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INTEGRATED MULTI-TROPHIC AQUACULTURE

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Food demand is rising due to the world's expanding population. In the past two to three decades, the aquaculture industry has made substantial advances despite population growth, advancements in human welfare, and a decline in natural aquatic resources (Tang et al., 2024). Biofilter organisms from the different trophic levels in the aquaculture plant are used in an integrated multi-trophic aquaculture (IMTA) system to remove animal waste from the water. Through an ecosystem-oriented methodology, the IMTA aims to improve sustainability in intensive aquaculture by combining fed aquaculture species with both organic and inorganic extractive species to create an equilibrium system that promotes social acceptance, financial viability, and environmental sustainability (Biswas et al., 2020; Sanz-Lazaro and Sanchez-Jerez, 2020). The IMTA technique was created to use excess nutrients from organisms at a higher trophic level to generate economically valuable lower trophic level commodities. The IMTA systems provide the best possible answer to the problems aquaculture faces, such as resource inefficiency, environmental contamination, aquaculture hazards, and model development obstacles. Thus, the application of IMTA systems in aquaculture is highly recommended (Troell et al., 2009; Zhang et al., 2022). The three primary issues facing aquaculture—pollution, feed input, and space—are addressed by IMTA. According to Chopin et al. (2001); Troell et al., 2003, integrated multi-trophic aquaculture (IMTA) is the practice of cultivating aquatic species of varying trophic levels close to one another in a way that recycles waste, by-products, or uneaten feed from one species and uses it as energy, fertilizer, or feed for another crop. This allows the crops to benefit from their synergistic interactions.

A Standard IMTA Configuration Consists of Three Main Parts (Troell et al., 2009)

1. Fed aquaculture species (finfish/shrimp) - Finfish contribute to the economy of an IMTA setup, form the upper trophic level, and provide nutrients to other system components (Sasikumar and Viji, 2015). Environmental is likely to have a predatory finfish as a fed species,

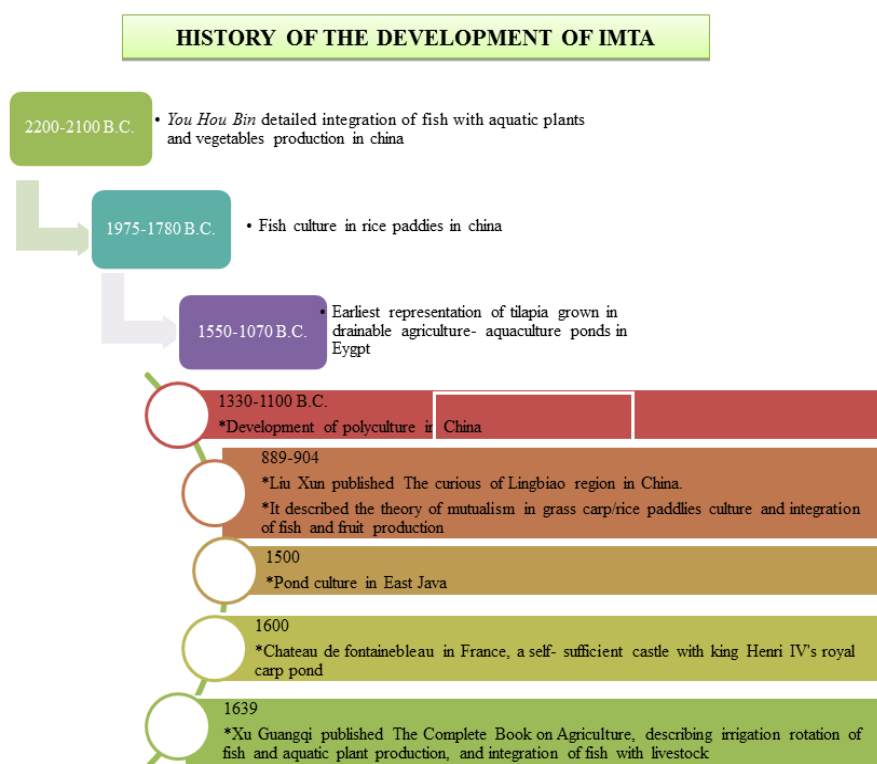
but the choice of fed aquaculture species is only chosen after a thorough economic, environmental, and dietary review. Carp, a lower trophic level fish, are more energy efficient than salmon, a top predatory fish, yet salmon has higher feed requirements and eventually excretes more nutrients.

