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## CHAPTER 3

# Integrated Multi-Trophic Aquaculture in India: Scope and Challenges

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**Abstract**

Integrated Multi-Trophic Aquaculture (IMTA) is a practice where the waste products of one species are used as inputs for another. Fish fed in a pond produces faeces (nutrients), which plants can utilise. Key aspects of integrated multi-trophic aquaculture in India may include species combination, environmental sustainability, diversification, nutrient cycling, research and adoption, and government initiatives. India's integrated multi-trophic aquaculture (IMTA) scope is promising and aligns with the broader global trend toward sustainable and diversified aquaculture practices. IMTA offers several potential benefits, and its scope in India can be evaluated from various perspectives, such as sustainability, diversification of species, nutrient recycling, economic viability, research and innovation, government support, market demand, etc. When selecting species for Integrated Multi-Trophic Aquaculture (IMTA), imitating natural ecosystems is the guiding criterion for environmental sustainability. Several conditions and criteria should be considered when choosing co-cultured species combinations. While integrated multi-trophic aquaculture (IMTA) holds great promise for sustainable and diversified aquaculture practices, several challenges may be faced in its implementation in India. These challenges include regulatory framework, higher investment, difficulty in coordination, increased requirement of farming area, difficulty in implementation without open water leasing policies, lower productivity, food safety concerns, public perception issues, species limitations, increased need for personnel training, development in expertise for each species, non-demonstration of mitigation capacity, lack of awareness and education, infrastructure and technology, availability of suitable species, market acceptance, economic viability, environmental conditions, research and development, financing and support, community engagement.

**Keywords:** IMTA, species selection, bio-mitigation, sustainability, nutrient recycling





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**Introduction**

Aquaculture is currently the fastest-growing food production industry worldwide. In a natural food chain, each organism consumes the one below it. These food chains are interdependent, forming a complex food web network. This web allows the flow of energy and biomass among the various species. At each trophic level, the waste produced by living organisms can be consumed by other species. Nature has a way of recycling everything, and nothing goes to waste. The different trophic levels in aquaculture can be broadly categorised as follows:

- ***Primary Producers (Autotrophs):*** These organisms can produce food through photosynthesis. In aquaculture, primary producers often include macroalgae (seaweeds) or other aquatic plants.
- ***Primary Consumers (Herbivores):*** These are organisms that consume primary producers. In aquaculture, this category may include herbivorous fish or invertebrates.
- ***Secondary Consumers (Carnivores/Omnivores):*** These organisms feed on primary consumers or a combination of primary producers and consumers. This category in aquaculture often includes carnivorous fish or other species that consume plant and animal matter.
- ***Detritivores/Decomposers:*** These organisms play a crucial role in breaking down organic matter, including waste products from other species. In aquaculture, this may involve filter-feeding organisms like bivalves or certain invertebrates.

Aquaculture faces several problems, such as self-pollution concerning sustainable development (Troell *et al.*, 2009; Alexander & Huges, 2017). The integrated aquaculture concept is vital to coastal zone management. The main aim is to minimise the adverse environmental impact of aquaculture on the coastal environment in an economically and socially beneficial manner (Chow *et al.*, 2001; McVey *et al.*, 2002). One solution only fits some. Integrated aquaculture systems are dynamic, changing according to location, season, species, and social environment (Edwards, 1998; Little and Muir, 1987). The trophic dynamics of the natural environment simulate the concept of integrated multi-trophic aquaculture (IMTA). It is an exercise wherein one species' by-products (wastes) are recycled to emerge as inputs (fertilisers, food) for another. The faeces produced by fed fishes in a pond, in turn, can be utilised as nutrients by plants. These plants may be a crop (e.g. tomatoes or watercress). It is a sustainable and innovative approach to aquaculture that involves cultivating multiple species from different trophic levels in the same aquatic system. The key idea behind IMTA is to mimic the natural ecosystem by creating a balanced and integrated environment where each species plays a specific role in the system's overall functioning. The various components in an IMTA system are chosen to complement and support each other, resulting in increased resource use efficiency, reduced environmental impact, and enhanced overall sustainability. Alternatively, the increased concentrations of nutrients make the water eutrophic, leading to microalgal and zooplankton blooms in ponds, which may feed other fish species that graze on these blooms. The idea is to rear fish with molluscs and/or crustaceans, algae, and/or aquatic plants to improve environmental and economic yields.

