jack Taylor merged integrated aquaculture and multitrophic aquaculture, thus coining the term integrated multi-trophic aquaculture in 2004.

Design of IMTA

An effective IMTA operation necessitates carefully selecting, arranging, and placing various components or species to effectively capture particulate and dissolved waste materials that fish farms produce. To achieve a successful IMTA operation, it is imperative to meticulously select, arrange, and position various components or species to collect solid and dissolved waste materials that fish farms efficiently produce. The selection of species and the design of the system should be strategic to optimize the recovery of waste products. Larger organic particles, such as uneaten feed and faeces, settle beneath the cage system and are consumed by deposit feeders, such as sea urchins and sea cucumbers. Concurrently, the finer water column's suspended particles are removed by filter-feeding organisms such as scallops, mussels and oysters. The seaweeds are positioned slightly further away from the site, in the direction of the water flow, to enable them to remove certain inorganic dissolved nutrients from the water, such as nitrogen and phosphorus (Sukhdhane 2018) [36]. IMTA species should be cultivated at densities that maximize waste material absorption and use throughout the production cycle and be commercially viable as aquaculture products. The IMTA technique is wildly flexible. IMTA systems can consist of many species combinations, such as freshwater or marine, land-based, or open-water systems (Neori *et al.*, 2004) [24].

Criteria for selection of species

Environmental sustainability is the primary factor to consider in IMTA. Consequently, the selection of species in IMTA is guided by criteria that involve understanding the limitations of the natural ecosystem. It is essential to consider a species' appropriateness in a particular habitat or culture unit when choosing which species to use in an IMTA system. Farmers need to understand the species' compatibility and potential future effects on the environment to guarantee successful growth and economic value. Carnivorous fish and shrimp are examples of fed creatures that get their nutrition from feed, which is made up of waste fish or pellets.

On the other hand, extractive organisms derive their nourishment from the environment. Bivalves and seaweed, which are two economically significant cultured groups, fall into this category. interact of co-cultured species must be meticulously chosen based on various conditions and criteria:

1. **Complementary functions within the system with other species:** Select species compatible with one another through various trophic levels. For instance, for newly integrated species to flourish and enhance the water quality, they need to be able to consume the waste products of other species. Not all species can be successfully reared simultaneously.
2. **Acclimatization to the environment:** Native animals can be employed if they are well within their natural geographic

range and can access technology. Invasive species' potential to harm the local ecology and other commercial endeavors will be reduced. Native animals have also evolved to be highly adapted to their surroundings.

3. **Environmental site conditions and cultural technologies:** When selecting a farm site, the size range of particles, dissolved inorganic nutrients, and particulate organic matter should be considered.
4. **Ability to provide both efficient and continuous bio mitigation:** This particular characteristic holds great significance if these organisms are intended to serve as bio-filters, capturing many surplus nutrients and enabling their extraction from the water. Alternatively, another approach involves employing a species of significant value, thereby allowing for the cultivation of smaller quantities. However, it should be noted that this latter option results in a diminished role in bio-mitigation.
5. **Market demand for the species and pricing as raw material or for their derived products:** Choosing species that are thought to have a known or established market value is advisable. To increase their economic input, farmers need to be able to sell several species Hence, they must establish buyers in markets before making significant investments.
6. **Commercialization potential:** Apply species for which policymakers and regulators will encourage the search for new markets rather than placing more regulatory barriers in the way of commercialization.
7. Supporting to achieve improved environmental sustainability.
8. Harmony with many social and political issues.

Species cultured in IMTA

The IMTA involves the co-culture of species of different trophic levels (fed, extractive and deposit feeders). IMTA systems can consist of many species combinations, either freshwater or marine, land-based or open-water systems (Neori *et al.*, 2004) [24]. Some combinations of shellfish and shrimp, fish and seaweed, fish and shrimp, and seaweed and shrimp have been included in IMTA systems (Troell *et al.*, 2003) [37].

IMTA is regarded as a more sustainable alternative to the conventional monoculture systems. Monoculture systems, which involve the cultivation of a single species, are known to have detrimental effects on their surrounding environments. This is primarily due to their reliance on external sources of food and energy, which often leads to negative consequences without any mitigation (Chopin *et al.*, 2001) [4]. Finfish constitute the sole fed constituent in the majority of IMTA systems, thereby serving as the exclusive source of nutrient energy introduced into the system by humans. Within the framework of an IMTA system, fish are responsible for supplying dissolved and particulate nutrients, in addition to compounds that possess oxidation-reduction potential, to the other organisms involved while simultaneously generating revenue for the industry. The specific quantity and composition of these nutrients depend on various factors, including but not limited to species, size, and feed formulation. The extractive species used in IMTA includes organic (bivalves/ shellfish or herbivorous fishes) and inorganic (seaweeds or aquatic plants) extractive species which together sustain the ecological balance. The organic extractive species sub-system in IMTA involves the cultivation of filter-feeding bivalves in close proximity to meshed fish cages. This arrangement decreases nutrient loadings utilizing the bivalves' ability to filter and assimilate particulate wastes such as fish feed and faeces, as well as any phytoplankton production that may be stimulated by introduced dissolved nutrient wastes. Waste nutrients are extracted from the cultured bivalves during harvest, as opposed to waste in the surrounding environment as in typical monoculture. Aquatic plants' assimilative bio-filtration process increases the environment's ability to absorb nutrients. Due to their potential for high production and their ability to be cheaply cultivated, seaweeds are the ideal plant material for bio-filtration. The inclusion of deposit feeders in IMTA is particularly seen Japan and many parts of Asia, where these species are found to have high demand; while disregarded in Europe, United States, India, etc. (Granada *et al.*, 2016) [14]. Holothurians can consume up to 70% of the organic material that accumulates, eliminating significant quantities of waste nitrogen and organic carbon from fish production (Ren *et al.*, 2012; Cubillo *et al.*, 2016) [26, 10]. Sea cucumbers exhibit low mortality rates and demonstrate rapid growth, thus presenting themselves as viable options as secondary species within the framework of Integrated Multi-Trophic Aquaculture (IMTA). These organisms, characterized as detritus feeders, effectively supplement the particle size spectrum consumed by filter feeders like bivalves. The integration of species from both groups can be effectively combined to attain enhanced efficiency in the removal process.