2. Inorganic extractive species (seaweeds)- Since algae are an essential part of IMTA because of their capacity to absorb nutrients, the selection of algae should be based on their capacity to eliminate phosphate and nitrogen in addition to their ideal temperature range (Skriptsova and Miroshnikova, 2011). Along the Atlantic coast, it has been common practice to use *Gracilaria bursa-pastoris*, *G. gracilis*, *Chondrus crispus*, *Palmaria palmata*, *Porphyra dioica*, *Asparagopsis armata*, *Gracilariopsis longissima*, *Ulva rotundata*, and *U. intestinalis* as biofilters in conjunction with sea bass and turbot (Barrington et al., 2009). Algal growth modeling in the finfish-sea urchin-sea-seaweed system showed that nutrients, radiation, and ambient temperature typically operate as growth-limiting factors. Temperature and radiation shouldn't be limiting considerations in an algae farm; instead, nutrients could be one (Lamprianidou et al., 2015).

3. Organic extractive species (suspension and deposit feeders)- Many organisms, such as crustaceans and echinoderms, have been tested for their suitability for open water IMTA setups (Barrington et al., 2009; Nelson et al., 2012). However, macroalgae and bivalves have been found to be suitable for the setup because they are grown in the down current area of fed aquaculture cages, which makes it easier for farm waste to flow towards these suspension extractive species or SES. There are two primary types of organisms in the SES group: bivalves, which use organic waste, and macroalgae, which use inorganic waste. Particulate fish waste serves as an extra food source for suspension-feeding bivalves, which are generalist consumers that take a wide variety of particles of various sizes and types (Troell et al., 2003). Echinoderms are the top prospect for the deposit extractive species, which is the group that occupies the bottom of the culture site. The garbage that the suspension feeders miss is what they eat.

Evolution: Modern IMTA, also known as Polyculture, emerged gradually over a long period of time, starting with integrated fish farming through polyculture and ultimately incorporating ecological engineering into aquaculture. The organic and inorganic extractive aquaculture species (bivalves, aquatic plants) and the fed-aquaculture organisms (fish, shrimp) are grown independently in designated production units in intensive monoculture or polyculture systems,

which clearly result in notable environmental changes. IMTA involves the cultivation of fed species that require nourishment from feed supplementation, while extractive species utilize the organic and inorganic waste generated in the production unit for maintenance and growth metabolisms. A deeper understanding of IMTA principles and practices is crucial to the creation of harmonious systems that support ecological sustainability (by mitigation), financial viability (through diversified products and risk elimination), and social acceptance (via improved management procedures) (Pinak et al., 2023). From a conceptual standpoint, the IMTA is an evolving agricultural method that entails growing two or more organisms together while considering the trophic levels, feeding preferences, and recycling byproducts from one species as inputs for another.



John ryther et al., 1975	Integrated waste recycling marine polyculture systems
Marilyn Harlin et al., 1979	Seaweeds in closed system fish culture
M.E. McDonald, 1985	Biological removal of nutrients in algal fish systems
Amir Neori, 1991	Seaweed biofilters for intensive mariculture
Muki Shpigel et al., 1991	Oysters in fish aquaculture ponds
Alejandro Buschmann et al., 1994	Seaweed cultivation with land-based salmon effluents
Max Troell et al., 1999	Aquaculture ecological engineering
Thierry Chopin and Jack Taylor, 2004	Integrated multi-trophic aquaculture