In the IMTA system, these different trophic levels are carefully selected and co-cultivated to create a symbiotic relationship. For example:

***Fish,*** which are primary consumers, produce waste that contains nutrients.

***As primary producers***, seaweeds can utilise these nutrients for growth, helping mitigate water pollution.

***Filter-feeding organisms,*** like bivalves, can help remove particulate matter and improve water quality.

By integrating these species, IMTA aims to achieve a more sustainable and ecologically balanced aquaculture system, reducing the reliance on external inputs, minimising environmental impacts, and optimising the use of resources. The concept of IMTA reflects a move toward more environmentally responsible and economically viable practices in the aquaculture industry.


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The harmful effect of aquaculture waste on the aquatic environment is often questioned and studied (Yokoyama & Ishihi, 2010; Park *et al.,* 2015). Fish can utilise less than 30% of nutrients from the feed for growth. In contrast, the remaining amounts of particulate organic matter (unconsumed feed and fish faeces) and inorganic nutrients (fish excretions) are released into the water, causing eutrophication, harmful algal blooms, and deoxygenation of the bottom water (Yokoyama, 2010; Irisarri *et al.,* 2015; Martinez-Espineira *et al.,* 2015). Rapid water quality deterioration endangers animals residing in the aquaculture area, regularly leading to fish sicknesses and death.

Traditional aquaculture pollutes the surrounding ecosystems by deoxygenating the bottom water with organic wastes and possibly promoting the growth of harmful algal blooms due to the dissolved nutrients, adversely affecting the animals inhabiting the aquaculture area. Therefore, the IMTA system aims to achieve sustainable development by recycling aquaculture wastes like food resources through co-cultivating the targeted species with others with different feeding habits at distinct trophic levels and enhancing the performance and productiveness of extensive monoculture systems.

IMTA aims at ecosystem management that considers site specifications, operational limitations, food safety guidelines, and regulations. The goals include environmental sustainability through bio-mitigation, social acceptability through economic stability and product diversification, reduction of risks, and better management practices. In IMTA, the wastes generated from one species are recycled to become inputs for another as fertilisers, feed, and energy. In IMTA, the fed species like finfishes and shrimps are integrated, in the right proportions, with species that are suspension feeders, deposit feeders, or herbivorous fish and extractive species (e.g. seaweeds). Multi-trophic implies incorporating species from different trophic or nutritional levels in the same system. It involves cultivating different species, connected by nutrient and energy transfer through water, balancing biological and chemical processes. It consists in cultivating different species, connected by nutrient and energy transfer through water, balancing biological and chemical processes. This balance is achieved by selecting appropriate species proportions to meet the different ecosystem functions. An effective Integrated Multi-Trophic Aquaculture (IMTA) system should lead to improved production from the farming system. This is accomplished by the co-cultured species providing mutual benefits to each other, resulting in improved ecosystem health. It is important to note that even if the individual production of some species is lower compared to what could be achieved in monoculture practices over a short period, the system's overall production is still improved (Neori *et al.,* 2004). Integrated multi-trophic aquaculture (IMTA) is a practice that involves the simultaneous cultivation of multiple species from different trophic levels in the same aquaculture system. The goal is to optimise resource use, reduce environmental impacts, and improve overall sustainability. In India, as in many other parts of the world, there have been efforts to explore and promote IMTA practices.

The main aspects of integrated multi-trophic aquaculture in India may include:

- **Species Combination:** IMTA typically involves ecologically cultivating species that complement each other. For example, cultivating fish alongside filter-feeding organisms, such as molluscs or seaweeds, can help in nutrient recycling and waste management.
- **Environmental Sustainability:** IMTA aims to minimise the environmental impact of aquaculture by creating a balanced ecosystem where the waste products of one species serve as nutrients for another. "This can enhance water quality and minimise the requirement for external inputs."
- **Species Diversification:** IMTA allows for the diversification of aquaculture activities. Farmers may reduce the risk of relying on a single species by cultivating species with different market demands and environmental requirements.


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- **Nutrient Cycling:** In an IMTA system, the waste produced by one species, such as fish, can be utilised by another species, such as seaweeds or bivalves. This nutrient cycling can enhance overall system productivity and reduce the environmental impact of aquaculture.
- **Research and Adoption:** Research institutions and aquaculture practitioners in India may be involved in studying and promoting IMTA practices. Efforts include identifying suitable species combinations, optimising production techniques, and assessing the economic and environmental benefits.
- **Government Initiatives:** Government bodies may support initiatives related to sustainable aquaculture practices, including IMTA. Policies and programs may be in place to encourage the adoption of environmentally friendly and economically viable aquaculture methods.