To conclude, the identification of the appropriate candidate organism primarily relies on the traditions and market principles in the regional IMTA implementation, and preference should be assigned to the indigenous species with significant economic worth. A brief account of different organism cultured in IMTA is represented in Table 1.

Table 1: Organisms experimented in IMTA

Organism	Species	References
Finfish	*Salmo*, *Oncorhynchus*, *Scophthalmus*, *Dicentrarchus*, *Gadus*, *Anoplopoma*, *Hippoglossus*, *Melanogrammus*, *Paralichthys*, *Pseudopleuronectes* and *Mugil sp.*	(Soto, 2009) [1]
	Most preferred- red seabream, salmon	(Zhou *et al.*, 2006; Yokoyama, 2013; Brito *et al.*, 2014; Cubillo *et al.*, 2016; Fang *et al.*, 2016; Shpigel *et al.*, 2016; Zamora *et al.*, 2018) [44. 41, 10, 11, 32, 42]
	Carp and catfish	(Kibria and Haque, 2018) [19]
	India- Cobia, Pearlspot, Mullet (*Mugil cephalus*, *Liza parsia*), Milkfish, Rohu	(Viji *et al.*, 2014;Johnson *et al.*, 2019; Biswas *et al.*, 2019; Nath *et al.*, 2021) [39, 17, 23]
Organic extractive species/Suspension feeder (Shellfish)	Molluscs are the most tested organisms in IMTA context	(Granada *et al.*, 2016) [14]
	Mussels (Mytilidae) with a high potential for usage as secondary species in IMTAs are *Mytilus edulis* and *Mytilus trossulus*, which are particularly successful in coastal temperate zones	(Ren *et al.*, 2012; Sarà *et al.*, 2009)
	India- Green mussel (*Perna viridis*), *Crassostrea madrasensis*, *C. cuttackensis*, *Lamellidens marginalis*	(Viji *et al.*, 2014; Biswas *et al.*, 2019; Nath *et al.*, 2021) [39, 23]

	Mytilus, Choromytilus, Argopecten, Placopecten, Haliotis, tapes and Crassostrea Mollusks: *Homarus* and *Penaeus*	(Soto, 2009) [1]
Deposit feeders	Echinoderms: *Strongylocentrotus, Paracentrotus, Psammechinus, Loxechinus, Cucumaria, Holothuria, Stichopus, Parastichopus, Apostichopus* and *Athyonidium*	(Soto, 2009) [1]
Seaweeds	Red algae *Gracilaria spp*. and the green algae *Ulva spp. Kappaphycus alvarzii, Gracilaria dura*, and *G. edulis*	(Rosa *et al.*, 2020) [27]
	Laminaria, Saccharina, Sacchoriza, Undaria, Alaria, Ecklonia, Lessonia, Durvillaea, Macrocystis, Gigartina, Sarcothalia, Chondracanthus, Callophyllis, Gracilaria, Gracilariopsis, Porphyra, Chondrus, Palmaria, Asparagopsis and *Ulva*	(Soto, 2009) [1]
	India – *Kappaphycus alvarezii, Enteromorpha spp., Wolffia globosa*	(Johnson *et al.*, 2019; Biswas *et al.*, 2019; Nath *et al.*, 2021) [17, 2, 23]

Benefits and Challenges of IMTA
Benefits
- **Effluent bio-mitigation:** This technique reduces effluents by using bio-filters that are appropriate for the aquaculture site's biological niche. This can address several environmental issues raised by aquaculture as a monoculture.
- **Increased profits through diversification:** It has increased a business's total economic worth due to growing and selling commercial byproducts. Any bio-filtration method has a high financial expense due to its intricacy. The industry must provide income for environmentally friendly aquaculture to be competitive. The farm can produce additional goods that can offset the expenses associated with setting up and maintaining an IMTA farm by using the extractive capabilities of co-cultured lower trophic level taxa. In integrated aquaculture, the waste nutrients are seen as a benefit rather than a burden for the supplementary cultivation of bio-filters.
- **Increasing the regional economy**: Through distribution of products, processing, and employment (both direct and indirect).
- **Product diversification is one form of "natural" crop insurance:** It can reduce economic risks and provide financial security in case of market risk or crop loss due to disease or unfavorable weather.
- **Disease control:** Certain seaweeds have antibacterial properties against fish pathogenic bacteria, so they can help prevent or reduce diseases in farmed fish.
- **Profit increases by attaining premium cost:** Possibility of IMTA product differentiation through programs for organic certification or eco-labelling.

Challenges
- **Higher upfront expenses:** Integrated farming at sea necessitates a greater degree of technology and engineering skills.
- **Coordination challenge:** If implemented by several operators (such as independent mussel and fish farmers cooperating), strong cooperation and coordination of management and production activity would be needed.
- **Increasing the requirement for farming areas:** poses challenges in the context of aquaculture. While aquaculture offers the potential to alleviate pressure on fish resources and integrated multi-trophic aquaculture (IMTA) presents specific benefits for enterprises and the environment, fish farming competes for limited coastal and marine habitats with other users. Stakeholder conflicts are common, encompassing concerns related to pollution, impacts on wild fish populations, site allocation, and local priorities. Expanding the practice of IMTA faces significant challenges, especially in areas where mariculture is viewed negatively and competes for space with other activities.
- **Implementing without open water leasing regulations is complicated:** Many nations need comprehensive national aquaculture strategies or effectively integrated coastal zone management, resulting in challenges regarding the implementation of open water leasing policies. Consequently, decisions about site selection, licensing, and regulation often lack a systematic approach and are highly susceptible to political influences and local preferences. Furthermore, the escalating congestion in coastal areas threatens numerous mariculture sites, as they become vulnerable to urban and industrial pollution, as well as accidental damage.

