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IMTA: Elevating Nutrient Extraction for Sustainable Nutrification

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ABSTRACT

Integrated Multitrophic Aquaculture (IMTA) presents a promising and innovative approach to address the challenges of sustainable aquaculture. This method revolves around the concept of converting waste generated in one system into valuable products through nutrient extraction, offering a more sustainable alternative. As intensive aquaculture becomes increasingly prevalent to meet the growing global demand for animal protein and confront impending food security issues, the discharge of substantial nutrients into the water poses environmental concerns. The discharge of nutrients from intensified aquaculture practices can have adverse effects on benthic flora and fauna, leading to alterations in bottom sediment and potential long-term impacts on benthic biodiversity. While the removal of these nutrients remains a topic of ongoing debate, Integrated Multitrophic Aquaculture emerges as a potential solution to mitigate the environmental impact of aquaculture. IMTA strives to achieve a balance in aquatic systems by integrating species in appropriate proportions, encompassing fed, organic, and inorganic extractive components. In the IMTA system, the interconnection of species within the food chain facilitates the recycling of wastes or by-products from one species into valuable inputs such as fertilizers, food, and energy for another. This cyclic process not only reduces environmental impact but also aligns with the principles of economic stability through product diversification and risk reduction. Additionally, IMTA addresses social acceptability and environmental sustainability by incorporating better management practices, making it a holistic and viable strategy for sustainable aquaculture.

KEYWORDS

IMTA, intensification, Sustainable production, ecological balance

Introduction

By the year 2050, the global population is anticipated to grow from 7.7 to 9.7 billion people, as projected by the Population Division of the UN Department of Economic and Social Affairs (World Population Prospects, 2019). This population surge, coupled with the plateauing production of seafood from capture fisheries, places significant pressure on aquaculture to meet the escalating demand for fish, especially seafood. In response to this challenge, intensive farming approaches, such as cage and pen culture in open water, have gained considerable importance in recent years to address the surging demand for fish. However, the intensification of aquaculture systems is associated with various issues, including nutrient overloading and inefficient resource utilization. The adoption of intensive aquaculture techniques can lead to excessive nutrient loading, resulting in eutrophication that significantly impacts fish stocks, biomass, and community structure. This, in turn, may lead to oxygen depletion, worsening water quality, spreading diseases, and causing broader effects on the surrounding areas of production sites.

To address these challenges, there is a critical need for the development of novel aquaculture systems that prioritize ecological sustainability, economic stability, reduced production costs, diverse species culture alternatives, societal acceptance, risk reduction, and improved yields. Integrated aquaculture emerges as a vital and practical approach to achieving the Ecosystem Approach for Aquaculture (EAA), which emphasizes the optimal use of nutrient resources and the exploration of various products and benefits while minimizing environmental impacts (Soto, 2009). Farming diverse species within an integrated system enhances operational resilience and mitigates risks by providing positive environmental benefits that help bio-mitigate waste production. This approach aligns with the principles of the EAA, offering a balanced and sustainable solution to meet the growing demands of the world's population while minimizing the adverse impacts on aquatic ecosystems. While integrated aquaculture is a well-established concept in freshwater locations, particularly in Asia, its application in the marine environment has received less attention. However, the idea of integrated aquaculture has gained prominence in recent years, particularly as a proactive measure to counter the excessive production of organic materials and nutrients associated with intensive aquaculture systems, predominantly in marine settings. The term "multitrophic" is central to this concept, signifying the intentional inclusion of organisms from multiple trophic positions or nutritional levels within the same system. This perspective has led to the evolution of integrated multi-trophic aquaculture (IMTA). IMTA systems incorporate organisms from diverse trophic levels, offering a solution to environmental concerns associated with aquaculture, while concurrently providing economic opportunities. IMTA represents an environmentally sound and sustainable approach to the development of aquaculture, distinct from polycultures where multiple species are cultured together but share the same trophic level. In essence, IMTA is a compelling concept that addresses the global demand for seafood while promoting the sustainable expansion of aquaculture in marine and coastal environments. By leveraging the interactions between different trophic levels, IMTA aims to optimize resource utilization, minimize environmental impact, and contribute to the responsible and sustainable growth of the aquaculture industry.