**Scope for IMTA in India**

India's integrated multi-trophic aquaculture (IMTA) scope is promising and aligns with the broader global trend toward sustainable and diversified aquaculture practices (Sukhdhane *et al.*, 2018). IMTA farming in India is mainly restricted to research with a few initiatives from ICAR-CMFRI and CIBA to promote a participatory mode among the coastal communities. ICAR- Central Marine Fisheries Research Institute (CMFRI) is undertaking ongoing studies below participatory mode with the fisherman agencies of Kerala and Tamil Nadu to sell and disseminate the technology to the rural poor people of the coastal community. ICAR- CIBA, in collaboration with Mangrove Cell Maharashtra, has also worked towards promoting IMTA among farmers in Sindhudurg District, Maharashtra (Biswas et al., 2019). ICAR-CMFRI reported 23,970 ha of potential areas suitable for seaweed farming in India. (Johnson *et al.*, 2019). ICAR-Central Marine Fisheries Research Institute (CMFRI) pioneered the adoption of the IMTA strategy in India in the year 2013-14 under participatory mode with fisherman groups in the coastal areas. The first trial commenced in the participatory mode with a fishermen's institution at Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu, with the aid of using integrating seaweed (*Kappaphycus alvarezii*) with cage farming of Cobia (*Rachycentron canadum*). Close to 100 fishers in the Ramanathapuram district of Tamil Nadu are adopting this IMTA technology with their investment. As the bamboo raft method is sometimes unsuitable for rough sea conditions, the tube net method could be better for integrating seaweeds with cobia farming cages. Seaweeds such as *Kappaphycus alvarezii* and *Enteromorpha* spp. are farmed/ being experimented on under IMTA in India.

In India, the scope of IMTA may be very excessive due to the range to be had in species that may be farmed, the tropical weather that's conducive for farming both Fed and non-fed species, and the growing call for plenty of farmed species for home intake in addition to export. In any IMTA system, the co-cultured species have to be more than simply bio-filters and have to be of business value (consisting of phrases of biodiversity). Cobia (*Rachycentron canadum)*, Asian seabass (*Lates calcarifer*), Orange spotted grouper (*Epinephelous coioides*), etc., are the major fin fish mariculture in India, and hatchery technology of seed production of these species is available in India. Capture-based mariculture of mangrove snapper (*Lutjanus argentimaculatus*) and giant trevally (*Caranx ignobilisare*) is also practised in several pockets of the Indian coast. Non-fed bivalve species like inexperienced mussels (*Perna viridis*) and fit-to-eaten oysters (*Crassostrea madras*sas) are also farmed to a greater volume inside the country. Extractive species farmed are a few purple and brown seaweeds like *Gracilaria edulis* and *Kappaphycus alvarezii*, which have precise marketplace calls for non-fit for human consumption purposes. However, IMTA needs to be practised on a business scale in India. Since mariculture is taken into consideration because of the destiny of the Indian seafood industry, IMTA has more scope and prospects. Once the mariculture coverage is implemented, the approach has to be closer to more vital manufacturing in a sustainable way primarily based totally on classes learned in different nations wherein mariculture has come to a standstill because of many motives consisting of eutrophication primary to pollution, sicknesses, and parasites and lack of appropriate sites. If IMTA is taken as the new and progressive method for


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mariculture in India, it is anticipated to revolutionise manufacturing sustainably within the country. IMTA offers several potential benefits, and its scope in India can be evaluated from various perspectives:

