



Integrated Multi Trophic Aquaculture: An Ecofriendly Approach towards Sustainable Aquaculture

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ABSTRACT

For the millions of people worldwide the ecosystem approach for aquaculture promotes the rational use of the nutrients as well as sustainable growth of environment. The development of modern techniques of aquaculture like Integrated multi trophic aquaculture (IMTA) played a key role in this process. This technology not only minimizes the risk of crop failure but also utilizes the waste generated during the process for nutrition purpose, which leads to the cutting down of cost and sustainable environment growth is also observed. It has given a new hope towards the sustainable aquaculture goal to be achieved.

KEYWORDS

IMTA, Filter feeders, Eco-physical, Biofilter, Bio mitigation

Introduction

Aquaculture has grown rapidly over the last few decades and has become one of the world's fastest-growing food production sectors. Today, aquaculture contributes more to the global supply of aquatic food than capture fisheries, helping to meet the increasing demand for fish and other seafood. This remarkable progress has been made possible through the successful cultivation of species such as tilapia, catfish, salmon, shrimp, seaweeds, and bivalves using well-developed and standardized farming techniques. As the demand for aquatic products continues to rise, farmers have adopted intensive culture practices such as high-density stocking, cage farming, and the use of nutritionally balanced pelleted feeds to increase production. While these methods improve productivity, they also generate considerable amounts of uneaten feed, fish faeces and other organic wastes. If these wastes are not managed properly, they can accumulate in the surrounding water, leading to poor water quality, disease outbreaks, environmental degradation, reduced farm productivity, and economic losses.

To address these challenges, the ecosystem approach to aquaculture has gained increasing importance. This approach focuses on making better use of natural resources by recycling nutrients and reducing waste, while promoting environmentally sustainable aquaculture. One of the most successful examples of this approach is Integrated Multi-Trophic Aquaculture (IMTA), where fed species such as fish are cultured together with extractive organisms like seaweeds, aquatic plants, and bivalves. Freshwater integration with recirculatory aquaculture system as well as with aquaponics has shown a new horizon towards bicircular economy and sustainable culture

approach. These organisms utilize the nutrients and organic wastes released by the cultured fish, thereby improving water quality, reducing environmental impacts, and enhancing the overall sustainability and productivity of the farming system.

Definition

“IMTA is a sustainable aquaculture practice that combines different aquaculture species at various trophic levels to utilize waste generated from one species as a nutrient for the other one.”

Genesis of the concept

1970: Ryther and co-workers created the modern, integrated, intensive, land mariculture and integration of extractive organisms like shellfish, microalgae, seaweeds in the experimental basis by using the domestic wastewater effluent mixed with seawater, which became a medium for plankton taken by the oysters as a food and finally the effluent filtered by seaweeds.

1976: Huguenin proposed method of treatment of wastewater effluents in both inland and coastal area. Tenor integrated that system for carnivorous fish and the macro agnivore abalone.

1977: Hughes and Games first used the marine fish, shellfish, phytoplankton culture which is followed by Gordin in 1981.

1989: Semi-Intensive seabreams & grey mullet pond system by the Gulf of Aqaba on the red sea which supported diatom population efficiently & feed the oyster in an excellent manner.

Recent advancements

2016-IMTA as a sustainability strategy: Greater emphasis on IMTA for reducing nutrient and organic matter discharge, using

extractive species as biofilters. Diversification to additional trophic levels was proposed.

2017-Technology transfer & commercialization: Research moved beyond experimental systems toward transferring IMTA technology to farms. Simplicity of system design and farmer adoption became important considerations.

2018-Offshore IMTA & regional development: Stronger interest in offshore IMTA, spatial arrangement and integration with marine cage systems. IMTA development was also demonstrated for tropical brackish water species in India.

2019-Optimization of species combinations: Greater attention to selecting complementary fed and extractive species, nutrient capture efficiency and appropriate biomass ratios.

2020-Economic sustainability: IMTA research increasingly examined profitability, market value, production diversification and economic feasibility, rather than environmental benefits alone.

2021-Circular nutrient recovery: Greater emphasis on treating aquaculture waste as a resource and improving nutrient recycling through multiple trophic components.

2022-System optimization & diversification: Increasing research on combining several extractive organisms—seaweeds, molluscs, echinoderms and other organisms—and optimizing system design.

2023-IMTA + RAS/Bio floc & freshwater applications: IMTA began to be increasingly discussed alongside RAS, bio floc, aquaponics and freshwater integrated systems. Tilapia and other freshwater species

were considered in closed-loop configuration.