Selection Criteria for Species

IMTA prioritizes environmental sustainability, which influences the selection criterion for species. Because of this, the selection of species is determined by an understanding of the constraints that are inherent in the natural ecosystem. It is crucial to carefully assess each species' compatibility with the habitat and culture unit when deciding which ones are appropriate for incorporation inside an IMTA system. Farmers must understand the compatibility of the species and its possible impacts on the ecosystem to guarantee both good growth and economic viability. For nutrition, organisms that need to be fed—such as carnivorous fish and shrimp—rely on outside supplies like pellets or abandoned fish. On the other hand, organisms that are extractive obtain their nourishment from their surroundings. This includes seaweed and bivalves, two economically important cultural groups.

Carefully choosing co-cultured species combinations requires consideration of several factors and situations.

1. **Complementary functions in the system with other species:** On various levels of trophic structure, select species that are complementary to one another. To enhance water quality and promote efficient growth, for instance, newly integrated species need to be able to consume the waste products of other species.
2. **Adaptability about the habitat:** Native species can be utilized for which technology is accessible and within their typical geographic range.
3. The **possibility that invasive species will damage the surrounding ecosystem** and possibly interfere with other commercial endeavors. Moreover, native species have developed strong adaptations to the local environment.
4. **Culture technologies and site environmental conditions:** When selecting a farm site, particulate organic matter, dissolved inorganic nutrients, and particle size range should all be taken into account.
5. Utilize species that can produce a sizable biomass to mitigate problems effectively and continuously. Another possibility is to have a species that is highly valuable, in which case smaller volumes can be produced. Nevertheless, the latter lessens the bio mitigating role.
6. **Pricing and market demand for the species** as a raw material or for products made from these organisms: Make use of species whose market worth is known or thought to exist.

7. Potential for commercialization: Make use of species for which legislators and regulators will allow the exploration of new markets without putting further regulatory barriers in the way of commercialization.

Benefits and Challenges

One advantage of IMTA is that it allows for the mitigation of wastewater by biological methods. This is accomplished by using bio-filters that are compatible with the ecological conditions of the aquaculture site.

- **Increased financial rewards from trading commercially generated by-products:** Increased profits through diversification. The farm can obtain additional products that surpass the costs of starting and maintaining an IMTA farm by utilizing the extractive potential of co-cultivated lower trophic level species. In integrated aquaculture, the excess nutrients are used as a resource to support bio-filters.
- **Enhancing the local economy:** Promoting economic expansion by creating jobs both directly and indirectly, as well as by processing and distributing goods.
- **Inherent risk mitigation strategy:** Product diversification can provide financial stability and lessen economic susceptibilities to price swings, crop losses from disease, or unfavorable weather.
- **Disease management:** Because of their antibacterial qualities against fish-pathogenic microorganisms, some seaweed species can help prevent or lessen fish infections.
- **Increased revenue through premium pricing;** the ability to set IMTA products apart through eco-labeling programs or obtaining organic certification.

Conclusion

With an innovative framework for creating the most effective food production system, IMTA systems are crucial to the sustainable growth of aquaculture operations within a balanced ecosystem approach in response to the growing global demand for seafood. The benefits of IMTA include disease prevention, bioremediation, increased carrying capacity, and a variety of products. IMTAs are still being developed in many countries, at least at full commercial scales, despite their immense potential. In various regions of the world, there are a few prospective open-ocean IMTA demonstration facilities that could serve as models for further development. Nevertheless, more effort is required to modify these designs for other species and circumstances. Demonstration research sites, with cost-sharing arrangements to lessen the

expensive nature of offshore research, will be able to offer the aquaculture industry invaluable information as designs are scaled up to commercial production levels. Therefore, this sustainable and environmentally friendly choice needs to be further pushed to provide coastal fishermen with a reliable source of income, mitigate the negative effects of climate change, and earn precious carbon credits for our nation.

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