Need of adopting Integrated Multi-Trophic Aquaculture

In order to meet the rising demand for seafood supplies, intensive cage or pen mariculture practices are being increasingly used in India and around the world. Figure 1 demonstrates the potential risk connected with these practices. *Pangasianodon hypothalamus* and Genetically Improved Farmed Tilapia (GIFT) are the species most commonly grown in cages in India, whereas salmon, yellow tail, and other species are most popular throughout the world (Marx et al., 2020). The production of non-native and genetically modified organisms (GMOs) has the potential to result in the escape of invading species from farming or during natural disasters like floods, which would alter the genetic diversity of the natural fauna.

The high stocking density can also cause new infections and pathogens to enter the culture water, drop the concentration of dissolved oxygen, and appear to worsen the water quality. Although confined spaces and stress can predispose organisms to disease and cause financial losses for the producers, the intensification of aquaculture is frequently linked to the high usage of chemicals in this sector. This could result in the uncontrolled usage of chemicals, together with insufficient information provided to farmers. Although parasitic infections may not result in the death of organisms, they can increase production costs or degrade product quality (Granada *et al.*, 2016), which may result in the commodity being rejected by markets because it is non-conforming. Antiparasitic drugs are therefore frequently used to control such infestations, although despite being prescribed, they frequently wind up being released into the environment and harming other species that are co-cultured in the same system.

The culture system may also be exposed to the usage of hormones, antibiotics, medicines, hormones, hormones, and algicides for the treatment of diseases, algal control, etc. Furthermore, the leftover feed and fish waste cause eutrophication and nutrient loading in the surroundings. Several years of intensive fish cage farming in these sites have resulted in the anaerobic decomposition of fish wastes, which releases deoxygenated water that is rich in hydrogen sulphide (Rosa *et al.*, 2020). Thus, the concept of Integrated Multi- Trophic Aquaculture (IMTA) found success in spreading as a remedy for nutrient enrichment and ecological degradation in mariculture practices, while also improving economic and environmental resilience, lowering production costs, and maximizing profits from organisms diversification for local coastal regions.

Integrated Multi-trophic Aquaculture (IMTA)

Integrated multitrophic aquaculture is a practical combination in which intensive aquaculture species are being reared with organic and inorganic extractors. Shellfish and herbivorous fish are examples of organic nutrient extractors, whereas seaweed and algae are examples of inorganic nutrient extractors. Overall, this combination creates a balanced system, and the sustainable environment provides extra-economic value as well as a potential remedy for nutrient dumping. IMTA improves bioremediation by lowering the risk of nutrient fate and offering a wide range of products. It also enables by-products from one culture to be recycled into another as commodities such as food or fertilizer. IMTA follows the highly intensive culture of different combinations which work in harmony to reduce the overall nutrient waste in the water.

The synergy between both biological and chemical processes is essential for the success of IMTA. Once applied, IMTA may be very successful by reaching an optimized performance involving the right proportion of diverse species offering multiple environmental services. The chosen extractor must have a commercial value at harvest in order to achieve economic efficiency. Today, IMTA is close to commercial levels in many regions of the world. Professor Theory Chopin, recognized as the inventor of the IMTA system, made a significant advancement in the field-based implementation of IMTA via his pioneering work. It has become a role model of IMTA, using a combination of fed species, organic extractives, and inorganic extractives. Recently, China’s assimilative approach to Sanggou bay IMTA systems has opened a new window to the door to environmental sustainability (Troell, 2009a).

It combines fed aquaculture (such as growing fish) with suspension organic extractive aquaculture (such as growing shellfish), which benefits from the enrichment in small particulate organic matter (POM), inorganic extractive aquaculture (such as growing seaweeds), which benefits from the enrichment in dissolved inorganic nutrients (DIN), and deposit organic extractive aquaculture (such as growing echinoids Moreover, some DIN is renewed by the bottom bioturbation, making it accessible to the seaweeds.