2024-Performance, welfare & life-cycle assessment: Research expanded to fish growth, survival, feed efficiency, animal welfare and product quality, while Life Cycle Assessment (LCA) became an important tool for evaluating environmental sustainability.

2025-Circular economy & freshwater closed systems: Stronger focus on freshwater IMTA + RAS + hydroponics, water conservation, nutrient recovery and circular bioeconomy. Seaweed's role as an inorganic nutrient extractor was also extensively reviewed.

2026-Smart, cascade & highly integrated IMTA: Current direction is toward closed-loop/cascade IMTA, precision monitoring, multiple trophic levels, automation and resource-efficient systems. Recent work is also assessing environmental, economic and social sustainability together.

Concept of IMTA

IMTA system involves the use of two important words “integrated” which refers to intensive and synergistic cultivation, “Multitrophic” refers to the different trophic levels are being taken care of in this system. Mainly two types of organisms are incorporated for the culture purpose;

a) Fed species: The organisms which are cultured primarily i.e. large carnivorous species.

b) Extractive species: These are the species which utilizes the waste generated from the fed species. It is further divided into 2 groups.

- **Inorganic extractive species:** The organism which utilizes the dissolved inorganic matters like nitrogen & phosphorous.

- **Organic extractive species:** These organisms utilize the particulate waste generated in the system for their nutrient purpose.

Unlike a conventional polyculture system, this approach involves the cultivation of organisms belonging to different trophic levels. Although the cultured organisms share common biological and chemical processes within the system, the major emphasis is on utilizing the nutrients and energy generated at one trophic level by organisms at another. Thus, the system supports intensive production of multiple species through efficient nutrient recycling and energy transfer. The system utilizes more space in open water systems like cage culture whereas in closed systems like recirculatory aquaculture system (RAS), it needs to be more compactly placed.

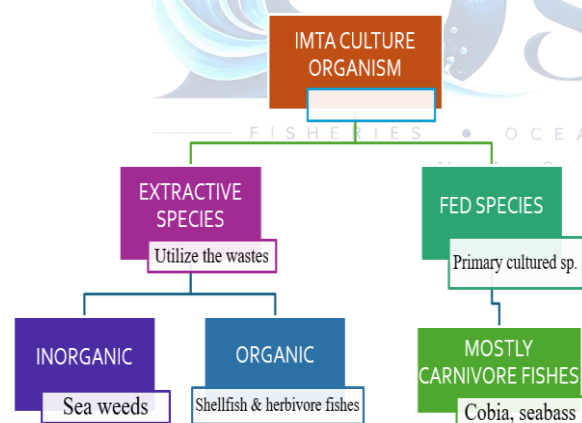


Fig: Components of IMTA

Different components of IMTA

A. Inorganic extractive sub-system in IMTA

In an Integrated Multi-Trophic Aquaculture (IMTA) system, the inorganic extractive component is mainly represented by seaweeds and other photosynthetic organisms. These organisms utilize dissolved

inorganic nutrients, particularly nitrogen and phosphorus, released from the culture of fed organisms such as fish. Thus, the autotrophic activity of seaweeds complements the heterotrophic processes associated with fish and microorganisms and contributes to maintaining a more balanced culture environment. Their incorporation into an IMTA system can reduce the nutrient load from intensive fish culture while also providing an additional harvestable crop. Moreover, seaweeds occupy a lower trophic level and obtain most of their nutrient requirements directly from the surrounding water, thereby requiring comparatively low external inputs for their cultivation. Several seaweed species, including *Kappaphycus alvarezii*, *Ulva* spp., *Gracilaria* spp., *Eucheuma* spp. and different kelp species, have been used or considered for integration into IMTA systems. Selection of a suitable seaweed species is important for achieving effective nutrient removal as well as obtaining an economically valuable secondary crop. The major criteria for selection include:

- High growth rate and capacity to accumulate nutrients, particularly nitrogen, in the tissues.
- Ease of cultivation, propagation and management of the life cycle under culture conditions.
- Resistance to epiphytes, diseases and other biological stresses.
- Compatibility of the eco-physiological requirements of the species with the prevailing environmental conditions of the culture site. Seaweeds with a high surface-area-to-volume ratio generally exhibit greater nutrient uptake potential.

- Preference for locally available species that do not pose a risk of becoming invasive or introducing pathogens into the culture environment.
- Adequate market demand and economic value of the harvested biomass.