Current status of IMTA
World
The rudiment of IMTA in fresh water has been found in China centuries ago, which was applied in marine aquaculture and arose the interest of many other countries in Asia (Bangladesh, Japan, Korea), North America (Canada, United States), Europe (France, United Kingdom, Spain), Oceania (Australia, New Zealand), and South America (Chile) in the last few decades. As per FAO reports, all the countries in world have enormous potential for IMTA growth and development. At present, the countries that have IMTA systems near commercial scale, or at commercial scale, are Canada, Chile, China, Ireland, South Africa, the United Kingdom of Great Britain and Northern Ireland (mainly Scotland) and the United States of America. Regarding the development of IMTA, France, Portugal, and Spain are engaged in ongoing research projects. Despite possessing a large finfish aquaculture network, the countries of Scandinavia, particularly Norway, have undertaken some individual groundwork towards the development of IMTA. The integration of seaweed with marine fish culture has been investigated and studied in the USA, Canada, Japan, Chile, New Zealand, and Scotland during the past fifteen years. Numerous nations have conducted studies on the integration of mussels and oysters as biofilters in fish farming, with notable outcomes noted. As per FAO newsletter 2020, Guidelines for sustainable aquaculture, The advanced utilization of integrated multi-trophic aquaculture (IMTA) in Asia is presently being highlighted by the Network of Aquaculture Centres in Asia-Pacific (NACA). It has been suggested as a suitable subject for a case study due to its employment as a bioremediation method against excessive nutrients. An alternative case study that could be considered is the employment of coastal ocean longline and raft IMTA, as this particular region is known for its production of oyster/scallop and kelp, as well as abalone, seaweed, and sea cucumber.

According to the fish site, investments in the seaweed business outside of Asia increased from 17 to 34% in 2021, while the total amount spent increased by 36 per cent to $168 million (Seaweed startup investments double in 2021- Fishsite). Hence, an emerging attention on IMTA worldwide has been identified by various fisheries professionals across the world.

India

The IMTA farming in India is still in infancy stage when compared to other countries (Sukhdhane *et al.*, 2018) [36]. ICAR-Central Marine Fisheries Research Institute (CMFRI) was the pioneer behind the adoption of IMTA farming in India in the year 2013-14 under participatory mode with fisherman groups in coastal area. The initial trial commenced in participatory mode, involving a group of fishermen at Munaikadu (Palk Bay) in the Ramanathapuram district of Tamil Nadu. This trial involved the integration of seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*). At present, approximately 100 fishers in the Ramanathapuram district of Tamil Nadu have embraced this IMTA technology and are investing in it themselves. In instances where the bamboo raft method is unsuitable due to rough sea conditions, the tube net method may offer better integration of seaweeds with cobia farming cages. Seaweeds such as *Kappaphycus alvarezii*, *Enteromorpha spp*. are farmed/ being experimented under IMTA, in India.

The IMTA farming in India is particularly restricted to research with a few initiatives from ICAR-CMFRI and CIBA to promote a participatory mode among coastal community. Currently, ICAR- Central Marine Fisheries Research Institute (CMFRI) is conducting ongoing research under participatory mode with fisherman group of Kerala and Tamil Nadu for the promotion and dissemination of the technology to the rural poor of coastal community. ICAR- CIBA in collaboration with Mangrove cell Maharashtra has also worked towards promotion of IMTA among farmers in Sindhudurg District, Maharashtra (Biswas *et al.*, 2019) [2]. ICAR-CMFRI reported that a total of 23, 970 ha potential area suitable for seaweed farming in India (Johnson *et al.*, 2020) [16]. Currently, Gujarat and Tamil Nadu dominate in seaweed production which is found to have potential as fodder, biofuel, nutraceuticals, etc. The IMTA farming is now increasingly gaining popularity among farmers adopting seaweed cultivation. However, the huge potential area of 23, 970 ha suitable for seaweed cultivation can be utilized for development of IMTA in context of better profitability and environmental balance especially in coastal community. IMTA farming as well as its percentage contribution to aquaculture production is yet to be elucidated in India as well as world.

Review on research trend lines in IMTA

An analysis of the research trend lines in Integrated multi-trophic aquaculture (IMTA) in the world particularly focused initially on the potential application of the IMTA system and the production efficiency. Much of the research were initially focused on finding a suitable combination of species for integration and the production potential in the system. The IMTA farming was traced back in 2200 BC in China where the fish farming was successfully integrated with aquatic planta and vegetables. A successful physical model of integrated waste recycling in marine polyculture system was demonstrated by Ryther *et al.* (1975) [29]. Chopin *et al.* (1999) [7] developed *Porphyra* and salmon integrated aquaculture and found that it's a suitable measure for bioremediation of coastal water contributing to significant reduction in inorganic nutrients. The incorporation of deposit feeder or organic settleable extractive component in IMTA was found to be a promising alternative for environmental biomitigation and economic diversification of the system (Chopin *et al.*, 2012) [5]. The integration of sea urchin (*Strongylocentrotus droebachiensis*) with mussels (*Mytilus spp.*) in IMTA resulted in 40-45% less fouling of nets and did not impair the mussel growth in the system. Shipgel *et al.* (2016) It was discovered that co-culturing seabream and grey mullet enhanced total biomass output by 5.6-7.3%, decreased FCR by 12-15%, and reduced the quantity of sludge in IMTA by 98%. Kibira and Haque (2018) [19] reported potential of IMTA in freshwater ponds as a sustainable food security option for poor pond farmers and found that the stinging catfish, carp, snail and water spinach showed the highest survival, yield and water quality in IMTA than monoculture system.

The major shift in the research focus from suitable species combination to its efficiency in overall biomitigation of the culture environment has gained popularity. The IMTA farming was found to be an efficient biomitigator of the culture environment showing a reduction efficiency of 58% phosphate, 48% nitrite, 61% ammonia, 47% nitrate (Huo *et al.*, 2012) [15], 18.9% increase in total organic carbon utilization (Li *et al.*, 2014), 86% and 99% reduction in particulate organic load at bottom in finfish and shellfish culture (Cubillo *et al.*, 2016) [10] and 30% reduction in surface phytoplankton and 35% increase in bottom dissolved oxygen (DO) (Zhang and Kitazawa, 2016) [43] compared with control without integration. Poli *et al.* (2019) [25] found that the indoor based IMTA application for shrimp rearing in biofloc system increased the yield upto 21.5% for *Lithopenaeus vannamei*, *Oreochromis niloticus* and *Sarcocornia ambigua*.

Research and development efforts in India

Case study 1

The initial endeavour in India to develop Integrated Multi-Trophic Aquaculture (IMTA) was instigated by ICAR-CMFRI. In 2013-14, they successfully demonstrated IMTA through a participatory approach with a group of fishermen in Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu. This demonstration involved the integration of seaweed species *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*) (Johnson *et al.*, 2019) [17].