1. **Sustainability:** IMTA promotes sustainability by optimising resource use, minimising environmental impacts, and improving overall system efficiency. Adopting sustainable practices like IMTA becomes crucial for India to address environmental degradation and resource constraints in aquaculture.
2. **Diversification of Species:** IMTA allows for the simultaneous cultivation of multiple species in the same system. Diversifying the farmed species can benefit aquaculture farmers as it helps minimise their risk and increases the resilience of their farming operations. By cultivating species from different trophic levels, such as fish alongside filter-feeding organisms or seaweeds, farmers can create a balanced ecosystem that maximises productivity.
3. **Nutrient Recycling:** One of the critical advantages of IMTA is the efficient recycling of nutrients. The system can effectively recycle waste products by integrating species that utilise different nutrients. For instance, the waste produced by fish can serve as nutrients for seaweeds or bivalves, contributing to improved water quality and nutrient cycling.
4. **Economic Viability:** IMTA has the potential to enhance economic viability by diversifying product offerings and income streams. Farmers can cater to multiple markets with different species, responding to varying consumer demands. Additionally, the reduced reliance on external inputs can result in cost savings.
5. **Research and Innovation:** Ongoing research and innovation in the field of aquaculture in India may contribute to the development and refinement of IMTA practices. Research institutions, government agencies, and private enterprises may collaborate to identify suitable species combinations, optimise production techniques, and address specific challenges related to IMTA implementation.
6. **Government Support:** If there is governmental recognition of the environmental and economic benefits of IMTA, there may be policy support and financial incentives for farmers adopting these practices. Government initiatives promoting sustainable aquaculture practices could further boost the scope of IMTA.
7. **Market Demand:** Consumer awareness and demand for sustainable seafood products are growing. IMTA, with its focus on environmental sustainability, can align with consumer preferences for responsibly sourced seafood.

### Criteria for species selection

The imitation of natural ecosystems guides IMTA species selection to prioritise environmental sustainability. Fed organisms, like carnivorous fish and shrimp, obtain nourishment from either feed comprising pellets or trash fish, whereas extractive organisms obtain nourishment from the environment. Bivalves and seaweed are the two economically significant cultured groups in this category. Combinations of co-cultured species must be carefully selected based on various conditions and criteria.

1. **Complementary roles with co-cultured species in the system:** Choosing species that complement each other on different trophic levels is essential. For instance, species should be able to feed on the waste of other species for the newly integrated species to enhance the quality of water and grow effectively. However, it is only possible to grow some species together efficiently.
2. **Adaptability concerning the habitat:** Native species, within their natural range and with available technology, should be used to prevent invasive species from harming the environment and economy. Native species have also evolved to be well-adapted to the local conditions.


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3. **Culture technologies and environmental conditions:** When selecting a farm site, it is essential to consider the size range of particles, particulate organic matter and dissolved inorganic nutrients.
4. **Ability to provide efficient and continuous bio-mitigation:** Use species capable of growing to a significant biomass. If we want to capture excess nutrients from the water, it is essential to have organisms that act as bio-filters. This can be achieved by growing larger volumes of a species capable of capturing these nutrients. However, if we choose a species with a very high value, we will need to grow fewer volumes, reducing the organisms' bio-mitigating role.
5. **Market demand of the species and pricing as raw material or their derived products:** Farmers need to consider the market value of alternative species before investing too heavily. They should establish buyers in markets beforehand to ensure economic profitability.
6. **Commercialisation potential:** Use species for which regulators and policymakers will facilitate the exploration of new markets, not impose new regulatory impediments to commercialisation.
7. Contribution to improved environmental performance.
8. Compatibility with a variety of social and political issues.

**Advantages of the IMTA System**

1. **Effluent bio-mitigation:** Mitigation of effluents can be achieved by using bio-filters tailored to the aquaculture site's ecological niche. This can address several environmental challenges posed by monoculture aquaculture.
2. **Increased profits through diversification:** Commercially sold by-products can increase overall economic value, but bio-filtration is costly. To make eco-friendly aquaculture competitive, it is necessary to raise its revenues. In Integrated Multi-trophic Aquaculture (IMTA), lower trophic level organisms can extract additional products from the farm. This offsets the costs of building and operating an IMTA system. The waste nutrients the primary culture produces are not considered a burden but a resource for growing bio-filters.
3. **Improvement of local economy:** Both direct and indirect economic development with employment (both direct and indirect) and product processing and distribution.
4. **Form of natural crop insurance:** Rearing various crop varieties can provide financial protection and mitigate economic risks in case of price fluctuations, diseases, or adverse weather conditions.
5. **Disease control:** Seaweeds possess antibacterial activity against fish pathogenic bacteria, which can aid in preventing or reducing disease among farmed fish.
6. **Increased profits through obtaining premium prices:** There is potential to differentiate the products of Integrated Multi-Trophic Aquaculture (IMTA) through eco-labelling or organic certification programs.

**Challenges before IMTA in India**

Despite these potential benefits, IMTA implementation could also generate potential drawbacks. While integrated multi-trophic aquaculture (IMTA) holds great promise for sustainable and diversified aquaculture practices, several challenges may be faced in its implementation in India. The challenges for expanding IMTA practice are significant. However, it can offer a mitigation opportunity to those areas where mariculture needs a better public image and competes for space with other activities. These challenges include:

1. **Regulatory Framework:** The regulatory framework for aquaculture in India may need to be adapted to accommodate the complexities of IMTA. Existing regulations and policies must explicitly address integrating multiple species and trophic levels within a single aquaculture system.