One of the major challenges associated with seaweed-based nutrient extraction in open-water IMTA systems is the relatively low and variable nutrient-recovery efficiency. Water movement, dilution and the three-dimensional hydrodynamics of the culture area can rapidly disperse dissolved nutrients away from the seaweed component. Therefore, proper spatial arrangement of the cultured organisms, site-specific hydrodynamic assessment and modelling of nutrient transport are important areas requiring further research for improving the efficiency of open-water IMTA systems.

B. Organic extractive species sub-system in IMTA

In an IMTA system, organic extractive organisms such as bivalves are generally cultured in close proximity to fish cages or other fed components. These filter-feeding organisms utilize suspended particulate matter, including uneaten feed, faecal particles and plankton, thereby helping to reduce the organic load in the surrounding water. At the same time, the assimilated nutrients are converted into bivalve biomass, providing an additional harvestable product from the system. Selection of a suitable bivalve species is important for improving the efficiency of organic waste utilization. The major criteria for selection include:

- Knowledge of the size and nature of particulate wastes generated from the fed component of the IMTA system, so that a bivalve species capable of efficiently

filtering the available particles can be selected.

- Feeding behaviour and interaction of the filter-feeding species with the surrounding culture environment.
- Filtration and nutrient uptake capacity of the selected bivalve species.
- Ability to grow efficiently under the prevailing environmental conditions of the culture site.
- Commercial value and market acceptance of the harvested species.

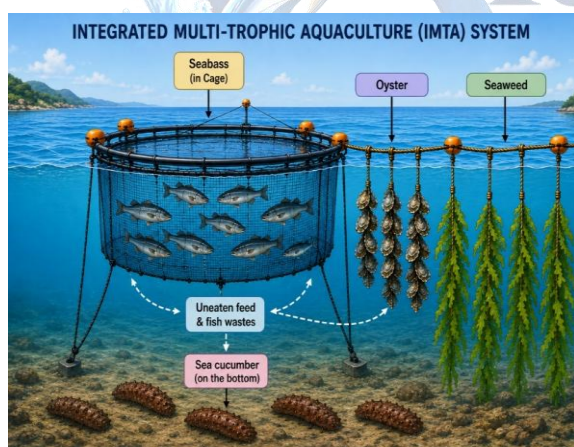
In some cases, marketability of the secondary extractive species may limit the economic performance of the system. Therefore, more than one extractive component may be incorporated at different stages of nutrient recovery. Suitable fish or other organisms may utilize larger organic particles close to the primary fed species, whereas bivalves can serve as a subsequent bio-filter by removing finer suspended particles from the water column. Commercially important bivalves such as the green mussel *Perna viridis* and the Indian backwater oyster *Magallana bilineata* (formerly *Crassostrea madrasensis*) can be integrated with fed aquaculture systems along the Indian coast. Their incorporation may contribute to the recovery of particulate organic nutrients, reduction of localized nutrient enrichment and generation of an additional economically useful crop.

C. Fed aquaculture sub-system in IMTA

The fed aquaculture component of an IMTA system is generally represented by finfish or other organisms that depend on externally supplied feed. This component serves as the primary source of nutrients within the system. During culture, a portion of the

supplied feed is released into the surrounding environment in the form of uneaten feed, faecal matter and dissolved metabolic wastes. These nutrient-rich outputs subsequently become available to the organic and inorganic extractive components of the IMTA system.

The quantity and composition of the wastes generated from the fed component depend on several factors, including the cultured species, stocking biomass, size of the organisms, feeding rate, feed composition and digestibility. Therefore, appropriate feed management and selection of compatible extractive species are essential for achieving effective nutrient utilization. Besides supporting nutrient transfer within the IMTA system, the fed species generally constitute the principal commercial crop and contribute substantially to the overall economic return of the production system.



Design of IMTA

The establishment and smooth operation of an efficient system depend on the organized assembling of all the components for the proper collection of all the waste generated in the system and its efficient utilization. For example, in a system model consists of a seabass culture unit, oysters, seaweeds, each performing a specific ecological function.