IMTA Design

A total of 16 bamboo rafts measuring 12×12 feet, each equipped with 75 kg of seaweed, were integrated for a duration of 4 cycles, accompanied by a cobia cage measuring 6m in diameter and 3.5m in depth, housing 750 cobia fingerlings (Figure 4a). Each complete cycle of seaweed cultivation extends for an average period of 45 days, and these four cycles were consecutively performed. The control was a set of separate rafts grown at distant location without any integration with fish cages (Figure 4 b)

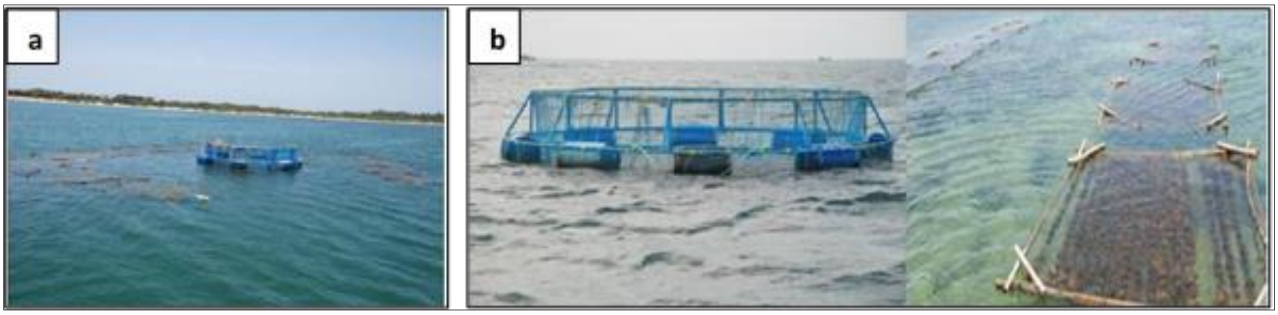


Fig 4: (a) Seaweed raft integrated with cobia cages (b) Cobia cage and seaweed raft without integration

The results of the study after 6 months exhibited an increased seaweed production by 704 kg through integration, increased number (average 90-100 NOS) of newly emerged apical portion/tips in seaweed in IMTA whereas the same was less (average 30-40 no.) in non – integrated rafts (Figure 5) and a profit margin of 41% increase from IMTA seaweed production. A 260 kg increase in cobia yield was observed in IMTA (1220 kg) than control (960 kg) providing an additional income of Rs. 75,400 (40% increase in profit margin from fish production). IMTA system was also found to provide environmental benefits through efficient organic waste mitigation, reduced organic matter load, better water quality and better carbon sequestration (and additional 113 kg) than non- integrated system. Table 2 represents the comparison economics from seaweed and cobia culture and the carbon sequestration potential with and without IMTA system.

Fig 5: Comparison of seaweed from non-integrated (left) and IMTA system (right)

Table 2: Comparison economics from seaweed and cobia culture and the carbon sequestration potential with and without IMTA system

Particulars	With IMTA	Without IMTA	Difference
Comparison of cost and returns of seaweed cultivation by IMTA (16 rafts/ one cage/4 cycle) and non-IMTA			
Dried seaweed Production	1280 kg	576 kg	704 kg
Price of dried seaweed (Rs. per kg)	37.50	37.50	-
Revenue (Rs.)	48,000	21,600	26,400
Net Profit (Rs.)	32,000	5,600	26,400
Profit Margin (%)	67	26	41
Comparison of economics of sea cage farming of cobia with and without IMTA (for one cage & one crop of 6 months duration)			
Fixed cost (one cage)	61,600	61,600	0
Total Operating cost	1,30,000	1,30,000	0
Total cost of production (Six months)	1,91,600	1,91,600	0
Yield of farmed fish (in kg) (in six months average wt. 2.2 kg)	1220	960	260 kg
Gross revenue in Rs. (@ Rs. 290 per kg)	3,53,800	2,78,400	75,400
Net income	1,62,200	86,800	75,400
Net operating income (Income over operating cost)	2,23,800	1,48,400	75,400
Farm gate Price (Rs.)	290.00	290.00	0
Capital Productivity (Operating ratio)	0.37	0.47	-
Cost of production Rs. per kg	157	199	42
Profit Margin (%)	85	45	40
Comparison of carbon sequestration potential of seaweed cultivation through IMTA			
Seaweed production as wet weight (for 4 cycles, 16 rafts) (1)	12800 kg	5760 kg	7040 kg
Average dry weight percentage of the harvested seaweed (%) (2)	8.75	8.75	-
Average carbon content (%) (3)	19.92	19.92	-
Total amount of carbon sequestered (1)× (2)× (3)	223 kg	100 kg	113 kg

Success story

Fig 6: Shri. L. Mohamed Noogu receiving State Level Best Farmer Award from Dr. K. Ramasamy, Vice-Chancellor, Tamil Nadu Agricultural University, Coimbatore

Shri Mohamed Noogu, a fisherman, was awarded the State Level Best Farmer Award. Seaweed cultivation has been carried out since 2004 by Shri L. Mohamed Noogu, a fisherman from Munaikadu, Ramanathapuram district, Tamil Nadu.

The participatory farming trials on Integrated Multi-Trophic Aquaculture (IMTA) were conducted by the Mandapam Regional Centre of ICAR-Central Marine Fisheries Research Institute (CMFRI) at Munaikadu in the year 2013-14. Shri. Noogu initially displayed skepticism towards this technology. However, his doubts were dispelled when he witnessed a twofold increase in seaweed harvest through the adoption of IMTA. This remarkable outcome led him to embrace the technology entirely. He further remarked that the production of seaweed had significantly declined in the Ramanathapuram district during the period of 2013-14 due to heat stroke. Nonetheless, the implementation of IMTA enabled him to double the yield compared to cultivating seaweed alone. The adoption of the ICAR-CMFRI technology, IMTA, has proven to be rewarding for him. In recognition of his achievements, he received STATE LEVEL RECOGNITION at the 'Kisan Samriddhi Mela' (Farmers Fair for Prosperity), (Figure 6).

Case Study 2

Development of integrated multi-trophic aquaculture (IMTA) for tropical brackish water species in Sindhudurg District, Maharashtra, west coast of India in 2015 by Mangrove cell Maharashtra aimed at the demonstrations of IMTA to the farmers of Sindhudurg and CIBA, Chennai.