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2. **Higher investment:** Integrated farming in the open sea requires higher technological and engineering sophistication and up-front investment.
3. **Difficulty in coordination:** Employing different operators (e.g., independent fish farmers and mussel farmers) working in concert would require close collaboration and coordination of management and production activities.
4. **Increase requirement of farming area:** Although aquaculture can relieve pressure on fish resources, fish farming competes with other users for scarce coastal and marine habitats. IMTA can provide specific benefits for the environment and enterprises. Conflicts among stakeholders are expected, including concerns about pollution, impact on wild fish populations, site allocation, and local priorities.
5. **Difficulty in implementation**: Many countries need more national plans for aquaculture and appropriately developed integrated management systems for coastal zones. Decisions related to site selection, licensing, and regulations for mariculture are often made based on ad hoc methods that are highly influenced by political pressures and local priorities. Furthermore, with the increase in congestion in coastal zones, many mariculture sites are at risk of being affected by urban and industrial pollution and accidental damage.
6. **Lower productivity:** Though the total productivity of the IMTA system is higher, the net fish production is lower than that of fed monocultures.
7. **Food safety concerns:** In the IMTA system, the faeces of one species are used as food or manure by another. Many coliforms and other parasites may present in faeces, affecting the consumer's health and food safety concerns.
8. **Public perception issues:** Religious and cultural beliefs influence Fish consumption in India. In India, Per capita fish consumption is too much lower than global fish consumption. People in Lakshadweep ate 105.6 kg of fish per person in 2019-20, while the Haryanvi people were at the bottom. The trends in fish consumption vary from state to state.
9. **Species limitations:** Diverse species of fish and other associated aquatic organisms reared in the IMTA system provide a wide range of nutrients to the people, and the benefits of consumption are far greater than the associated risks. In India, the consumption or even the rearing of some species is strictly prohibited by one communal group. Species preference in India is also a big issue.
10. **Increased need for personnel training:** The traditional fishermen in India depend exclusively on their ancestral traditional aquaculture knowledge. To meet the requirements of IMTA, these fishermen require special personnel training.
11. **Development in expertise for each species:** The fishermen in India are primarily engaged in capture fisheries. The type and number of species used in IMTA require each species' expertise. Expertise should be developed in this area to understand the feeding and breeding habits, their complementary behaviour, and the overall biology of these species.
12. **Non-demonstration of mitigation capacity:** The mitigation capacity of the extractive species has yet to be widely demonstrated in commercial farming operations. Thus, due to the perceived environmental benefits and subsequent increased complexity and costs, there is a debate about the actual benefits and drawbacks of IMTA.
13. **Lack of Awareness and Education:** Aquaculture needs more awareness and understanding about the benefits and practices of IMTA. Education and outreach programs are essential to inform farmers about the advantages of IMTA and to provide training in its implementation.


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14. **Infrastructure and Technology:** Adequate infrastructure and technology are required to implement IMTA successfully. This includes facilities for monitoring water quality, managing different species, and handling diverse aquaculture components. Small-scale farmers may need help accessing and affording the necessary technology.
15. **Availability of Suitable Species:** Identifying and integrating species compatible and suitable for the local environment can be challenging. Research is needed to determine the best species combinations for different regions in India.
16. **Market Acceptance:** The acceptance of IMTA products in the market may be uncertain. Consumers and markets need to be educated about the environmental and sustainability benefits of IMTA to create demand for products from such systems.
17. **Economic Viability:** Farmers may be concerned about the economic viability of transitioning to IMTA, especially if they are still determining market demand, the costs of implementing new practices, and the potential risks of managing multiple species.
18. **Environmental Conditions:** The success of IMTA can be influenced by local environmental conditions, such as water temperature, salinity, and nutrient levels. Adapting IMTA practices to different ecological settings in India may require careful planning and monitoring.
19. **Research and Development:** Continuous research and development efforts are essential to refine IMTA practices, address challenges, and optimise the integration of different species. Investments in research are crucial for the long-term success of IMTA in India.
20. **Financing and Support:** Access to financing and support mechanisms for farmers looking to adopt IMTA practices may be limited. Government incentives, subsidies, or support programs can play a crucial role in encouraging farmers to transition to sustainable aquaculture methods.
21. **Community Engagement:** Successful implementation of IMTA may require collaboration and coordination among various stakeholders, including local communities, government bodies, research institutions, and industry players. Community engagement is crucial for the acceptance and sustainable development of IMTA projects.