Seabass is cultured in a cage and fed with formulated feed, generating organic and inorganic wastes. Oysters, functioning as filter feeders, are placed near the fish cage to utilize suspended organic particles and improve water quality. Seaweeds are cultured on ropes around the culture unit and absorb dissolved nutrients, particularly nitrogen and phosphorus, released from fish wastes. Sea cucumbers are positioned at the bottom of the system, where they consume deposited organic matter and sediments. Thus, the model represents the flow and recycling of nutrients among different components, where the waste generated by one trophic group becomes a resource for another. The integration of these species helps reduce nutrient accumulation, improve water quality, enhance resource utilization, diversify aquaculture production, and minimize environmental impacts. Overall, the IMTA model illustrates the principle of “waste as a resource” and demonstrates how different aquatic organisms can be integrated to develop a more productive, balanced, and sustainable aquaculture system.

Transition towards freshwater IMTA

Freshwater IMTA replaces marine extractive species with organisms capable of utilizing nutrients under freshwater conditions. Depending on the system, combinations may include tilapia, carp or catfish as fed species; freshwater mussels and prawns/crayfish as consumers of particulate or organic material; and aquatic plants, microalgae or hydroponic crops as nutrient extractors. The fundamental principle remains the same: nutrients released through uneaten feed, faeces and metabolic excretion are redirected toward the production of additional biomass rather than being discharged as waste.

a. Integration with closed/RAS systems

The development of RAS has provided an important technological platform for freshwater IMTA. In a closed IMTA-RAS, water is continuously circulated between the different production and treatment components. A typical pathway is:

Fish culture → solids collection → biofiltration → microbial conversion → extractive organisms/plants → final water treatment → fish culture

This differs from open-water IMTA because the system has substantially greater control over water flow, nutrient concentration, hydraulic retention time, dissolved oxygen, temperature and biosecurity.

b. Emergence of IMTA-aquaponics integration

A particularly important recent advancement is the combination of freshwater IMTA with aquaponics/hydroponics. Rather than relying exclusively on aquatic extractive organisms, plants can act as additional nutrient sinks. This creates a more complete nutrient-recovery pathway:

Fish → organic/inorganic waste → microbial transformation → nitrate/phosphate → plants → harvested biomass



Benefits

- Biomitigation of aquaculture effluents: Extractive species utilize dissolved and particulate wastes generated from the fed component, thereby reducing the nutrient load released into the surrounding environment.
- Higher income through diversification: Production of more than one commercially valuable species provides additional sources of revenue from the same farming system.
- Support to the local economy: Diversified production can generate employment and create opportunities for processing, marketing and other associated activities.
- Natural crop insurance: Cultivation of species belonging to different trophic levels reduces complete dependence on a single crop and can partly compensate for losses if the performance or market value of one species declines.
- Improved environmental and health management: Better utilization of organic and inorganic wastes may improve the culture environment and, under suitable management, help reduce stress and disease risks.
- Possibility of premium pricing: Environmentally responsible production may provide scope for product differentiation through eco-labelling, sustainability certification or suitable organic certification programmes.

Challenges

- Higher initial investment: Establishment of an IMTA system may require additional infrastructure, culture units and management inputs.
- Complex farm coordination: Simultaneous management of organisms

belonging to different trophic levels requires greater technical knowledge and operational planning.

- Larger spatial requirement: Integration of multiple culture components may require more farming area than a conventional monoculture system.
- Policy and leasing constraints: Adoption of open-water IMTA can be difficult in regions where suitable leasing, licensing and regulatory provisions are not available.
- Limited availability of compatible species: Selection of species with appropriate feeding habits, environmental requirements, growth performance and market demand can be challenging.
- Food safety concerns: Extractive species may accumulate undesirable microorganisms, contaminants or toxic substances from the surrounding environment; therefore, proper site selection, monitoring and food-safety assessment are essential.

Conclusion

IMTA offers an effective approach for reducing both inorganic and organic nutrient loading in open-water as well as confined aquaculture systems, thereby contributing to better environmental management and ecological balance. By integrating species from different trophic levels, the system promotes more efficient utilization of nutrients and can also provide additional sources of income to coastal and inland fish

farmers. A major development in the concept of IMTA is that closed freshwater systems are no longer considered merely as a means of treating aquaculture wastes. Instead, they are increasingly viewed as resource-recovery systems in which nutrients such as nitrogen, phosphorus and carbon, which would otherwise be lost from the production system, can be captured and converted into additional marketable biomass. This approach is closely associated with the principles of circular bioeconomy and improved resource-use efficiency. With appropriate species selection, system design and management, IMTA also has the potential to contribute towards climate-resilient aquaculture by reducing nutrient losses, improving resource utilization and diversifying production. Its possible role in carbon sequestration and carbon-credit mechanisms is also receiving increasing attention, although such benefits require proper quantification and verification before being considered for carbon-credit generation.

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