IMTA Design

In each land-based system, two identically sized pens (250 m^2) were built for IMTA and control, respectively and open-water cages were placed in the estuary. A monoculture of *P. indicus* served as the control in the IMTA experimental system. In contrast, various combinations of fed species, including *Chanos chanos* (4 no/m^2), *Etroplus suratensis* (1 no/m^2), *Mugil cephalus* (0.5 no/m^2), *Penaeus indicus* (2 no/m^2), and an extractive crop, *Crassostrea madrasensis* (0.5 no/m^2), were stocked. It was discovered that the water quality features were within allowable bounds. Comparing the IMTA system to the control, it was found that the soil organic carbon was lower. With 3250 kg/ha compared to 2000 kg/ha, the IMTA system's productivity was higher than the control. Additionally, it was shown that IMTA pens had more significant income and benefit-cost ratios. In order to diversify both systems and species without sacrificing the financial viability of culture, the study finds that IMTA is a viable approach. Table 3 represents the economic comparison between IMTA and monoculture of shrimp farming.

Table 3: Comparison of economic returns of land based IMTA ponds with shrimp monoculture ponds (values are average of two farms adjusted for 6 months

Items	Amount (Rs/ha)	Price rate (Rs.)	IMTA (Rs.)	Amount (Rs.)	Monoculture shrimp (Rs.)
Operational cost					
Seed					
Penaeus iindicus	20000	0.2	4000	60000	12000
Chanos chanos	20000	2	40000		
Etroplus suratensis	10000	1	10000		
Mugil cephalus	10000	2	20000		
Crassostrea madrasensis	5000	0.2	1000		
Bleaching powder (kg); 15 ppm 1 m depth	200	25	5000	200	5000
Fertilizers	1000	2	2000	1000	2000
Labour man days	200	270	54000	200	54000
Feed	9000	30	270000	9000	270000
Total operational cost			406000		343000
Interest in operation cost for 6 months	12%		24360	12%	20580
Total cost			430360		363580
Total revenue					
P. indicius	250	250	62500	2000	500000
C. chanos	2000	200	400000		
E. suratensis	800	150	120000		
M. cephalus	200	200	40000		
C. madrasensis			10000		
Total profit			632500		500000
Profit per kg			194.6		250
Benefit cost ratio (BCR)			1.5		1.4

Case Study 3

Application of Integrated Multi Trophic Aquaculture (IMTA) Concept in Brackishwater Ecosystem: The First Exploratory Trial in the Sundarbans, India by ICAR-Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu & Kakdwip, West Bengal for 150 days (Biswas *et al.*, 2019) [2].

IMTA Design

A field experiment lasting 150 days was undertaken in six brackishwater ponds, each measuring 600 m^2. Two groups were randomly allocated, namely IMTA and polyculture (control), with three ponds serving as replicates for each group. In the IMTA ponds, mullets and tiger shrimp were stocked at densities of 10000 and 30000 no./ha, respectively. Additionally, *C. cuttackensis* was suspended in the water column at a density of 1600 no./ha using a basket, and *Enteromorpha spp*. was present at a biomass of 200 kg/ha. The control ponds were stocked with mullets and shrimp at the same densities as the IMTA ponds but lacked oysters and seaweed.

Mullets attained a significantly higher growth in the IMTA system compared to that of control ponds, whereas tiger shrimp had insignificantly higher growth in IMTA than in control. Significantly higher production of 1707 kg/ha (19% higher; Mullets: 926 + shrimp: 781) with better water quality was obtained in IMTA system compared to that of control ponds (1434 kg/ha; Mullets: 772 + shrimp: 662). There was a significant reduction in apparent feed conversion ratio by 22%, and an increase in net income by 69% and benefit-cost ratio by 30% in the IMTA system than that of the control. The oyster species has high water filtration capacity to remove suspended matters, including planktons. The experiment indicates the application of IMTA concept in brackishwater as a viable environment-friendly option and warrants further refinement for species combination with the economic viability and environmental suitability. Table 4 represents the comparison of economic returns between IMTA and polyculture (control) systems.

Table 4: A comparison of economic returns between IMTA and polyculture (control) systems

Particulars	IMTA				Polyculture			
	Expenditure		Income		Expenditure		Income	
	Items	INR	Item	INR	Item	INR	Item	INR
Fish seed		2000×20=40000		874×220=192280		2000×20=40000		727×180=130860
	L. parsia	8000×1=8000		52×150=7800		8000×1=8000		45×130=5850
	P. monodon	30000×0.7 =21000		781×550=429550		30000×0.7=21000		662×480=317760
	Oyster	1600×3=4800	-	-		-		-
	Enteromor pha	200×5=1000	-	-		-		-
Fish feed		114500	-	-		112080		-
Other inputs		20000				20000		-
Manpower		20000				2500		-
Total operational cost (OC)		229300				214580		-
Interest on OC (@10% annually)		9554				8941		
Total expenditure		238854	Total income	629630		22351	Total Income	454470
Net income		390776				230949		
Benefit cost ratio (BCR)	2.64				2.03			

Case Study 4

ICAR-CMFRI's IMTA Practice in Kerala yields bumper harvest in Green Mussels-Dr. Shoji Joseph & team, Mariculture Division, CMFRI

An experimental endeavour known as Integrated Multi-Trophic Aquaculture (IMTA) was carried out commercially by the ICAR-Central Marine Fisheries Research Institute in Kochi, Kerala. This endeavor proved to be immensely successful in the state of Kerala. The integrated farming technique involved the cultivation of finfish in cages, along with the cultivation of green mussels and seaweed. As a result of this combination, a plentiful harvest of Green Mussels was obtained, demonstrating a noteworthy growth rate.

This practice involves carefully integrating fish, filter-feeding bivalves, and seaweeds, aiming to create a balanced farming system that is both environmentally and economically stable. To develop a sustainable Cage Fish Farming Model that is suitable for Kerala's ecosystem, the Institute commenced this program in December 2020 in Moothakunnam, located in the Ernakulam District. The program was carried out in collaboration with local fishermen. By suspending approximately 150 strings around four fish cages, a production of about 1 tonne of Green Mussels was achieved. This practice was found to be economically viable and well-suited to the conditions of the state. The individual mussels reached an average size of 72g, indicating a successful growth rate in mussel farming. The fish contained within the enclosures achieved enhanced growth and are expected to be harvested by the conclusion of June. The progress of cultivating seaweed encircling the enclosures also displayed positive advancement. Dr A Gopalakrishnan, the Director of ICAR-CMFRI, declared that the Institute would undertake measures to promote the practice of Integrated Multi-Trophic Aquaculture (IMTA) throughout the nation's coastal states. Promoting this innovative technology, in conjunction with the increasing trend of adopting cage farming technology, will profoundly impact the livelihoods of the coastal community. The glimpse of the experimental yield is shown in Figure 7

Fig 7: Green mussel yield from IMTA farming

Case Study 5

Research carried out in collaboration between ICAR-CMFRI and ICAR-CIFE on eutrophication control using oyster in oyster-fish farming at Moothakunnam, Vembanad lake, Ernakulam during February-November, 2012 (10 months), (Viji *et al.*, 2014) [39].