The wastes caused by the targeted species (e.g., fish) could become food for other species. For example, small organic particles from the fish cage or resuspended from the sediment can be used by suspension feeders, while larger particles sinking at the bottom of the sea can be consumed by deposit feeders; seaweeds can absorb the dissolved nutrients generated by the cultured species or released from sediment through water flow exchange (Yokoyama and Ishihi, 2010; Yokoyama, 2013).

Choice of species selection for IMTA

In accordance with the IMTA, environmental sustainability is fundamental, therefore comprehending the constraints of the natural ecosystem is a key component of species selection. One must carefully evaluate the right species compatibility in culture before attempting IMTA production.

The species used for fed aquaculture in the IMTA is preferably a carnivorous fish fed pelleted food. Organic and inorganic extractors extract nutrition from the environment through waste recycling. Notable species in the extractors group that are better known include bivalves with organic material and seaweed with inorganic material. The following criteria will be applied to choose various cultivated species for synergy:

1. **Complementary roles:** When choosing diverse species, consideration for different trophic levels should come first. It is preferred that the waste of one species be consumed by the other for better water quality.
2. **Habitat adaptation**: Careful consideration must be given to choosing the most tolerant species before beginning the culture. Native species ought to be used in the first place to prevent the spread of infection, prevent invasiveness, and maybe damage other commercial endeavours.
3. **Environmental factors and the appropriate culture strategy**: While considering waste generation, there should be a distinct provision for dissolved inorganic matter (DIM) and particulate organic matter (POM). Size of small particulates must also be taken into account.
4. **Effective bio-mitigation**: Selected species must be able to recycle a lot of waste to lower the nutrient load from water. As an alternative, a very high value may be considered, where smaller volumes could be grown.
5. **Market demand and customer preference**: Utilize species with a known or regarded market value. For extractive species to be profitable, they must have some commercial value. They have to prepare market buyers as an outcome before making an investment.

IMTA system design

To recycle organic and inorganic nutrients, the integrated multi-trophic aquaculture (IMTA) system identifies, organizes, and deploys different species. The system design should be adjusted in line with the need that the species selected to recapture the waste. Leftover foodstuff, along with feces, is dumped in massive amounts below the cage area. Deposit feeders are crucial in minimizing this adverse environmental impact. In addition, sea urchins and sea cucumbers are prominent deposit feeders. Through their special filtering capabilities, mussels remove small particulates simultaneously. Scallops and oysters are also regarded as excellent filter feeders. Seaweed has the ability to absorb and circulate inorganic compounds like excess nitrogen and phosphorus. In its current configuration, the IMTA concept seems to be quite versatile.

Trophic dynamics within the IMTA

When considering the potential of various filter feeders, nutrient bioremediation is a promising approach. While macroalgae, or algae, may take up inorganic nutrients, molluscs are the most well-known natural filters that can filter organic pollutants. In contrast to polyculture, which provides less diversity and offers a smaller number of synergistic advantages, IMTA offers a larger variety and allows for the acquisition of a considerable proportion of benefits without compromising environmental sustainability.

Fig.1 Trophic dynamics within the IMTA

Seaweeds

Seaweed is thought to be the best natural bio-filter due to its ability to recycle nitrogen and phosphorus proficiently. Fish species including seabass, Indian pompano, grouper, and cobia may be raised with seaweed species like *Kappaphycus alvarezii*, *Gracilaria dura*, and *G. edulis*.

Fig. 2 Inorganic extractives

Invertebrates

The researchers discovered that certain invertebrates have a wide range of abilities to remediate heavy metals, microbial contaminants, hydrocarbons, nutrients, and persistent organic pollutants—a variety of filter-feeding creatures filter enormous volumes of water for their nutritional requirements. The optimum method for lowering the nutrient load from cage culture farming, according to several studies, is to use invertebrates that feed on detritus. The green mussel *Perna viridis* and the Indian backwater oyster *Crassostrea madrasensis* are both commercially farmed in India using a variety of techniques including raft, rack, and longline systems (Anil and Gomathi, 2023). They could be one of the species most equipped to eliminate excess nutrients. These species offer the additional benefit of a free-of-charge natural biofiltration system.