Addressing these challenges will require collaboration among government agencies, research institutions, NGOs, and the aquaculture industry. Tailored strategies considering local conditions and involving stakeholders at various levels can contribute to successfully adopting integrated multi-trophic aquaculture in India.

## Conclusion

India's integrated multi-trophic aquaculture (IMTA) scope is promising and aligns with the broader global trend toward sustainable and diversified aquaculture practices. IMTA farming in India is mainly restricted to research with a few initiatives from ICAR-CMFRI and CIBA to promote a participatory mode among the coastal communities. Integrated multi-trophic aquaculture (IMTA) holds great promise for sustainable and diversified aquaculture practices, but several challenges may be faced in its implementation in India.

## References


1. Alexander KA & Hughes AD (2017). A problem shared: technology transfer and development in European integrated multi-trophic aquaculture (IMTA). Aquaculture, 473: 13-19.
2. Biswas G, Kumar P, Kailasam M, Ghoshal TK, Bera A & Vijayan KK (2019). Application of Integrated Multi Trophic Aquaculture (IMTA) Concept in Brackishwater Ecosystem: The First Exploratory Trial in the Sundarban, India. *Journal of Coastal Research*, 86(SI): 49-55.



ISBN: 978-93-95369-85-5 | 

3. Chow FY, Macchiavello J, Cruz SS, Fonck E & Olivares J (2001). Utilisation of Gracilaria chilensis (Rhodophyta: Gracilariaceae) as a biofilter in the depuration of effluents from tank cultures of fish, oysters, and sea urchins. *Journal of World Aquaculture Society*, 32 (2): 215 – 220.
4. Irisarri J, Fernandez-Reiriz MJ, Labarta U, Cranford PJ & Robinson SMC (2015). Availability and utilisation of waste fish feed by mussels Mytilus edulis in a commercial integrated multi-trophic aquaculture (IMTA) system: a multi-indicator assessment approach. *Ecological Indicators*, 48: 673-686.
5. Johnson B, Nazar AKA, Jayakumar R, Tamilmani G, Sakthivel M, Ramesh Kumar P, Anikuttan KK, Samal AK & Sankar M (2019). Integrated Multi-Trophic Aquaculture (IMTA): A technology for uplifting rural economy and bio-mitigation for environmental sustainability. *Aquaculture Spectrum*, 2(5): 9-18
6. Martinez-Espineira R, Chopin T, Robinson S, Noce A, Knowler D & Yip W (2015). Estimating the biomitigation benefits of integrated multi-trophic aquaculture: a contingent behavior analysis. *Aquaculture*, 437: 182–194.
7. McVey JP, Stickney R, Yarish C, Chopin T (2002). Aquatic polyculture and balanced ecosystem management: new paradigms for seafood production. In: Stickney, R.R., McVey, J.P. (Eds.), Responsible Marine Aquaculture, CABI Publishing, Oxon, UK, pp. 91 – 104.
8. Neori A, Thierry C, Troell M, Alejandro HB, George PK, Christina H, Muki S, Charles Y (2004). Integrated aquaculture: rationale, evolution and state of the art emphasising seaweed biofiltration in modern mariculture. *Aquaculture*, 231: 361 – 391.
9. Park HJ, Han E, Lee WC, Kwak JH, Kim HC, Park MS & Kang CK (2015): Trophic structure in a pilot system for the integrated multi-trophic aquaculture off the east coast of Korean peninsula as determined by stable isotopes. *Marine Pollution Bulletin*, 95: 207-214.
10. Sukhdhane KS, Kripa V, Divu D, Vase VK & Mojjada SK (2018). Integrated multi-trophic aquaculture systems: a solution for sustainability. *Aquaculture Asia Magazine*, 22(4): 26-29.
11. Troell M, Joyce A Chopin T, Neori A, Buschmann AH & Fang JG (2009). Ecological engineering in aquaculture-potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture, 297: 1–9.
12. Vijay Amirtharaj KS, Ahilan B & Arul Oli TM (2017). Integrated multi-trophic aquaculture (IMTA) -an environmentally friendly farming approach. J. Aqua trop., 32 (3-4): 209-222.
13. Yokoyama H & Ishihi Y (2010). 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, 310: 74-83.



ISBN: 978-93-95369-85-5 | 