The study was performed in four cages (1 x 1 × 1 m) known as treatments T1, T2, T3, and T4 were used for the investigation. Fish (*Etroplus suratensis*) and oysters (*Crassostrea madr%asensis*) were utilized in the four treatments at the following ratios: 1:0.3, 1:0.5, 1:0.7, and 1:0, respectively. The eutrophication index (E) is calculated as:

$$E=COD\times DIN\ (mg/L) \times DIP\ (mg/L)\times 10^{6/4500}$$

Where DIP stands for dissolved inorganic phosphate and DIN for dissolved inorganic nitrogen made up of orthophosphate, ammonia, and nitrite, there is eutrophication when the E value is more than 1, and the more severe the eutrophication, the higher the E value.

The four treatments' eutrophication index (E) values were determined to be 9.45 ± 4.41, 5.25 ± 3.23, 11.32 ± 6.17, and 11.52 ± 5.45, respectively. The fish to oyster ratio of 1:0.5 (T2) showed lowest eutrophication index (E) (5.25±3.23) as compared to fish monoculture (11.52±5.45). The lower E value for T2 supports the conclusion that oysters may regulate eutrophication in an integrated aquaculture system. The current investigation yielded the ideal co-cultivation ratio of fish to oysters, which was 1:0.5.

Case Study 6

Lamellidens and Wolffia canopy improves growth, feed utilization and welfare of *Labeo rohita* (Hamilton, 1822) in integrated multi-trophic freshwater aquaculture system (Nath *et al.*, 2021) [23]. A 90-day experiment evaluated the efficacy of integrated multi-trophic aquaculture (IMTA) in an outdoor tank culture system. An inorganic extractive, floating weed *Wolffia globosa*, and an organic extractive, bivalve *Lamellidens marginalis*, were incorporated during the trial. The growth, survival, yield, water quality and welfare of *Labeo rohita* (Rohu) were assessed. To conduct the trial, twelve cement tanks with a capacity of 20 m^3 were randomly divided into four treatments (in triplicate), where *L. rohita* was used as the fed species. The treatments included a control group (C) with only rohu, T1 with rohu and partitioned Wolffia canopy, T2 with Rohu and *L. marginalis*, and T3 with Rohu, Wolffia and *L. marginalis*. The stocking densities for Rohu and *L. marginalis* were 30,000 fingerlings ha^{-1} and 750 kg ha^{-1}, respectively. Wolffia was transplanted to cover 30% of the tank surface area, and the fish to mussel biomass ratio was maintained at 2:1. The fish were fed with a sinking pelleted feed (30% Crude Protein) at a rate of 4% body weight. The findings indicated that T3, in comparison to T1 (the control group) and T2, demonstrated significantly higher total biomass, survival, and net fish yield (NFY). There was a notable difference in the total protein and lipid content of rohu (whole-body) among the treatments. Concerning welfare parameters, the nitroblue tetrazolium (NBT) activity was significantly elevated in T1 and T3, while superoxide dismutase (SOD) activity reached its peak in T1. In contrast, catalase (CAT) activity was lowest in T3 compared to all other treatment groups. The water quality parameters, including NH_4-N, NO_3-N, and PO_4-P, were notably lower in T3 than in all other treatment groups. Furthermore, T3 and T1 exhibited higher water transparency, with no observed algal bloom. These findings imply that the co-cultivation of *L. rohita* with *W. globosa* and *L. marginalis* has the potential to enhance water quality and welfare parameters while also improving fish survival and productivity.

Case Study 7

Design and Development of a Freshwater Integrated Multi-Trophic Aquaculture (FIMTA) System for Selected Cultivable Aquatic Species-ICAR-Central Institute of Freshwater Aquaculture (CIFA), 2018-2021 (CIFA Annual Report, 2020)

The evaluation of various combinations of *Labeo rohita* (a fish), *Macrobrachium rosenbergii* (a prawn), *Lamellidens marginalis* (mussels), and *Ipomoea* sp. (a plant) was conducted for 90 days. The species ratio, specifically the ratio of the fed species (fish) to the deposit feeder (prawn) to the organic extractive species (mussels) to the inorganic extractive species (plant), was set at 10:10:2.5:1. This study aimed to develop a FIMTA.

The control was the monoculture of fish and fed species were provided with 10% bodyweight containing 20% protein. The analysis of water quality parameters revealed no significant difference among treatments. No water exchange was performed during the trial. The findings unveiled a twofold increase in the equivalent production within the FIMTA system (4.4 tonnes/ha/ 3 months) compared to (2.2 tonnes/ha/ 3 months).

SWOT analysis of integrated multi-trophic aquaculture (IMTA)

Strengths	Weakness
▪ Efficient use of open water resources.	▪ Insufficient scientific knowledge leading to trial and error.
▪ Recycling of nutrients- reduced nutrient load and eutrophication	▪ Compromised site selection- sub optimal culture conditions (salinity, temperature, water current)
▪ Increased seaweed production- agar, fodder, biofuel, nutraceuticals, etc.	▪ Difficult business planning (timing of different crops)
▪ Improved livelihood opportunities for rural poor especially in coastal states.	▪ Unknown customer reaction
▪ Increased profit through species diversification.	▪ Lack of proper funding for development of IMTA
▪ Improved environmental condition, better water quality.	▪ Greater capital cost at start-up
▪ Year round production from multiple species.	▪ **Threats**
▪ **Opportunities**	▪ Risk of pest transmission between crops.
▪ Remediation to eutrophication in open waters.	▪ Potential risk of food safety- extractive species may take up various contaminants and chemicals from surrounding environment. ▪ Venture capital and insurance.
▪ Potentially increased profitability. ▪ Reduced environmental impact- can be adopted as a sustainable bioremediation method for natural water bodies.	▪ Conflict in uses- large scale operation especially in marine waters hinders transport, fishing and allied activities.
▪ Diversified job opportunities especially among coastal community.	▪ Social acceptance.
	▪ Natural threats-flood, storm, cyclones, etc.