Fig. 3 Organic extractive

Table 1. Organisms experimented in IMTA

Finfish	*Salmo*, *Oncorhynchus*, *Scophthalmus*, *Dicentrarchus*, *Gadus*,*Anoplopoma*, *Hippoglossus*, *Melanogrammus*, *Paralichthys*, *Pseudopleuronectes* and *Mugil sp*. (Troell, 2009b) 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.*, 2017);(Zamora *et al.*, 2018). Carp and catfish- Kibria and Haque, 2018 India- Cobia, Pearlspot, Mullet (*Mugil cephalus*, *Liza parsia*),Milkfish, Rohu ((Sasikumar and Viji, 2015);(Johnson, 2021);(Balasubramanian *et al.*, 2018);(Biswas *et al.*, 2020);(Nath *et al.*, 2021))
Organic extractive species/Suspension feeder (Shellfish)	Molluscs are the most tested organisms in IMTA context(Granada *et al.*, 2016) Mussels (Mytilidae) such as *Mytilus edulis* or *Mytilus trossulus* are particularly effective in coastal temperate areas and present high potential to be used as secondary species in IMTAs ((Ren *et al.*, 2012);(Sarà *et al.*, 2009). *Haliotis*, *Crassostrea*, *Pecten*, *Argopecten*, *Placopecten*, *Mytilus*, *Choromytilus* and *Tapes* (Soto, 2009) Crustaceans-*Penaeus* and *Homarus* (Soto, 2009) India- Green mussel (*Perna viridis*), *Crassostrea madrasensis, C. cuttackensis, Lamellidens marginalis* ((Sasikumar and Viji, 2015);(Balasubramanian *et al.*, 2018); (Biswas *et*

	al., 2019); (Nath *et al*., 2021)

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

Advantages of IMTA:

The advantages of IMTA include:

- **Waste bio-mitigation**: One of the most significant advantages of IMTA over other aquaculture techniques is the ability to mitigate aquaculture waste using bio-filters appropriate for a region. Nutrient leaching is now a concern in monoculture aquaculture, however, IMTA can alleviate this problem with an inherent ability to extract pollutants.
- **Benefit through species diversification**: Since multiple harvests are undertaken, the system's economic value increases. The cost of biofilters is currently quite expensive in the market, and this natural intervention provides the majority of low-cost solutions for aquaculture. By adding extractive species, such load may be reduced in aquaculture practices where these waste nutrients cause disturbance and deteriorate water quality.
- **Boost in local farmer economy**: Local farmer economy may be strengthened by IMTA by offering a range of direct and indirect opportunities.
- **Disease prevention**: Some seaweeds have antibacterial properties that can combat harmful fish pathogens.

Challenges of IMTA:

IMTA poses several challenges:

- **Higher capital expenditure**: Considering the current state of technology, IMTA in open waters demands a higher capital outlay.
- **Healthy collaboration and coordination**: If IMTA practice has to be done by separate entrepreneurs like cage farmers and mussel farmers working in a group, it would require a healthy understanding of various production activities to get good production potential.
- **Higher area requirement**: The area requirement for IMTA is relatively high, and conflicts cannot become uncommon in competition with another coastal sector

Conclusion and Prospectus

Aquaculture has gained massive momentum in providing a good source of animal protein globally, where population rises are continuing demand to the next level. Sustainable production has become a key function supporting development in the sector. IMTA provides an opportunity to enhance fish production with higher ecological precautions and economic returns. IMTA has not yet gained global commercialization, but it shows great potential to become sustainable aquaculture practice for next-generation aquaculture. IMTA provides multiple benefits like increased production diversity, quality, and ecological, economic, and social sustainability. The method of bioremediation with filter feeders and plants in IMTA provides nitrification with reduced waste discharge. The probability of disease occurrence would reduce along with a combination of environmental and net return benefits. Ultimately, wastewater treatment costs get reduced while producing different species without adding any extra commercial feed, providing an essential income generation source. Tremendous opportunities are waiting to utilize natural biofilters to solve the big problem of nitrification in the aquaculture industry.

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