Future Research Prospects

The IMTA is currently in its nascent stages. Yet, it harbours significant prospects of evolving into the future's aquaculture industry, characterized by enhanced efficiency and a more comprehensive range of products. Moreover, it demonstrates the potential for improved quality while simultaneously promoting environmental, economic, and social sustainability. The further research for development of IMTA must focus on the following:

- Identifying the most appropriate species for integration in IMTA systems, along with the necessity of developing models to more accurately evaluate the densities and conditions required for successful co-cultivation to maximize profitability, presents significant research opportunities
- The extractive species may take up various contaminants and chemicals administered during production and from surrounding environment- Food safety and human health concerns of IMTA raised products need to be tackled
- The suitable integration of various native species in freshwater IMTA must be experimented.
- Optimization of stocking densities of various extractive and fed species in IMTA
- The suitable integration of aquatic planta and medicinal herbs with high market demand in IMTA
- Suitability of high valued marine and brackishwater fishes and halophytes in open water IMTA.

Conclusion

IMTA systems play a crucial role on a global scale in the sustainable expansion of aquaculture operations within a well-balanced ecosystem approach. This is in response to the worldwide need for seafood and represents a paradigm shift in creating the most effective food production system. IMTA offers several advantages, including incremental carrying capacity, bioremediation, diversified products, and disease prevention. However, despite their immense potential, IMTAs still need to be in the developmental stage in most countries, particularly at complete commercial scales. Currently, there exists a limited quantity of promising open-ocean IMTA demonstration facilities across various regions of the globe, which possess the potential to function as blueprints for approaching advancements. Nonetheless, further endeavours are necessary to modify these designs to accommodate different species and circumstances. As these designs are expanded to commercial production levels, demonstration research sites that involve cost sharing agreements have the capacity to alleviate the exorbitant expenses associated with offshore research. These sites can furnish invaluable insights to the aquaculture sector and assist in determining the feasibility of IMTA in offshore environments. Therefore, promoting this eco-friendly and sustainable option is imperative to ensure a steady income for coastal fishers. It also permits the nation to accumulate priceless carbon credits and acts as an essential mitigating strategy against the negative effects of climate change.

References

1. Barrington K, Chopin T, Robinson S. Integrated multi-trophic aquaculture (IMTA) in marine temperature waters. In: Soto D, ed. Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. 2009;529:7-46.
2. Biswas G, Kumar P, Kailasam M, Ghoshal TK, Bera A, Vijayan KK. Application of Integrated Multi Trophic Aquaculture (IMTA) Concept in Brackishwater Ecosystem: The First Exploratory Trial in the Sundarban, India. Journal of Coastal Research. 2019;86(SI):49-55.
3. Chopin T. Integrated multi-trophic aquaculture. What it is, and why you should care… and don't confuse it with polyculture. North. Aquac. 2006;12(4):4.
4. Chopin T, Buschmann AH, Halling C, Troell M, Kautsky N, Neori A, *et al*. Integrating seaweeds into marine aquaculture systems: a key toward sustainability. Journal of Phycology. 2001;37(6):975-986.
5. Chopin T, Cooper JA, Reid G, Cross S, Moore C. Open-water integrated multi-trophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. Reviews in Aquaculture. 2012;4(4):209-220.
6. Chopin T, MacDonald B, Robinson S, Cross S, Pearce C, Knowler D, *et al*. The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN)—a network for a new ERA of ecosystem responsible aquaculture. Fisheries. 2013;38(7):297-308.
7. Chopin T, Yarish C, Wilkes R, Belyea E, Lu S, Mathieson A. Developing Porphyra/salmon integrated aquaculture for bioremediation and diversification of the aquaculture industry. Journal of Applied Phycology. 1999;11(5):463-472.
8. CIFA Annual Reports, 2020. http://cifa.nic.in/sites/default/files/AnnualReport_2019-20.pdf.
9. CMFRI, Kochi., 2021. CMFRI Newsletter No.169 April - June 2021. http://eprints.cmfri.org.in/id/eprint/15353
10. Cubillo AM, Ferreira JG, Robinson SM, Pearce CM, Corner RA, Johansen J. Role of deposit feeders in integrated multi-trophic aquaculture—a model analysis. Aquaculture. 2016;453:54-66.
11. Fang J, Zhang J, Xiao T, Huang D, Liu S. Integrated multi-trophic aquaculture (IMTA) in Sanggou Bay, China. Aquaculture Environment Interactions. 2016;8:201-205.
12. FAO. The state of world fisheries and aquaculture 2014. Rome, Italy: Food and Agriculture Organization of the United Nations; c2014.
13. Gaspar MB, Carvalho S, Curdia J, dos Santos MN, Vasconcelos P. Restoring Coastal Ecosystems from Fisheries and Aquaculture Impacts, in: Treatise on Estuarine and Coastal Science. Elsevier Inc; c2012. p. 165-187. doi:10.1016/B978-0-12-374711-2.01008-1.
14. Granada L, Sousa N, Lopes S, Lemos MF. Is integrated multitrophic aquaculture the solution to the sectors' major challenges?: A review. Reviews in Aquaculture. 2016;8(3):283-300.
15. Huo Y, Wu H, Chai Z, Xu S, Han F, Dong L, *et al*. Bioremediation efficiency of *Gracilaria verrucosa* for an integrated multi-trophic aquaculture system with *Pseudosciaena crocea* in *Xiangshan harbor*, China. Aquaculture. 2012;326:99-105.
16. Johnson B, Divu D, Jayasankar R, Ranjith L, Dash G, Megarajan S, *et al*. Preliminary estimates of potential areas for seaweed farming along the Indian coast. Marine Fisheries Information Service, Technical and Extension Series. 2020;246:14-28.
17. Johnson B, Nazar AKA, Jayakumar R, Tamilmani G, Sakthivel M, Kumar RP, *et al*. Integrated Multi-Trophic Aquaculture (IMTA): A technology for uplifting rural economy and bio-mitigation for environmental sustainability. Aquaculture Spectrum. 2019;2(5):9-18.
18. Kadowaki S, Kitadai Y. Advantages of environmentally sound poly-eco- aquaculture in fish farms. In: Application of recirculating aquaculture systems in Japan. Springer, Tokyo; c2017. p. 267-278.
19. Kibria ASM, Haque MM. Potentials of integrated multi-trophic aquaculture (IMTA) in freshwater ponds in Bangladesh. Aquaculture Reports. 2018;11:8-16.
20. Laramore S, Baptiste R, Wills PS, Hanisak MD. Utilization of IMTA-produced Ulva lactuca to supplement or partially replace pelleted diets in shrimp (*Litopenaeus vannamei*) reared in a clear water production system. Journal of Applied Phycology. 2018;30(6):3603.
21. Laxmilatha P, Appukuttan KK, Velayudhan TS, Girijavallabhan KG, Alloycious PS. Experimental long-line culture of mussels *Perna indica* and *Perna viridis* at Andakaranazhi, South India. 1996.
22. Li J, Dong S, Gao Q, Wang F, Tian X, Zhang S. Total organic carbon budget of integrated aquaculture system of sea cucumber *Apostichopus japonicus*, jellyfish *Rhopilema esculenta* and shrimp Fenneropenaeus chinensis. Aquaculture Research. 2014;45(11):1825-1831.
23. Nath K, Munilkumar S, Patel AB, Kamilya D, Pandey PK, Sawant PB. Lamellidens and Wolffia canopy improves growth, feed utilization and welfare of Labeo rohita (Hamilton, 1822) in integrated multi-trophic freshwater aquaculture system. Aquaculture. 2021;534:7360207.
24. Neori A, Chopin T, Troell M, Buschmann AH, Kraemer GP, Halling C, *et al*. Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture. 2004;231(1-4):361-391.
25. Poli MA, Legarda EC, de Lorenzo MA, Pinheiro I, Martins MA, Seiffert WQ, *et al*. Integrated multitrophic aquaculture applied to shrimp rearing in a biofloc system. Aquaculture. 2019;511:734274.
26. Ren JS, Stenton-Dozey J, Plew DR, Fang J, Gall M. An ecosystem model for optimising production in integrated multitrophic aquaculture systems. Ecological Modelling. 2012;246:34-46.
27. Rosa J, Lemos MF, Crespo D, Nunes M, Freitas A, Ramos F, *et al*. Integrated multitrophic aquaculture systems–Potential risks for food safety. Trends in Food Science & Technology. 2020;96:79-90.
28. Roubach R, Oh K, Menezes A. Guidelines for Sustainable Aquaculture. FAO Aquaculture Newsletter. 2020;61:20-21.
29. Ryther JH, Goldman JC, Gifford CE, Huguenin JE, Wing

AS, Clarner JP, *et al*. Physical models of integrated waste recycling-marine polyculture systems. Aquaculture. 1975;5(2):163-177.
30. Sarà G, Zenone A, Tomasello A. Growth of Mytilus galloprovincialis (mollusca, bivalvia) close to fish farms: a case of integrated multi-trophic aquaculture within the Tyrrhenian Sea. Hydrobiologia. 2009;636(1):129-136.
31. Seaweed startup investments double in 2021. Available at: https://thefishsite.com/articles/seaweed-startup-investmentsdoublein2021#:~:text=New%20research%20has%20shown%20that,percent%20to%20reach%20%24168%20million.
32. Shpigel M, Ari TB, Shauli L, Odintsov V, Ben-Ezra D. Nutrient recovery and sludge management in seabream and grey mullet co-culture in Integrated Multi-Trophic Aquaculture (IMTA). Aquaculture. 2016;464:316-322.
33. Soto D. Integrated mariculture - A global review. FAO Fisheries and Aquaculture Technical Paper No. 529 194. doi:10.1016/S0044-8486(03)00469-1. 2009.
34. Sterling AM, Cross SF, Pearce CM. Co-culturing green sea urchins (*Strongylocentrotus droebachiensis*) with mussels (*Mytilus* spp.) to control biofouling at an integrated multi-trophic aquaculture site. Aquaculture. 2016;464:253-261.
35. Subramanian CP, Shailesh S, Sukumaran K, Panigrahi A, Vasagam K, Kumararaja P, *et al*. Development of integrated multi-trophic aquaculture (IMTA) for tropical brackish water species in Sindhudurg district, Maharashtra, west coast of India. Indian Journal of Fisheries. 2018;65:59-64. doi:10.21077/ijf.2018.65.1.70128-10.
36. Sukhdhane KS, Kripa V, Divu D, Vase VK, Mojjada SK. Integrated multi-trophic aquaculture systems: a solution for sustainability. Aquaculture Asia Magazine. 2018;22(4):26-29.
37. Troell M, Halling C, Neori A, Chopin T, Buschmann AH, Kautsky N, *et al*. Integrated mariculture: asking the right questions. Aquaculture. 2003;226(1-4):69-90.
38. United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects 2019: Highlights. ST/ESA/SER.A/423. 2019;39p.
39. Viji CS, Chadha NK, Kripa V, Prema D, Prakash C, Sharma R, *et al*. Can oysters control eutrophication in an integrated fish-oyster aquaculture system? Journal of the Marine Biological Association of India. 2014;56(2):67-73.
40. Yokoyama H, Ishihi Y. Bioindicator and biofilter function of *Ulva* spp. (Chlorophyta) for dissolved inorganic nitrogen discharged from a coastal fish farm—potential role in integrated multi-trophic aquaculture. Aquaculture. 2010;310(1-2):74-83.
41. Yokoyama H. Growth and food source of the sea cucumber *Apostichopus japonicus* cultured below fish cages—potential for integrated multi-trophic aquaculture. Aquaculture. 2013;372:28-38.
42. Zamora LN, Yuan X, Carton AG, Slater MJ. Role of deposit-feeding sea cucumbers in integrated multitrophic aquaculture: Progress, problems, potential and future challenges. Reviews in Aquaculture. 2018;10(1):57-74.
43. Zhang J, Kitazawa D. Assessing the bio-mitigation effect of integrated multi-trophic aquaculture on marine environment by a numerical approach. Marine pollution bulletin. 2016;110(1):484-492.
44. Zhou Y, Yang H, Hu H, Liu Y, Mao Y, Zhou H, *et al*. Bioremediation potential of the macroalga *Gracilaria lemaneiformis* (Rhodophyta) integrated into fed fish culture in coastal waters of north China. Aquaculture. 2006;252(2-4):264-276.